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Roadmap for port preparation of alternative fuel bunkering in support of shipping decarbonization

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ROADMAP FOR PORT PREPARATION OF ALTERNATIVE FUEL BUNKERING IN SUPPORT OF SHIPPING DECARBONIZATION

By

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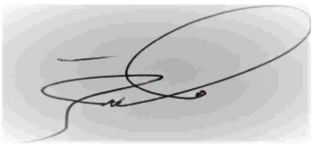
Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): 
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(Date): 15th of September 2022
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Supervised by: Fabio Ballini
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Supervisor’s affiliation**.......**

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Abstract

Title of Dissertation: **Roadmap for Port Preparation of Alternative Fuel Bunkering in Support of Shipping Decarbonization**

Degree: **Master of Science**

The dissertation is a study of the ports' preparation for alternative bunkering as well as operation in support of decarbonization.

A systematic literature review analysis is conducted to analysis the current types of alternative fuels that can be used in ports. Five European ports were selected to study the alternative fuels used in these ports for bunkering as well as operation.

Additionally, the drivers and limitations of alternative fuels in ports are discussed, and selected solutions are provided as recommendations to overcome these limitations. Moreover, a SWOT/PESTEL combined analysis was conducted, and the external and internal factors, including those affecting the port's decision-making to adopt alternative fuels, were analyzed. Finally, a roadmap is created for ports to help in the adoption of alternative fuels.

KEYWORDS: Ports, Alternative fuels, Bunkering, Sustainability, Shipping decarbonization.

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List of Abbreviations

BCH code: Code for the Construction Equipment of Ships Carrying Dangerous Chemicals in Bulk.
CO: Carbon Monoxide
DMDC: Dimethyl Dicarbonate
DME: Dimethyl ether
EPA: Environmental Protection Agency
EU: European Union
ECA: Emission Control Area
FAME: Fatty Acid Methyl Ester
GHG: Green House Gas
g/kWh: Grams Per Kilowatt-hour
Gtkm: Giga ton-kilometers
HFO: Heavy Fuel Oil
HPA: The Hamburg Port Authority
HGHH: Hamburg Green Hydrogen Hub
HVO: Hydro-treated Vegetable Oil
Ha: Hectares
ICG Code: The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk.
IBC code: International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk.
IMO: International Maritime Organization
Kg: Kilogram
kL: Kiloliters
ktoe: Thousand tonnes of oil equivalent
kW: Kilowatts
kWh: Kilowatts hour
LPG: Liquefied Petroleum Gas
LNG: Liquefied Natural Gas.
LOHC: Liquid Organic Hydrogen Carrier
L: Liters
NOx: Nitrogen Oxides
MGO: Marine Gas Oil Fuel
MDO: Marine Diesel Oil
MARPOL: International Convention for the Prevention of Pollution from Ships
Ml: Milliliter
ML: Million Liters
MPa: MegaPascal
Mtoe: Million tonnes of oil equivalent
MW: Megawatt
Mt: Metric Ton
N2: Nitrogen Gas
µg/m3: Microgram/cubic meter
PA: Port Authorities

PM: Particulate Matter Emission
PJ: Petajoules
SO_2: Sulfur Dioxide
SO_x: Sulfur Oxide
SVO: Straight Vegetable Oil
SECA: Sulfur Emission Control Areas
Toe: Tonnes of oil equivalent
UNFCCC: United Nations Framework Convention on Climate Change
UN: United Nations

Chapter 1: Introduction

1.1 Background

The world is facing the extremes of climate change. Extreme weather events, droughts, rising temperatures, and on top, global warming are all hitting the world so hard. This is due to the anthropogenic GHG emissions. The transport industry contributes to the world GHG by around 36%, of which, a 12 % are from the maritime transport. In particular, the shipping contributes to 3% of total global GHG emissions (IMO, 2020). Thus, all the industries need to decarbonize soon including shipping. However, the main issue is that all industries including maritime transport are not able to decarbonize soon (IMO, 2020).

The maritime industry is getting ready to meet the IMO strategy to cut GHG emissions by half and the intensity by 70% by 2050. Some of the measures to decarbonize shipping are alternative fuels (Alamoush, Ölçer, et al., 2022). While shipping and manufacturers are working on this, questions are raised if ports are prepared, either port or maritime authorities, to bunker shipping or enact the required legal frameworks to minimize emerging safety risks, among other issues.

It is thus seen necessary that ports set new regulations to deal with these because alternative fuels are challenging issue. Hence, the preparedness of ports around the world is a vital issue that needs to be further addressed, especially in emerging countries where the financial and technical knowhow and capabilities are limited compared to developed countries.

1.2 Problem statement

According to the principles of sustainable development, several measures have been made to decrease environmental pollution in recent years (Peng et al., 2021). The IMO has made a concentrated effort by introducing the International Convention for the Prevention of Pollution from Ships (MARPOL) to implement restrictions to reduce hazardous emissions from ships, dedicated emission control areas (ECAs) were created by MARPOL Regulation 13 in order to reduce airborne pollutants (IMO, 1997).

Total shipping GHG emissions rose by 9.6% during 2012 and 2018 according to the IMO's fourth GHG study (1,076 Mt4). As a result, the percentage of anthropogenic emissions attributed to shipping went from 2.76 percent to 2.89 percent between 2012 and 2018. CO2 jumped by 9.3%, or from 962 Mt to 1,056 Mt, during the same time period (IMO, 2020). According to the latest voyage based distribution, CO2 emissions climbed by 5.6 percent, from 701 Mt in 2012 to 740 Mt in 2018, i.e., 2 percent of world GHG emissions. There are also business as usual scenarios in which total shipping emissions (domestic and international) are anticipated to grow from roughly 1,000 Mt CO2 in 2018 to 1,000–1,500 Mt CO2 by 2050, which represents a rise of 0–50 percent over 2018 levels and 90–130 percent over 2008 (Alamoush, Ölçer, et al., 2022). Climate change is exacerbated by the GHG emissions from ships and ports, which is why the marine industry as a whole must decarbonize (Bouman et al., 2017).

Under the Paris Agreement, ports must reduce overall GHG emissions, including shipping emissions, in order to pursue the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Because of this, there are a variety of GHG rules that are significant to both the public and port authorities for consideration (Alamoush, Olçer, et al., 2022). Port authorities have a role in policy making and this include the alternative fuels bunkering (Schröder-Hinrichs et al., 2020).

Cold ironing, the use of LNG, and vessel speed reduction at the port are the primary ways for reducing ship emissions in ports (Bergqvist & Monios, 2018). In the ship-port interaction, ports can implement operational and technical steps to support maritime decarbonization, the most important step is to provide technical and operational means to provide bunkering for alternative fuels such like LNG, Ammonia, Methanol and others (Styhre et al., 2017).

Understanding the problems and restrictions as well as possible policy and operational situations is vital since ports are profitable organizations and well not be driven to spend money unless it is absolutely essential. These include the use of current best practices, as well as stricter regulations to encourage the use of new technologies and the adoption of greener practices more rapidly (Bergqvist & Monios, 2018).

For ports to adopt a certain type of alternative fuel there should be the enough demand for it. One of the problems that ports are facing in this matter is the commitment from the maritime industry to use alternative fuels specially that throughout most situations, the business case does not heavily rely on the engine technology investment. A ship's fuel costs throughout the course of its service life, or the expected return on investment, is usually the most important consideration (DNV.GL, 2019).

Ports need to invest in bunkering, training of human resources to handle the alternative fuel adapted by the port, update the safety and technical regulations. It is also important for ports when adopting alternative fuels to recognize the new challenges that comes with it, with the usage of alternative fuels, ports face a number of new risks and challenges. The dangers associated with alternative fuels, such as in the case of LNG, include the potential for leaks, hose separation, and tank overpressure and overload (Aneziris et al., 2020).

Investing in port infrastructure to adopt alternative fuels is a key driver to achieve the UN sustainable development goal, however, when it comes to emerging and developing countries, priorities are different. For emerging and developing countries, investing in health system, educational system, road infrastructure maybe more important to these countries (Foster et al., 2022).

One of the most critical solutions to reduce GHG emissions is using alternative fuels, such as LNG, Methanol, and ammonia. Other measures include engine electrification and hybridization. However, the new alternative fuels need a new way of handling, bunkering and storage. Additionally, the use of alternative fuels creates various challenges and issues for ships and ports. Hence, alternative fuels come with new risks that should be addressed such as the case of LNG risks of leakage, hoses disconnection, overpressure and overpower in tanks (Peng et al., 2021). The LNG, therefore, requires more safety assurance, environmental protection and structural integrity, both during bunkering activities and in storage. Accordingly, suitable legislative framework must be established for ships and shore (Aneziris et al., 2021). Indeed, there should be a re-examination of the legislation, technical standards, and recommendations for LNG storage and bunkering (IACS, 2016), and other alternative fuels.

1.3 Aim and objectives

The proposed aim of this dissertation is to analyze the readiness of ports, including port and maritime authorities, in order to utilize future alternative fuels for shipping decarbonization. Thus entails looking at the current frameworks (regulations) and measures to minimize risks of investment in alternative fuels.

The objectives of the research are:

1) Identify the future shipping alternative fuels that ports can adopt.
2) Evaluate the current opportunities and threats emerging from ports being adopter of future fuel bunkering.
3) Study the current ports steps (Roadmap) to facilitate the future shipping alternative fuels bunkering.

1.4 Research questions

1. What is the future shipping alternative fuels that ports can adopts and use to support decarbonization?
2. What are the opportunities and threats emerging from ports facilitating future fuel bunkering?

3. What are the current ports steps to facilitate the future alternative fuels for shipping industry?

1.5 Methodology

In this dissertation, a systematic literature analysis methodology, would be utilized. This methodology is unbiased due to the fact that it uses very restrictive methods that can be repeated and thus yield the same results. It is worth noting that the systematic approach is recommended owing to its comprehensive coverage of various reach issues. The systematic literature review is based on the guidelines of (Denyer, D., & Tranfield, 2009; Petticrew, M., & Roberts, 2008; Snyder, 2019). Further details of the search, database, inclusion and exclusion criteria and filtering stages are explained thoroughly in the methodology chapter.

1.6 Scope of the study

The scope of the study will be international ports. Therefore, the study provides guidance for ports and maritime authority all over the world. In terms of alternative fuels, the study will examine international ports steps and frameworks related to alternative fuels particularly looking at what type of alternative fuels ports can facilitate.

1.7Contribution of the study

This study contributes the global efforts to curb climate change. Specifically, it also contributes to the port sustainability performance. Additionally, the study has implications for port authorities and maritime administrations to prepare their selves to the future, i.e. gain knowledge and decisions support in terms of what is required for the future bunkering and reception of vessels that carry alternative fuels. Notably, the study contributes to the literature because there are not many studies addressing this problem.

1.8 Limitation

We found it hard and challenging to find the ports preparations for alternative fuels. When researching this subject, we only found some reports done by recognized organizations that discuss the forerunner ports preparation for alternative fuels. On the other hand, we did not found any relative documents that discuss the alternative fuels preparations in ports in emerging countries.

1.9 Dissertation structure

Chapter 1: Introduction

This chapter will be an overview of the process of this project which included the background, problem statement, aim and objectives, research questions, scope and contribution of this study and limitation.

Chapter 2: Methodology

This chapter describe the methodology used to research and answer the questions of this project.

Chapter 3: Result and analysis

This chapter will discuss the systematic literature review analysis, types of alternative fuels that ports can use for bunkering and operation as well as the drivers and limitation of these types of alternative fuels.

Chapter 4: Current situation, analysis and roadmap.

In this chapter, the current situation in ports regarding alternative fuel bunkering will be discussed alongside the road map for ports to adopt alternative fuels and the way to overcome their limitations.

Chapter 5: Conclusion and recommendations.

This chapter will conclude the work of the project. In part will include the summery, recommendations for countries and ports adopting alternative fuels, limitation of this project as well as the future researches areas in this field.

Chapter 2: Methodology

2.1 Systematic literature review

This dissertation proposes a comprehensive literature review analysis to address the research problems raised in this project. A systematic review methodology will be used to identify and discuss the Ports' steps necessary to prepare for future shipping of alternative fuels in support of decarbonization. In order to find relevant research, it is necessary to begin the search with a well-defined query that has a clear response. The review is driven by the guidelines in (Denyer, D., & Tranfield, 2009; Petticrew, M., & Roberts, 2008; Snyder, 2019).

After the review question has been decided, a four-step method begins. In the first phase, an electronic database search is conducted to locate the most complete source or a combination of sources. At this point in the process, we have selected the journals and articles to research, as well as the period in which they will be analyzed. The second stage is to evaluate the papers based on their relevance to the review topic. A first search is undertaken to determine the criteria for rejecting non-related items. The next step is to analyze the papers for relevance to the review topic. After establishing the parameters for removing irrelevant content, a preliminary search is conducted. In the end, keywords and preferable places were found. After that, the next stage is to obtain and use relevant information to investigate the review questions further. An in-depth review of the relevant literature is the third step in this process, and it is here that the most useful information is gleaned, compared, and compiled. A review is complete when all of the findings of a previous study are thoroughly examined (Alamoush, Ballini, & Ölçer, 2021b).

The systematic literature review, therefore, adopts the following criteria:

- Searching: specific terms for searching will be established. The Boolean connectors would be used (AND, OR, NOT)
- Databases: Scopus and IBESCO would be the main database for searching. Thus, the search terms established above would be run in these bases. Scopus

is well-known for its comprehensiveness of having multiple academic resources.

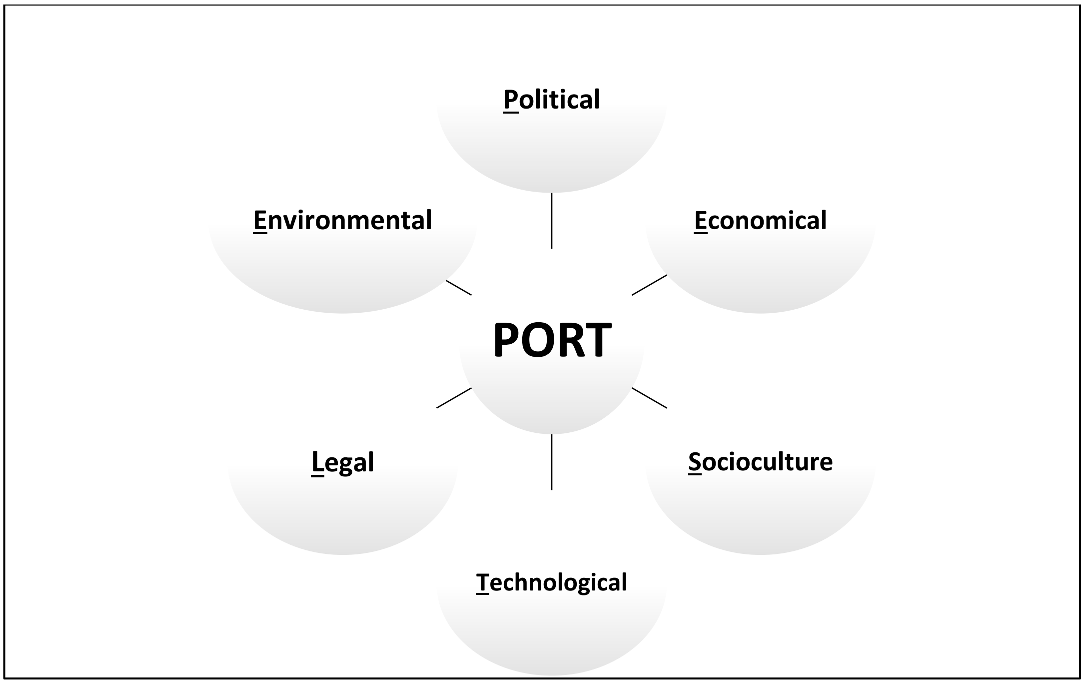
- Filtering: it is certain that the search would result in thousands of studies, therefore, filtering should be used. That is, we need to designate inclusion and exclusion criteria while reading and reviewing the downloaded articles. The result should maintain less but comprehensive articles that guide the analysis and provide significant results.
- Data extraction: we will extract data from articles based on literature review matrix which collects data from the included articles.
- Synthesis: after data being collected, it would be synthesized to answer the study objectives. It is worth noting that meta-analysis of the included articles would be also presented, e.g. articles' years, journal name, methodology used, country of authors, affiliation, ports as case studies, among others.

2.2. PESTLE analysis

In this dissertation, a PESTLE analysis will be conducted. PESTLE will help us in better predict the considered decisions desired to guarantee the correct improvement and sustainability of the port by identifying future macroeconomic factors and creating multiple scenarios. The abbreviation created by the initials of the groups of variables enclosed in the model as shown in Figure 1 (Political, Economic, Socio-cultural, Technological, Legal, and Environmental) gave the study the term PESTLE. Opportunities vs. possible dangers that are still somewhat unpredictable might be taken into account in the model's decision-making process for the port. It is, therefore, possible to begin imagining possible futures using the model to assist decision-makers in better anticipating what could happen and making the appropriate choices today for the future (Marmol & Feys, 2015).

Figure 1

The PESTLE analysis variables



Note. From "PESTILE analysis, understand and plan for your business environment" by Thomas del Marmol, Brigitte Feys. Copyright 2015 by Business 50minutes.

Political aspect: Political trends have a substantial influence on the decision making choosing to locate in a specific part of the country. The recognized public authorities can directly impact of the decisions making process of the daily operations and prospects of a firm financial (such as nominal interest) and social (such as employment aid) aspects. Other factors, such as the degree of violence, corruption, or official interference, should also be taken into account. A company owner in a conflict-ridden area must also guarantee that their products and services meet the demands of the local needs, which will be distinct from those in a more stable and peaceful environment (Wilkinson & Kannan, 2013).

Economical aspect: Preparations can be made to better deal with economic volatility, even if the firm cannot change the economic circumstances. It is essential to keep track of GDP growth, tax rates, and the purchasing power of its citizens in a country in order to make effective management decisions. Key indicators relating to the sector and consumer trends are also crucial to a company's financial performance. In order to minimize losses, the corporation might adjust its entire strategy if it anticipates a significant drop in purchasing power (Wilkinson & Kannan, 2013).

Socio-culture aspect: Understanding a population's demographics, age distribution, and purchasing habits are vital to gaining an industry's foothold. In addition, the firm can fine-tune its understanding of the unique requirements of the persons involved by drawing on historical, religious as well as socio-cultural influences (Christodoulou & Cullinane, 2019).

Technological aspect: Today, specialists worldwide are working tirelessly to re-imagine and re-engineer the way things are done. A few discoveries may not impact the intended audience, but others might radically change the rules of engagement. Internet usage has grown at a rapid pace, surprising many decision-makers, and those that saw it coming earned a substantial competitive edge. Since research and development and innovation are critical to the firm core operation, it makes sense to explore these methods. The key to practical technical observation is the constant reassessment of the product and the procedures involved in its repair and acquisition by the client (Wilkinson & Kannan, 2013).

Legal aspect: Decision making depends on where the port will be based in a nation where legislation differs significantly. The consideration of the legal aspect will help to defend the port operations from any legal assaults by the citizens and will keep all operation within legal restrictions by being aware of local rules (Christodoulou & Cullinane, 2019).

Environment aspect: Since the end of the 20th century, environmental issues and sustainable development have taken centre stage in more and more public debates. Climate change, pollution, waste sorting, and other issues are becoming more important to public and leaders. This issue might have a direct influence on the maritime industry at times. Regional, national, and international authorities have implemented a variety of steps to restrict energy usage and/or pollution levels. These have the potential to have an impact on how an organization conducts business (Wilkinson & Kannan, 2013).

2.3. SWOT analysis

A SWOT analysis examines the port current strengths, weaknesses along with opportunities, and threats as shown in Figure 2. An organization's resources, capital, abilities, core competencies, and market competitive advantages are identified through an internal study. An outside research studies the resources of competitors as well as the industry and larger environment in order to discover market possibilities and threats. SWOT analysis is a strategic planning tool that uses an organization's internal and external knowledge to create a plan of action (Sammut-Bonnici & Galea, 2017).

Figure 2

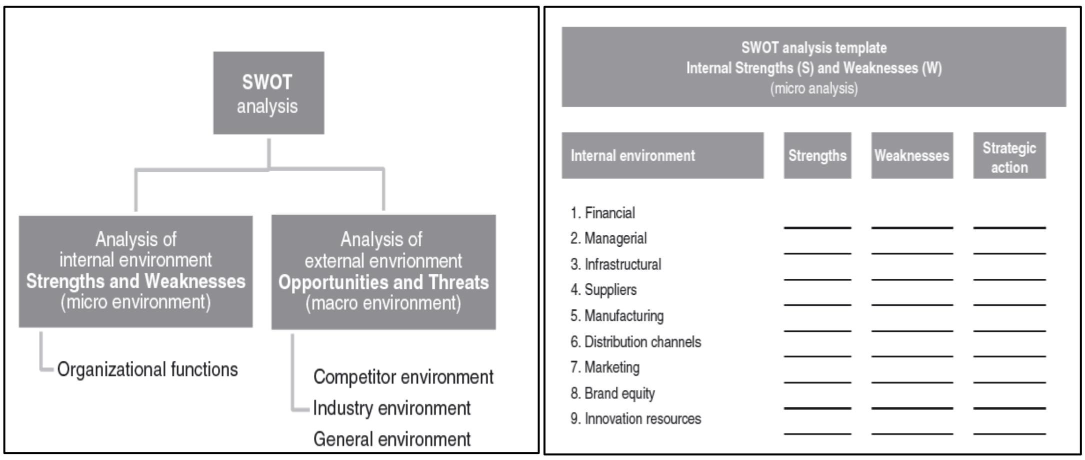
SWOT analysis dimensions

Note. From "SWOT analysis dimensions" by (https://realwealthbusiness.com).

Finding an organization's competitive edge requires an in-depth examination of the internal operations. It recognizes the resources which have to be shaped and maintained to stay competitive. An organization must have a distinct edge to make profits above the industry average. First, an organization's internal resources and skills must be thoroughly assessed to identify its core competencies, which provide a competitive edge; finding the proper recourses and knowing the capabilities are all parts of internal analysis. On the other hand, various sources of information, including industry-specific journals, news articles, published studies, market analysis studies, corporate publications, and trade exhibits, are used by organizations to develop a picture of the external environment. Clients, suppliers, future customers, and the general public can be addressed via informal communication or formal study. Competitiveness, competitive behaviour, and forthcoming trends may be learned by individuals and industry personnel directly involved in the market. Interacting with the external environment is the main element for the organization's success. (Sammut-Bonnici & Galea, 2017).

Figure 3

SWOT internal & external analysis modes and template



Note. From" SWOT analysis", by Tanya Sammuit-Bonnici and David Galeaby 2017. Copyright 2017 by research gate.

Internal analysis challenges: Most management professionals make the mistake of putting all of the reasons they feel make their business strong or vulnerable when completing the internal strengths and weaknesses part of a SWOT analysis. A lengthy array of variables is the ultimate result, making analysis and strategic action difficult. While compiling such a list may be acceptable in certain circumstances, its value in formulating corporate strategy is limited. It is important for management professionals to focus their attention on those aspects that directly impact an organization's ultimate source of competitive advantage (Christodoulou & Cullinane, 2019).

External opportunities and threats analysis: In order to support the port in identifying significant variations and their possible future ramifications, an external environment study is performed. While a corporation cannot influence the external environment, it must do analysis to adjust its business strategies in response to evolving market conditions. Analysis of the external environment reveals potential risks and possibilities (Wilkinson & Kannan, 2013).

The competitor environment is a field of study that emphases the importance of gathering and analysing all the data about competitors. Analysing all the rival's resources, capabilities, capacities, and competitive advantages is essential. Recognizing the port factor helps to reveal the port strengths and weaknesses. On the other hand, an industry environment study looks at the aspects which directly affect the port income flow and demand a strategic reaction to be effective. The aim is to diminish the negative significances and take advantage of the possibilities that exist (Wilkinson & Kannan, 2013).

Chapter 3: Systematic literature review, results and analysis

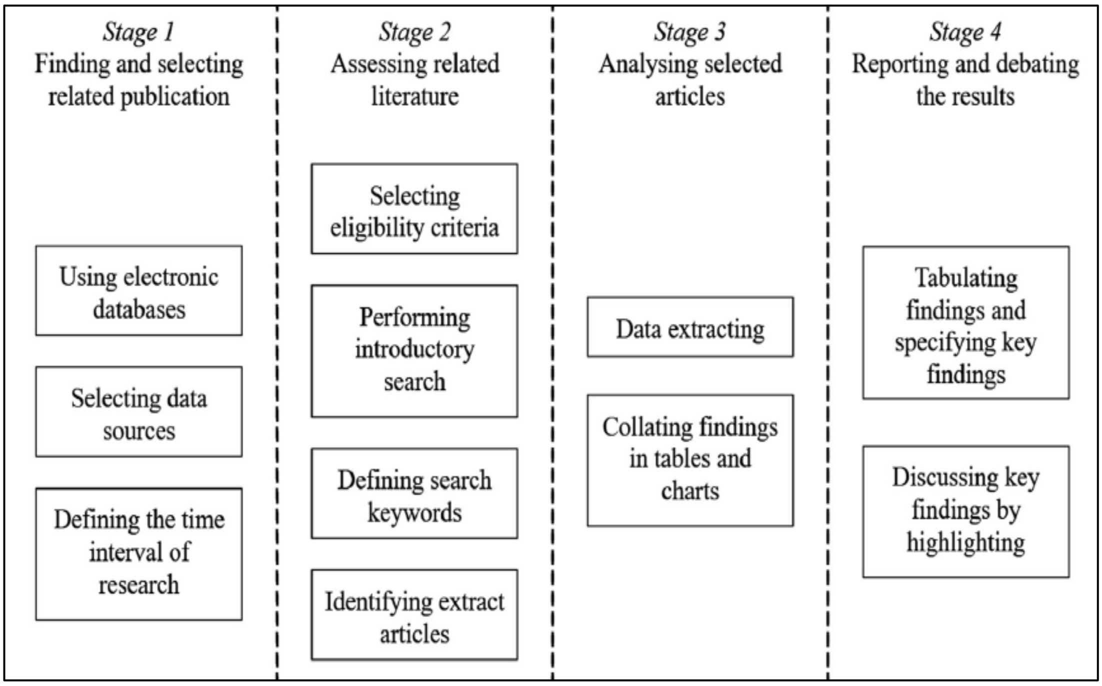
3.1 The result and analysis of the systematic literature review

In this dissertation, the systematic literature review analysis is proposed to answer the questions of this project. Using (Denyer & Tranfield, 2009; Petticrew & Roberts, 2008; Snyder, 2019) proposed systematic review technique, we will identify and discuss topics of interest in the Ports' measures required to prepare for future shipping of alternative fuels in support of decarbonization. As part of this strategy, a specific, meaningful, answered question must be defined at the beginning of the search to help identify relevant research. The four-step procedure begins once the review question has been determined. In this initial step, an electronic database search is carried out to find the most complete source or a mix of sources.

Additionally, we have picked which journals and publications to examine and the time period for their study at this point in the process. The papers that are relevant to the review question are evaluated in the second step. First, the criteria for excluding non-related material are established, and an initial search is conducted. Next, papers that are relevant to the review issue will be evaluated. As a result, keywords and their preferred locations were identified. The next step is gathering and using relevant material to further research the review questions. The third stage of the technique comprises a thorough examination of the chosen literatures in order to extract valuable data, compare the findings of the many studies under consideration, and compile the most relevant data. The fourth stage is to discuss the finding and highlight the results. A review is complete when all of the findings from a prior study are discussed in detail. All steps of the systematic literature review procedure are depicted in Figure 4.

Figure 4

Systematic literature review phases



Note. "Producing a systematic review" by David Denyer and David Tranfield. D. Buchanan, & A. Bryman (Eds.), "The SAGE handbook of organizational research methods" (pp. 671–689). Copyright 2009 by Sage Publication Ltd.

3.1.1 Search

There were two primary groups of search phrases, as shown in table 1. The port is the primary focus of the first category, while alternative fuels are the primary focus of the second. The Boolean operator (OR) was utilized to connect search phrases within each category, while the Boolean operator (AND) was employed to connect categories (AND). The search was limited to the last ten years, as shown in (Figure 6) in prominent databases such as Scopus and IBESCO, the library database in Feb. 2022. There were 380 studies found after combining the search results (Alamoush et al., 2020).

Table 1

Categories of combinations of search terms and strings

Category 1		Category 2
Ports OR Seaports OR Terminals	AND	Alternative Fuels OR Methanol OR LNG OR Hydrogen OR Ammonia OR Biofuel

3.1.2 Filtering stage

A two-stage filtering process based on inclusion and exclusion criteria was used to narrow the research and ensure that only relevant material was included, as shown in table 2. Only papers that answered the research questions were included in the first round of filtration, which involved reading titles and abstracts. Afterward, all studies were filtered and checked for relevance by full text reading in the second step of filtering, using criteria two (exclusion). Thus, studies that were too similar to one other and those that did not address the questions were excluded.

Table 2

Inclusion and exclusion criteria

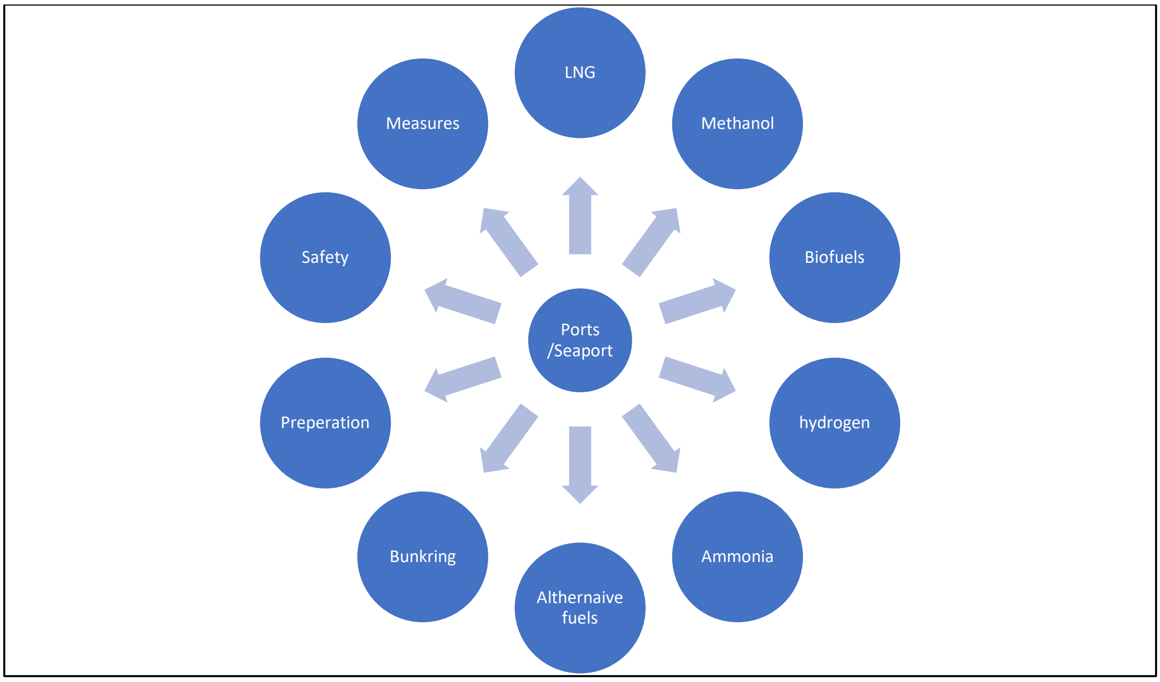
<table>
<tr><th></th><th>Criterion one (Inclusion)</th><th>Criterion two (Inclusion)</th></tr>
<tr><td>Language</td><td>English</td><td>Other Languages</td></tr>
<tr><td>Peer-reviewed articles</td><td>Appropriate to answer the study questions and specifically addresses the aspects of port preparedness for alternative fuels</td><td rowspan="2">Generally speaking, papers dealing with the macro concept of sustainability, eco-friendly ports, and air pollution do not adequately address the port's preparedness for alternate fuels: repeated studies, those of low quality, and those published in peer-reviewed journals.</td></tr>
<tr><td>Grey literature</td><td>Books, High-quality conferences proceeding and reports that add further valuable information and ensure variety of opinions</td></tr>
</table>

Note. From "Port greenhouse gas emission reduction: Port and public authorities' implementation schemes" by Anas S. Alamoush, Aykut I.Ölçer and FabioBallini 2022. Copyright 2022 ELSEVIER 2022.

We had to select and set up the keywords of this literature review that would help us in our search. Figure (5) shows the selected research words.

Figure 5

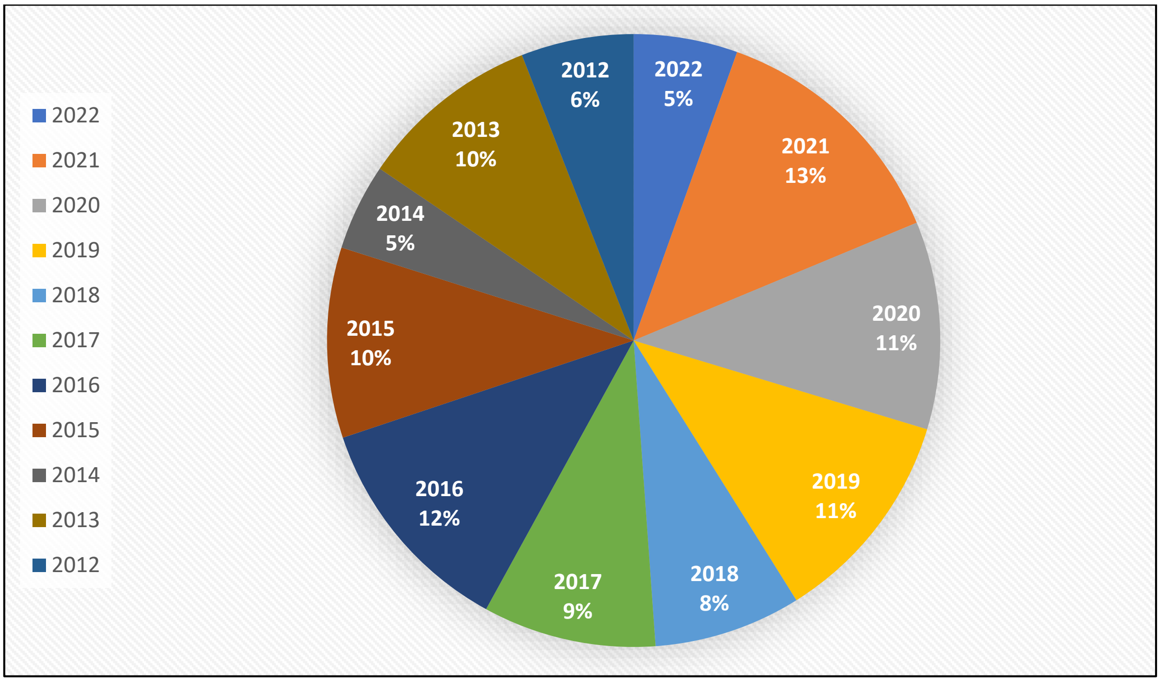
Selected Research Word



In order to conduct a search of the most recent ten years' worth of scientific publications (i.e., 2012–2022), the Scopus database was used. Journal articles and conference proceedings are listed as "documents" by writers. The literature search relating to the port preparation was based on the following precise keywords specified in figure (5). Figure (6) describes the results of the electronic database search that show the percentage of studies conducted each year for the last ten years.

Figure 6

Distribution of documents by publication time span



3.2. The result and analysis of the Alternative Fuels

In this part, alternative fuels will be discussed and will look at the limitations of these types of alternative fuels.

3.2.1 Liquefied natural gas (LNG)

LNG is currently being used in ships as a fuel with reduced environmental implications due to its current abundance of resources, competitive cost, and excellent thermodynamic yields. Several states currently use LNG-powered ships; the first of them was the Norwegian passenger ship MV Glutra, constructed in 2000 and certified by DNV. Reduced emissions have been mandated since 2005 in many Baltic and North Sea countries, which are currently leading the way in using liquefied natural gas (LNG) (IMO, 1997). The port of Stockholm was the first European port to use LNG bunkering; other ports in EU has followed, such as those port of Rotterdam and port of Zeebrugge. The port of Jacksonville in the United States, as well as Singapore and

Kochi in Asia, both serve as LNG bunkering ports. DNV-"LNGi" GL's database shows that there are already twenty-one LNG terminals in operation worldwide, with ten confirming that they expect to open (Aneziris et al., 2020).

Methane, ethane, propane, butane make up the bulk of the gas, while nitrogen and CO2 make up the rest of the mixture. The gas comprises methane, ethane, and propane hydrocarbons predominantly, with trace quantities of sulphur (less than 4 ppmv) and CO2 making up the rest of the gas (Mokhatab et al., 2014). At normal atmospheric pressure, LNG is cooled to a temperature of -162 °C and condensed into a liquid condition (Aneziris et al., 2020).

To carry and store in insulated tanks (such as LNG carriers, LNG-fueled ships, etc.), this form minimizes capacity. Due to fractures and frostbites, low LNG temperatures pose a significant risk to both materials (such as tank walls and ship structures) and persons in touch with it. As a result, specific cryogenic materials must be used for all tanks, pipelines, and valves that come into contact with LNG (Bahadori, 2014).

Leaks and spillage in the incidence of ignition sources can lead to fire and explosions in LNG storage and bunkering. A vapour cloud of LNG will develop in the absence of fire and disperse into the environment. The possible outcomes if LNG is ignited can be a flash fire, explosion in a vapour cloud, jet and pool fire (Aneziris et al., 2014; Mokhatab et al., 2014). As previously noted by (Pio, G., Salzano, 2019), the severity of the effects of the explosion of LNG can be effected by the starting temperature and composition of the LNG and the width of the flame in the pool (Aneziris et al., 2020; Pio et al., 2019).

Initially, LNG has utilized to power steam engines aboard LNG carrier vessels. It has been a decade since the growth of dual fuel marine diesel engines, which can use LNG fuel tank as well as boil-off gas as supplementary fuel, to meet IMO NOx Tier III requirements (Ekanem Attah & Bucknall, 2015). The same reasoning was used to employ LPG, ethanol as well as methanol as backup fuels. The maritime sector at the time anticipated that LNG would be an important avenue to decarbonization because of its lowest carbon to hydrogen ratio and highest energy release per carbon emission amongst hydrocarbon and alcoholic fuels (Xing et al., 2020). According to theoretical estimates, a reduction in net GHG emissions of 12–20 percent is possible due to the possibility of some methane escape when using LNG instead of conventional marine fuel oils (Fernández et al., 2017). Spark ignited gas engines as well as low pressure dual fuel engines at low engine loads are particularly vulnerable to methane slide (Xing et al., 2020).

Currently, a lack of LNG supply, storage infrastructure as well as operational risk, and regulatory ambiguity has impeded the widespread deployment of LNG-powered vessels (Schinas & Butler, 2016). Financial feasibility and the acceptance of ships powered by LNG in the market are expected to grow substantially in the next two decades as the manufacture, transportation, and storing technology improves, resulting in end-use and cost advantages over traditional marine fuels. As a faster way of transition to zero-carbon shipping, low carbon shipping is conceivable in selected locations and vessels utilizing LNG (Burel et al., 2013).

3.2.1.2 LNG bunkering

In the bunkering process, "small facilities" are used to store pressurized LNG tanks at ports. An example of fixed bunkering installations is cryogenic pipe and loading arm from fixed LNG storage tanks are utilized for the bunkering process. Other LNG vessels (capacity: 500 to 3000 m3) or LNG trucks carry the LNG from a local LNG bunker facility or an extensive LNG import facility to these stations (Aneziris et al., 2021).

The primary stages in the bunkering procedure of LNG may be delivered to the port either by (a) truck or by ship, (b) installing mooring equipment, attaching hoses, inserting and abolition filling lines, (c) LNG fuelled ship , done in a variety of ways including truck to ship, tank to ship, or ship to ship (d) removing, cleaning, inserting, and unplugging the grounding and bunker hoses (Aneziris et al., 2021).

It is possible for a small fishing boat to receive as little as 50 m3 of the bunker, whereas a huge ship or oil container may require as much as 20.000 m3 (EMSA, 2018). LNG bunkering facilities are increasing worldwide; for example, there are currently no LNG bunkering facilities in the Adriatic-Ionian area, but many are currently being built. As stated by the Sea-LNG database, Ravenna, Venice and Bari is where LNG storage tanks are being built. In contrast, La Spezia, Piraeus and Sardinia is where LNG ship to ship transfer facilities are being built at (Aneziris et al., 2021; DNV-GL, 2021).

3.2.1.3 LNG limitation

The numerous dangers associated with LNG bunkering have been assessed using quantitative risk assessment methodologies. The risk assessment carried out by Zhang was one of the earliest in the time period under consideration. His method of quantitatively assessing the hazard of LNG tanks operating near ports was devised. Since the social risk of LNG transportation was predictable to be in the permissible range, the risk was considered acceptable. Designers might utilize this technique to help port safety management and emergency rescue planning (Vairo et al., 2021).

Additionally, it was highlighted by researchers that the possibility of emerging hazards when deploying innovative technology, expertise and emphasized the need for unique vessels that use LNG as a source of power. Moreover, when it comes to maritime incidents, human factors are the most causes among other factors, thus it is crucial to have safety regulations for the new designs and operational requirements. The crew as well as operators that are involved in LNG bunkering procedures would benefit from a planned competence management system, which aims to reduce human mistakes (Stokes et al., 2013).

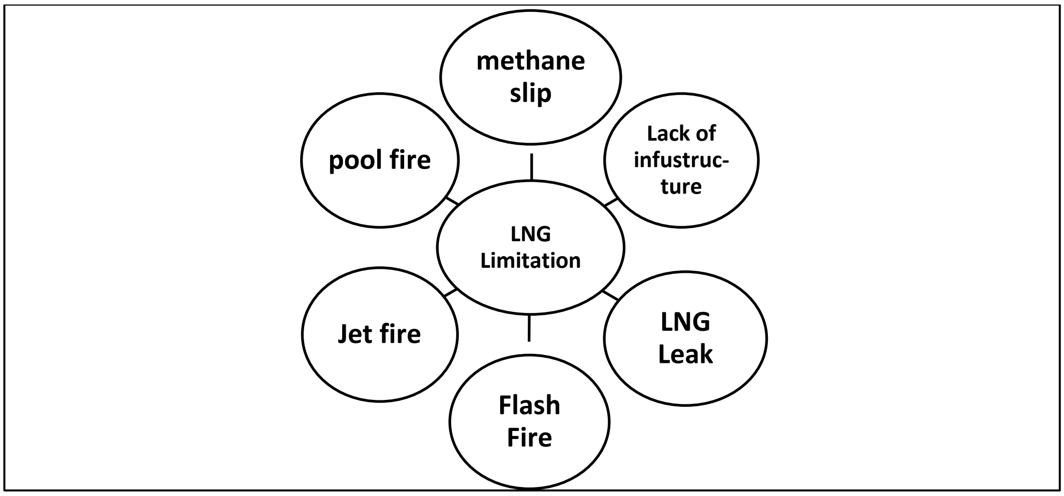
LNG leakage is possible when pontoons are used for bunkering activities. Unwanted outcomes, such as pool fire as well as flash, jet and pool fires and gas spreading were explored in detail. In the event of a pool fire, the danger distance was calculated using the point source and solid flame models (Fan et al., 2013).

The LNG exclusion zone for bunkering activities might be accurately calculated quantitatively by Jeong et al. (2017, 2018). Various ways of bunkering have been studied, including ship to ship, truck to ship, and pipeline to ship. The bunkering capacity, population, and acceptable risk threshold have all been considered. The integrated quantitative assessment technique, which includes the phases listed below, was taken into account during the evaluation process: As a first step in determining a ship's bunkering capacity, an event tree analysis was used to determine the likelihood of all risky occasion occurring, and the consequences were considered and analyzed using fire and explosion models (for pool and flash fire or an explosion) to account for the liquid discharge level and the LNG distribution and evaporation. A proper risk assessment was made based on FN curves and results. (Jeong et al.) used a simple case study to show the technique. An important conclusion in the frequency analysis shows the total annual time needed for bunkering is a crucial component. In contrast, human element should be rigorously controlled within the safety perimeter (Aneziris et al., 2020; Jeong et al., 2017).

A study by (Iannaccone et al., 2018) evaluated the safety characteristic of different types of bunkering systems founded by several parameters. It is possible to identify and enhance critical process units when using fossil fuel bunkering rather than LNG. Moreover, researchers have studied the port of Venice as a case study in developing a risk matrix technique to measure risk levels and evaluated the safety of LNG regulations in bunkering operations (Ovidi et al., 2018). Figure 7 shows the main limitation of LNG as an alternative fuel.

Figure 7

LNG limitations as an alternative fuel



Note. From the sources above in section 3.2.1

3.2.2 Ammonia

It is widely accepted that ammonia is an environmentally friendly fuel since, like hydrogen, it can be produced synthetically from fossil fuels, biomass, or other renewable resources. Combustion engines (compression and spark ignition engines), gas turbines, and boilers may run on ammonia as a single fuel source (Xing et al., 2020). Combining ammonia with fuels like diesel, hydrogen, and methanol can improve combustion in combustion engines and is a more likely option (Christoph; et al., 2019).

Since ammonia has no carbon or sulphur atoms in its chemical composition, it has the potential to help the shipping sector reduce its carbon and sulphur emissions. Ships have already carried ammonia, so there is a wide range of storage and delivery mechanisms in place for the chemical (Kim et al., 2020). Compared with liquefied hydrogen or LNG, ammonia may be kept at substantially lower pressures or greater temperatures. Moreover, ammonia has several benefits, including a lower cost per stored unit of energy, a greater volumetric energy density similar to gasoline, simpler manufacturing, processing, and transport, and improved economic viability, well-established infrastructure, and reasonably mature operating expertise (Hoang et al., 2022; Zamfirescu & Dincer, 2008).

It has been determined that ammonia is a viable source of power for mobile and remote machines. It is possible to get ammonia from either fossil fuels, biomass, or other renewable resources. A direct internal combustion engine-powered ammonia power system might attain a system efficiency of more than 44% (Zamfirescu & Dincer, 2008). Ammonia may also be utilized as a feedstock for the synthesis of hydrogen. Comparatively, ammonia is more efficient in volumetric energy density, less expensive to store, and has a well-established infrastructure for manufacturing and transport. When it comes to energy storage and transportation, ammonia has a lot going for it. As a result, it is reasonable to assume that ammonia will have a more significant potential for economic success (Xing et al., 2020).

Ammonia is a commercially accessible contender for fulfilling the worldwide decarbonization agenda. On the other hand, liquid ammonia has a lower density, yet it has been chosen as a viable alternative fuel for marine engines (Elishav et al., 2020). Moreover, to get the ammonia/air combination to ignite, the minimum ignition energy required was more significant than that required for the propane/air mixture (Chiong et al., 2021).

Several types of research on ammonia combustion showed that combining ammonia with other fuels rather than relying only on ammonia as a fuel was the most reasonable option (Foretich et al., 2021). Moreover, according to a study by C. Zamfirescu & I. Dincer, ammonia was more sustainable than gasoline and LPG. Ammonia is the least costly fuel in terms of the purchase price and ongoing maintenance. Furthermore, the product's financial viability, worldwide distribution network, and ease of handling make it a worthwhile investment. There are many ways to regulate and store it, but it is still harmful and challenging to deal with (Zamfirescu & Dincer, 2008).

3.2.2.1 Ammonia limitations

Fuel cells appear to be the most promising use for ammonia since they are versatile fuels that may be utilized in various ways. Ammonia-operated fuel cells are thought to be more efficient and quieter than traditional engines since they use less fuel and produce less noise (Dimopoulos et al., 2016). Compared to fuel cells, diesel engines as an example which is considered as a traditional energy systems require a pilot fuel to utilize ammonia, which results in NOx emissions. This is a consideration; as a result, the most effective method for generating power from ammonia is through the use of fuel cells (Mazloomi & Gomes, 2012). However, the various sorts of fuel cells face a variety of obstacles. Catalytic hydrogen production from ammonia in low-temperature fuel cells, such as the Polymer Electrolyte Membrane, has been found to be difficult at these low temperatures (Mckinlay et al., 2020). On the other hand, because they don't require 'ammonia cracking,' Solid Oxide fuel cells are the favoured choice (Han et al., 2014).

Many issues and obstacles exist when it comes to ammonia fuel cells because of their incompatibility with ammonia and the high temperatures needed for ammonia cracking (Mckinlay et al., 2020). Moreover, anode catalysts are also critical and must have a high selectivity for N2. Because of the thinner membrane, reducing ammonia cross-over is another problem with low-temperature fuel cells. For these reasons, the Maintenance Engineering Handbook in 2008 concluded that Solid Oxide fuel cells are now the most promising for ammonia fuel cell applications (Higgins & Keith, 2008). However, commercial ammonia-fed Solid Oxide fuel cells still need to be developed (Mohanty, 2015).

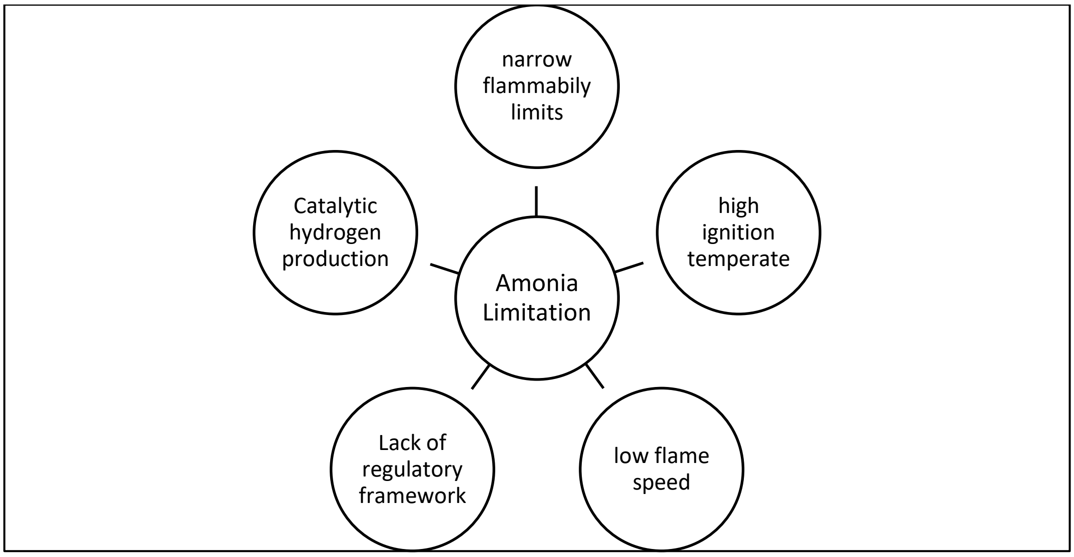
Temperature, narrow flammability restrictions, slow flame speed and high ignition pose significant obstacles to ammonia's expansion as a fuel. In addition, because of ammonia's greater vaporization heat, the cylinder temperature decreases as it transitions from liquid to gas (Ashirbad & Agarwal, 2022). Finally, the formation of a regulatory framework for fuel cells and ammonia is an issue that must be addressed. Ammonia transport on ships is currently covered by a number of international regulations, such as the IGC Code [1]and IBC code [2]and BCH code[3]. On the other hand, the only code relevant to the use of ammonia as a shipping fuel is the IGF code which was adapted in 2017 for using LNG as an alternative fuel (Cheliotis et al., 2021). Thus IGF code must be amended to accommodate ammonia as an alternative fuel.

The risk, safety, and reliability of systems may be assessed using reliability assessment techniques. In order to meet the criteria of the technology qualification process and the IMO alternative design regulations, they are commonly utilized throughout the design phase of systems to assure their safety and dependability. These methods are also used to create new systems to ensure that risks associated with new technologies are appropriately handled and minimized (OECD, 2018). Figure 8 shows the main limitation of ammonia as an alternative fuel.

1 ICG Code: The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk.
2 IBC code: International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk.
3 BCH code: Code for the Construction Equipment of Ships Carrying Dangerous Chemicals in Bulk.

Figure 8

Ammonia limitations as an alternative fuel



Note. From the sources above in section 3.2.2

3.2.3 Hydrogen

The combustion of green hydrogen emits almost no carbon, sulphur, or other pollutants since it is made from various renewable energy sources; therefore, it is considered an optimum replacement for fossil fuels. Spark ignition and compression ignition engines, gas turbines, and boilers may use hydrogen (Xing et al., 2020). Hydrogen's low lean-combustion limit helps for steady ignition and minimal NOx emissions but also restricts the power density in potential implementation. Because of this, developing sophisticated hydrogen engines is concerned with increasing power densities and minimizing NOx emissions at high engine loads (Xing et al., 2020).

For the time being, the hydrogen-fuelled engine generally operates using dual fuel engines. Adding hydrogen to the ignition progression of an engine operated by hydrocarbons such as diesel, LNG and biodiesel reduces exhaust emissions, improves engine performance, and simplifies operation (Köse & Ciniviz, 2013). The use of low-NOx engine technology is possible. Increasing the power density of marine engines and gas turbines powered by hydrogen while reducing exhaust pollutants has been the research focus (Bicer & Dincer, 2018). For maritime transportation, even as a combination fuel with marine fuel oil, if hydrogen was utilized, the reduction might reach around 40% of CO2 emissions per unit of work (Xing et al., 2020).

Hydrogen's wide range of production sources and minimal emissions make it an attractive fuel for transportation in the long run. End-users of energy might overcome restrictions by developing more hydrogen-based technology. Nevertheless, establishing a long-term hydrogen economy relies on large-scale hydrogen generation, storage, transportation, and distribution ability to be cost-effective and feasible (Salvi & Subramanian, 2015).

In comparison to fossil fuels, hydrogen has a low volumetric energy density. It must be stored either as a liquid at 253 °C at atmospheric or ambient temperature with more than 200 bar pressures. There are substantial obstacles to implementing a hydrogen-based economy for global shipping due to the need for a significant investment in infrastructure for storage and transportation (Xing et al., 2020).

3.2.3.1 Hydrogen limitation

Hydrogen can only be derived from water by electrolysis or carbon fossil fuels since it is the most abundant element in the universe. In order to carry out either of these actions, a substantial quantity of energy is required. Additionally, this energy can be more potent than hydrogen, making it costly and requiring huge investments (Mckinlay et al., 2020). Moreover, fuel cells and other types of water electrolyzers typically need the use of precious metals like platinum and iridium as impetus, which can increase the initial cost of these devices to become more expensive. Some people have shied away from hydrogen fuel cell technology because of the steep price tag. These prices must be reduced for hydrogen fuel cells to be a viable fuel source for everyone (Serrano et al., 2013).

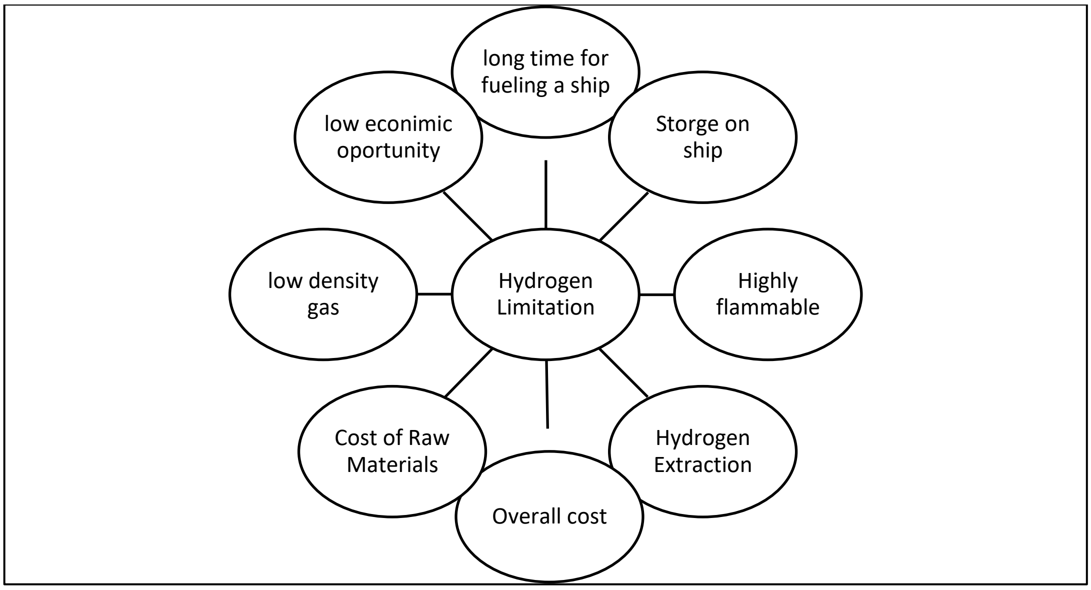
The ease with which fuel may be loaded into a ship is a significant consideration while picking the fuel of the future. Within a few hours, certain ships in the shipping sector may be entirely fuelled as well as bunkered with high amount of heavy diesel fuel which could reached up to thousands of cubic meters. A bunkering ship navigates itself directly near the ship so that the fuel reloading may be conducted. At the same time, cargo is loaded to the ship or unloaded to the shore, which is the typical method. Many ongoing initiatives are looking into the possibility of hydrogen bunker facilities for compressed and liquid hydrogen (Hoecke & Verbruggen, 2021; Tonstad et al., 2017).

Compressed hydrogen presents a two-pronged problem when it comes to storing it. On the one hand, the system's weight and volume density are reduced thanks to using gas cylinders for storage. As a result, storing the cylinders will need to use a significant portion of the ship's deck and hold. Another problem with delivering low-density gas is the lengthy period required for refuelling and bunkering. The SAE J2601 Protocol has been established for the automobile sector to fuel hydrogen gas at 70 MPa. By cooling it to - 40 C and limiting the fuelling pace to 1 kilogram of hydrogen per minute, this method assures the safe functioning of hydrogen fuelling in automobiles (Reddi et al., 2017).

Fuelling a big seagoing ship can take up to several weeks or necessitate a huge amount of nozzles for several weeks at a time. Even if all the nozzles were released simultaneously, attaching and releasing them to a ship would be a lengthy and difficult process. An idea for bunkering is to employ hydrogen tanks that can be placed in a regular 20 or 40-foot size container, which can then be carried into a ship. For smaller ships like ferries, cassette-type fuel systems may be a possibility, but for large vessels, port call could be significantly extended due to the process of loading and unloading of the containers (Hoecke & Verbruggen, 2021).

Figure 9

Hydrogen limitations as an alternative fuel



Note. From the sources above in section 3.2.3

Finally, though it is clear that hydrogen fuel cells are a superior alternative to fossil fuels, more work has to be done before they can fully realize their full potential as a crucial facilitator of a low-carbon energy system. On the bright side, stationary and mobile applications might soon benefit from hydrogen fuel cells as a renewable and clean power source. Decarbonized hydrogen production and fuel-cell manufacturing need to be increased, and the necessary legislative framework for commercial deployment models to be developed. Further technical advancements and infrastructural investments are anticipated to reduce extraction, storage, and transportation costs. Figure 9 shows the main limitation of hydrogen as an alternative fuel.

3.2.4 Methanol

Marine engines that can work on methanol as a dual-fuel have recently gained much interest. There are some estimates that Stena Germanica[4] has decreased SOX emissions by (99 percent); NOx emissions by (60 percent); particulates (95 percent); CO2 emissions (25 percent) on its Baltic Sea route in order to comply with the most recent ECA requirements (ETIP Bioenergy, 2022).

It is not uncommon to see maritime methanol initiatives, like METHAPU[5], which ran from 2006–2009 on-board vessels (Radonja et al., 2019). It was in 2018 that SUMMETH[6] was put through its paces. Small marine engines (between 250 and 1200 kW) are the focus of this project, which also intends to develop feasible possibilities for introducing renewable methanol into the maritime industry (Ellis & Tanneberger, 2015). Methanol-powered vessels have been claimed to have decreased emissions of SOx as well as NOx, and PM. A methanol-fuelled Vasa 32 marine engine produced NOx emissions of 3–5 g/kWh, whereas an MGO-fuelled engine produced 11.8 g/kWh (Dankwa et al., 2021; Radonja et al., 2019). Compared to HFO380, methanol reduced PM, SOx, and CO2 by 95 percent, 99 percent, and 7 percent. Emission Control Areas regulations have been satisfied using methanol as a fuel for maritime vessels. Non-renewable methanol from natural gas, on the other hand, emits 10% more greenhouse gas emissions than HFO and MDO (Dankwa et al., 2021). GHG emissions may be

4 “The first commercial ship in the world to run on methanol as its main fuel, which is more environmentally friendly. Fully refurbished to a high standard and now offering a comfortable, bright & spacious crossing from Germany to Sweden”. (https://www.stenaline.com/about-us/our-ships/stena-germanica/)

5 The METHAPU is a European Commission project in which methanol technology will be tested on a cargo ship involved in international trade as part of this special research study (https://cordis.europa.eu/project/id/31414).

6 Sustainable Marine Methanol (SUMMETH) aims to advance technological development and provide suggestions for the adoption of methanol as an alternative fuel for coastal and inland waterway ships in order to minimize their emissions and carbon footprint. The project proposes to research methanol combustion technologies and ship fuel systems that will lead to cost-effective options for ship operators to minimize their carbon footprint and emissions (http://summeth.marinemethanol.com/?page=home).

reduced by roughly 56% if methanol from biomass feedstock is used instead of HFO. When compared to LNG, methanol's capital expenditures are minimal. If the value on an equivalent energy source is less, it would be cost competitive with MGO. If maritime ships were to use more methanol, it would be contingent on the carbon credentials of the fuel being established and incentives being offered (Balcombe et al., 2019; Dankwa et al., 2021).

It is suitable for producing methanol from various sources, including natural gas, waste CO2, or biomass. CO2 emissions may be ignored for biomass feedstock because they are biogenic. It is important to note that the supply chain of methanol generates considerable emissions depending on its feedstock and processing. Due to the supply chain, gas reforming, and methanol synthesis of natural gas, the life cycle GHG emissions of methanol from natural gas are approximately 10% greater than those of HFO or MDO. There must be significant caution in carbon accounting if waste CO2 is to be utilized to generate methanol (with renewable hydrogen) (Balcombe et al., 2019). Catalytic hydrogenation may produce significant methanol life cycle emissions; however, no research was identified to assess these emissions (Dankwa et al., 2021).

3.2.4.1 Methanol limitation

Fire risk and toxicity are the most limitation points of this fuel type. When it comes to fire risk, under broad daylight conditions, methanol burns with an invisible flame, which might be a safety hazard if no other materials are burning (IEA-AMF, n.d.). Blended fuels, which increase the brightness of the flame, are a standard solution in many regions of the world. An orange flame can be seen when gasoline and/or ethanol are employed in the fuel mixture. Additionally, methanol has a higher fire safety rating than gasoline. Because it is not easily ignited below 10 °C and has a flammability index close to diesel, it may be used the same way as gasoline (Future Fuel Stategies, 2020).

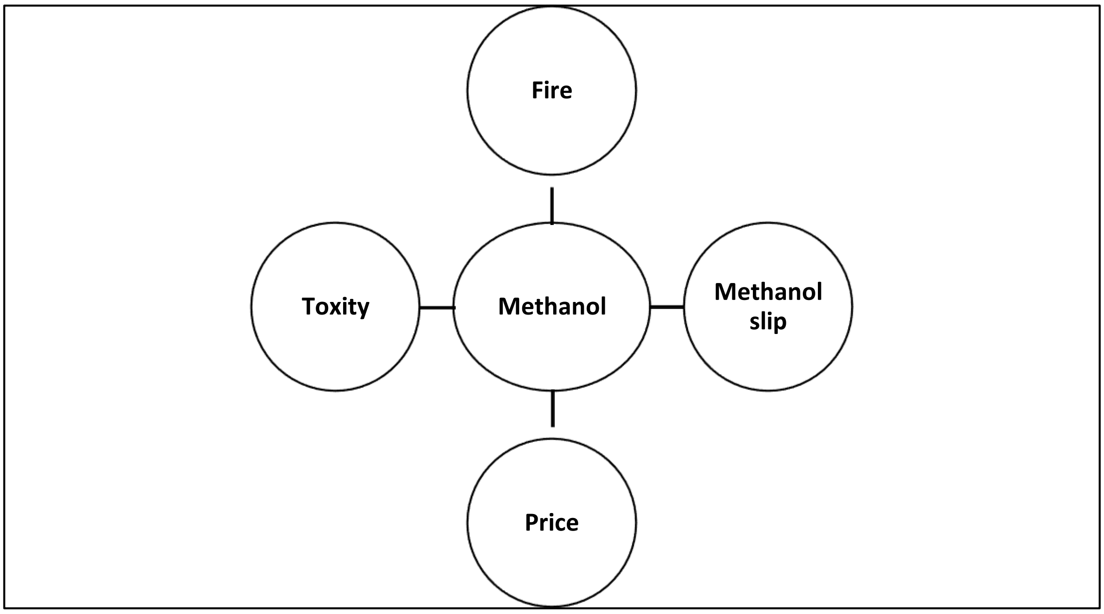
Methanol must be handled cautiously, as with other transportation fuels and chemicals. In the case of methanol vapor, electric currents may spark it due to its flammability. The use of grounding and bonding is essential wherever there is a risk of static electricity build-up, regardless of the kind of equipment. It is common practice to employ carbide-tipped clamps and dip tube filling to protect against static electricity. Other common-sense precautions, such as banning smoking, ensuring sufficient ventilation, grounding lightning, and rapidly remediating any spills, can also be performed to reduce the risk of fire (Future Fuel Stategies, 2020).

On the other hand, when it comes to toxicity, methanol comes from a variety of sources, including food, water, and air. Humans are exposed to methanol on a daily basis through the atmosphere, water as well as the food they consume. According to most experts, methanol levels in the blood are thought to be influenced by food intake. Food usually contain methanol at low levels in the human diet. (Future Fuel Stategies, 2020; Hoseini et al., 2020).

The toxicity of alcohol, which is included in methanol, presents the most serious problem. Health effects on humans arise as a result of elevated concentrations of the hazardous intermediate products formaldehyde and formic acid. The risk of ingestion must be taken into consideration. As little as one ml of methanol has the potential to result in life-threatening effects from methanol exposure. The deadly dose is around 10 to 30 ml for an adult, assuming that 100% methanol fuel is swallowed (Alliance Consulting International, 2008; Future Fuel Stategies, 2020). Moreover, the price of methanol is much higher than LNG. As a result, while methanol fuel may dramatically cut air pollution emissions, its carbon credentials must be established, and incentives must be provided to encourage greater adoption (Dankwa et al., 2021). Figure 10 shows the main limitation of methanol as an alternative fuel.

Figure 10

Methanol limitation as an alternative fuel



Note. From the sources above in section 3.2.4

3.2.5 Biofuels

Many types of the first conventional biofuels such as straight vegetable oil (SVO), hydrotreated vegetable oils (HVO), FAME, and biofuels are easily available today. Traditional biofuels cannot be used worldwide because of the environmental concerns involved with big-scale production. Using biofuels as a 'drop-in' fuel means that existing engines do not need to be modified at all, which can help reduce GHG emissions significantly (Gowen, 2017). When it comes to biofuels, using waste oils can help alleviate some of these issues. The lowest FAME and HVO levels may be obtained by utilizing waste oils. Biofuels have the potential to help in the reduction of NOX, SOX, and GHG emissions. Sulphur is included in extremely small amounts in all biofuels (Wei et al., 2018). Compared to marine gas oil, FAME has much reduced sulphur content (20 ppm) and fewer NOX and PM emissions. When it comes to accidental spills, biofuels have an edge over fossil fuels since they are biodegradable (Balcombe et al., 2019).

Many diesel-like fuels that may be used in marine vessels today can also be stored and bunkered using the existing storage and bunkering infrastructures, with no or minimal engine changes (Balcombe et al., 2019). Bio-ethanol, bio-methanol, bio-LNG, and bio-DME, as well as other alcohols and gaseous fuels, need more substantial modifications to the engine, storage, and bunkering facilities, resulting in higher upfront expenditures. Due to their lower cetane number (except for DME), Spark-ignition engines, dual-fuel compression ignition-engines, or modified compression-ignition-engines are needed for all of them (Radonja et al., 2019).

The price difference between conventional fuels like HFO and MDO biofuels is a deterrent to widespread use. It is estimated that FAME and HVO will cost 1040 and 542 dollars per ton in 2016, nearly twice the price tag of their fossil fuel counterparts, HFO (290 dollars per ton) and MDO (482 dollars per ton). As a result of the infancy and complexity of the manufacturing processes, advanced biofuels have higher costs even if they save more GHG emissions and have fewer long-term sustainability issues (Gowen, 2017).

In the near and medium future, biofuels can replace the current fossil marine fuels. Second generation biofuels, such as FTdiesel and pyrolysis oil, have a greater possibility to reduce greenhouse gas emissions than first-generation biofuels (Darley, 2015). Fuels like LC ethanol and bio-methanol would need even more extensive engines, storage, and infrastructure upgrades than bio-LNG. Suppose a substantial GHG reduction strategy or carbon price is implemented. In that case, advanced biofuels, such as ethanol, will not compete with fossil fuel alternatives because of their high cost and limited supply. There are ways to minimize the impact on other agricultural and food resources, but careful resource management is required (Balcombe et al., 2019).

3.2.5.1 Biofuel limitation

If we take biodiesel as an example, since engine and fuel modification research is still ongoing, direct practical biofuel deployment is not yet possible. At this time, the only significant biofuels that can be used in engines are bioethanol and biodiesel. It has been found that biodiesel may be used as a fuel for forceful engines as an alternate to conservative diesel, which has been tested and approved. Each feedstock's fatty acid makeup influences the biodiesel's fuel characteristics. When using biodiesel in an engine, the fuel must have the same properties as diesel. Flashpoint, cold flow, oxidation stability, density, acid value, calorific value, viscosity, cetane value and moisture content qualities are among the most critical fuel parameters (Serrano et al., 2013; Yaakob et al., 2014).

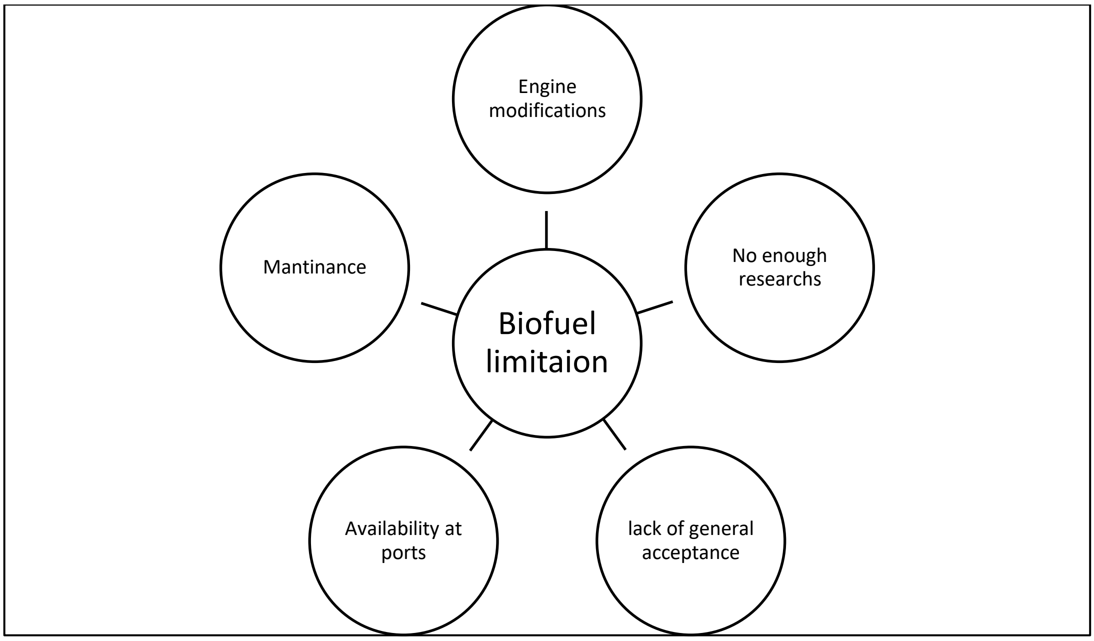
One of the most critical aspects of biodiesel application is maintaining the specified specifications. In moderate weather, most diesel engines may run on biodiesel for a limited number of hours, according to current studies. Due to the lack of a generally accepted and maintained the quality standard for biodiesel fuels, several restrictions are imposed on the use of biodiesel fuels. Due to compatibility concerns, biodiesel was accessible at the pump in Germany, but only at extremely low levels. The ASTM D-7467[7] standards have created new potentials for greater fuel blending. Saturated and unsaturated fatty acid esters in biodiesel make it very vulnerable to self-oxidation (Joshi et al., 2017; Serrano et al., 2013).

Finally, we can say that the biggest challenge for biofuels is their availability at ports. Fuel compatibility with the engine as blended biodiesel has the greatest impact on engine performance in terms of fuel precipitation and filter clogging. Using low biodiesel blends for a lengthy period of time necessitates careful consideration as the effect of biofuel on the equipment (fuel injector, filters and other fuel system) is not well known (Joshi et al., 2017). Figure 11 shows the main limitation of biofuel as alternative fuel.

7 ASTM D7467 is a specification standard for diesel fuel oil and bio-diesel blend.

Figure 11

Biofuels limitations as an alternative fuel



Note. From the sources above in section 3.2.5

3.3 Alternative fuels drivers and limitations.

Each alternative fuel has its own drivers that ship-owner and ports can benefit from. As we can see from table 3 which summarize the drivers of alternative fuels, ammonia is less expensive in term of storage and is more available commercially comparing to other types of alternative fuels and have a good global distribution network. Biofuels on the other hand have an advantage that its fungible with existing marine engine and bunkering infrastructure and have a high energy density. Moreover, Hydrogen characterized with the minimal emission and less volumetric energy density when comparing it to fossil fuels and have a steady ignition. Furthermore, the most driver for methanol is that it can be produced from various sources and have minimal capital needs compared to LNG. Finally, LNG is the most used type of alternative fuel in the maritime industry, for the time being it is considered the safest alternative fuel to invest in.

Table 3

Drivers for alternative fuels

Fuels	Divers
Ammonia	• Less expensive fuel in term of storage • Commercial-availability • Feasibility • Global distribution network • Easy handling experience
Biofuels	• Life cycle emissions reduction • High energy density • Fungibility with existing marine engine • Fungibility with existing bunkering infrastructure
Hydrogen	• Wide range of production sources • Minimal emissions • low volumetric energy density than fossil fuel • low lean-combustion limit helps for steady ignition
Methanol	• Methanol can be produce from various sources, including natural gas, waste CO2, or biomass. • Capital expenditures are minimal comparing to LNG • Pure fuels, and do not contain sulphur.
LNG	• Already used in maritime sector • Abundance of resources • Competitive cost • Excellent thermodynamic yields

Note. From the sources of this chapter.

On the other hand, alternative fuels have also some limitations, as we can see from table 4 which summarize the limitations of alternative fuels.

Table 4

Accumulation of limitations of all alternative fuels

Limitations for alternative fuels	• Economics (require funds)
	• Lack of use of electricity based on renewable energy (solutions), they still use fossil fuel to generate and produce alternative fuels.
	• Environmental issues (methanol slip, increase of energy consumption, life cycle emissions increase.
	• Security and Safety issues
	• Lack of regulations
	• Sustainability issues natural resources consumption e.g. biofuel

Note. From sources of this chapter.

Starting from the economic needs as alternative fuels need a huge funding from the stakeholders. Moreover, for the time being the lack of regulations for these types of alternative fuels as well as the security and safety issues and environmental risks such like (methanol slips and life cycle emission increase) are considered a limitation. Furthermore, these alternative fuels are produced by natural resources that will led to resources sustainability issues in the future.

4. Chapter 4: Alternative fuels in Ports – Implementations, strength, weakness and roadmap of solutions

Not many ports have prepared for the alternative fuel, except for the LNG in developed countries' ports. Therefore, after presenting some front-running ports experiences. In this chapter, the current situation in ports regarding alternative fuel bunkering will be discussed alongside the road map for ports concerning alternative fuel. From a European, regional, and municipal standpoint, as well as a port authority perspective, waterborne transportation must become sustainable. LNG and low-sulphur fuel are the only two options that shipping businesses explore when it comes to meeting new laws of SECA-zones. The maritime industry's current bunker plans are a significant consideration when selecting a fuel (Aronietis et al., 2017).

4.1 Port case studies for the use of alternative fuels in bunkering and operation

4.1.1 Port of Rotterdam

The Port of Rotterdam, according to its mission statement, is working on building new roles and enterprises that are aligned with a thorough decarbonization strategy in order to actively promote EU climate policy as well as transportation and logistics. As a significant European GHG emissions hotspot, the port of Rotterdam produces more than 30 million tons of CO_2 annually from the industrial cluster and around 24.8 million tons from the transportation of goods to and from the port (Lechtenböhmer et al., 2018).

In 2015, the port of Rotterdam handled over 460 million tons of cargo, making it the largest European port and one of the top twenty ports in the world. That region's and the Rhine Valley's economies benefit greatly from its presence. According to the data, liquid bulk for freight and transportation volume in 2015 contributed 225 Mt or over half of the total volume. Containers and other general goods dominate freight volume. Incoming general freight travels the most extraordinary lengths (over 9,500 kilometers on average), nearly double that of liquid bulk. A total of 3378 Giga ton-kilometers (Gtkm), or 21.4 million metric tons of CO_2 emissions, are transported by sea each year. Including “empty return” transports, hinterland transportation accounts for an estimated 2.22 million tons of CO2 emissions (Lechtenböhmer et al., 2018).

Port Rotterdam is the largest seaport in Europe. In order to maintain its position as the world’s busiest port, it must be easily accessible to ships at sea. Enhancing port competitiveness as an international logistics centre and world-class industrial complex is the port of Rotterdam Authority’s primary goal. Dimensions are critical, but so is the level of craftsmanship. As a result, the port authority is taking the lead in switching to renewable energy and embracing digitalization to improve port operations and the supply chain. Sustainable port development, management, and use, as well as quick and secure shipping services, are the primary responsibilities of the port authority. The port authority is a public company (N.V.) owned by the city of Rotterdam and the Dutch government (together, 70%) (30 %) (AIVP, 2020).

In Rotterdam’s port region, the infrastructure and fuel facilities necessary for the development of alternative fuels are already in place. The port is home to several large multinational firms for fuel production, storage, handling, distribution, and trade. CO2 emissions might be reduced significantly by improving shipping efficiency. However, there are other choices available if marine transportation is to meet the international community’s goal of reducing greenhouse gas emissions by 50% by 2050 (WPSP, 2022c).

Port of Rotterdam is already using LNG as an alternative fuel; regasification or loading onto ships or trucks are two options for transporting the LNG from Gate to the European gas distribution network. On top of being able to replenish the natural gas pipeline system, the Gate LNG terminal also offers reloading capabilities for ships, containers, and tank trucks. This makes it possible to transport LNG via inland tanker, short sea tanker, or truck to locations without natural gas pipelines or fuel stations. Each tank has a capacity of 180,000 m3, allowing for the unloading of enormous volumes of LNG at once. Vopak and Gasunie, the creators of Gate, are collaborating with the port of Rotterdam Authority to build LNG break bulk facilities beside the current Gate terminal to meet increased demand for LNG (PortofRotterdam, n.d.).

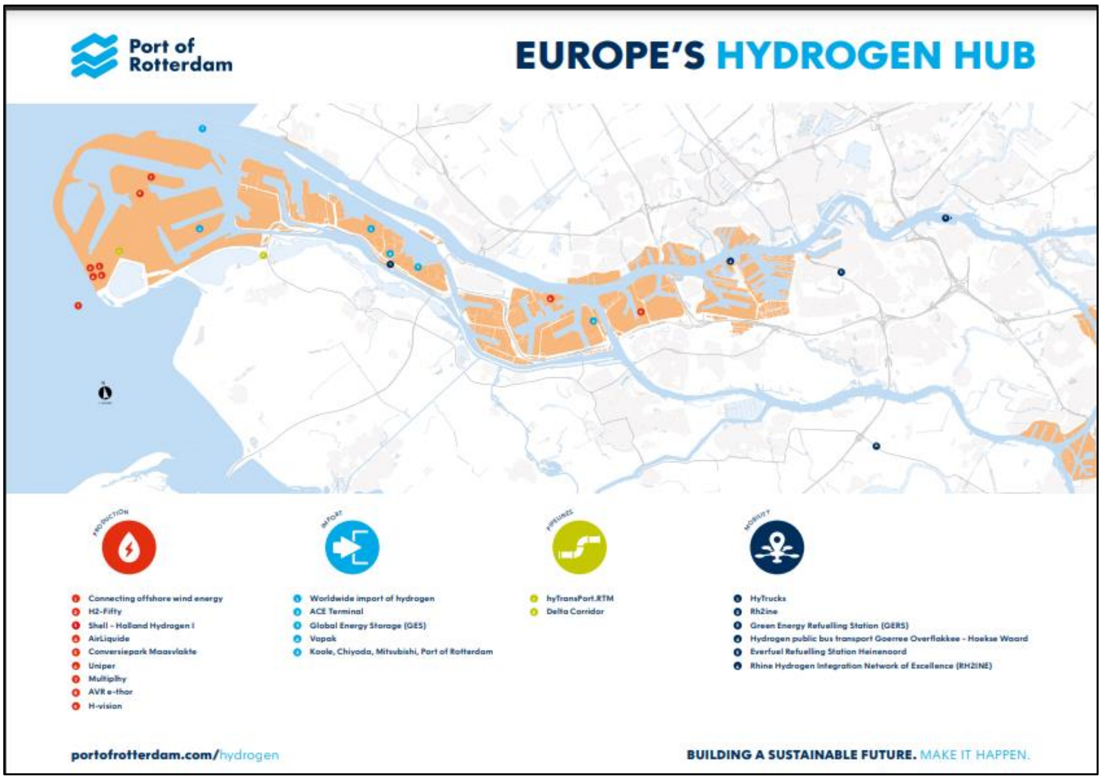
On the 10th of May 2022, the port of Rotterdam announced that Rotterdam will provide an estimated 4.6 million metric tons of hydrogen will be supplied to North and Central Europe by 2030, according to the port of Rotterdam and its partners. Based on current projects and realistic projections, the port of Rotterdam authority has arrived at this hydrogen total. Companies and exporting nations are now trying to achieve it. The port of Rotterdam authority has made this offer to European commissioner on behalf of more than 70 firms and exporting nations (Pekic, 2022). Plans and projects in the REPowerEU[8] framework reflect an actual execution of the European aim (EU, 2022). As fuel and feedstock for transportation and industry, this hydrogen might help ensure the sustainability of society (Pekic, 2022).

Rotterdam's establishment of a hydrogen centre has several benefits. A noteworthy drop in carbon emissions may be attained by the widespread use of hydrogen in industry. The port can maintain its position as the generator of the national economy if it has access to a hydrogen network (PortofRotterdam, 2022).

8 REPowerEU is a project that is created by the EU as a response to Russia's invasion of Ukraine and the resulting hardships and disruption of the global energy sector (European Commission, 2022).

Figure 12

Port of Rotterdam as a hydrogen hub map



Note. From Port of Rotterdam website (portofrotterdam.com/hydrogen).

The port authority's research reveals that it does not matter how far it is moved once hydrogen gets on board a ship. The majority of the expenditures are connected to the process of transporting hydrogen. Hydrogen, unlike oil, must be cooled significantly (to -253 degrees Celsius) to become a liquid state. If ammonia (NH3), methanol, or a Liquid Organic Hydrogen Carrier (LOHC) is accessible, it may simply stuff hydrogen into another molecule (LOHC). That takes much energy. However, many countries that may produce hydrogen are too far away to ship it to the Netherlands in a gaseous state by pipeline (PortofRotterdam, 2022).

Many stakeholders are considering import terminals in the port of Rotterdam. Rotterdam now has the capability to accommodate a variety of different hydrogen carriers. According to current projections, the terminal capacity of (green) hydrogen is predicted to rise in the following years. The planned HyTransPort.RTM[9] hydrogen pipeline will run straight through the port area and may be connected to these terminals. A joint venture between the port authority and Gasunie is creating this pipeline. Thus, the port complex as a whole, as well as the Dutch countryside and northern Europe as a whole, will benefit from hydrogen distribution (PortofRotterdam, 2022). Moreover, Maasvlakte 2 will be the location of Europe's largest green hydrogen plant. The ultimate investment decision for this was made by Shell. Holland Hydrogen I is a future plant projected to be operational in 2025 (PortofRotterdam, 2022).

Hydrogen may be imported into all ports, from Pernis to Maasvlaak 2. These ports all have the capacity and safety, as well as environmental and navigational considerations, to handle the import of hydrogen, depending on the amount. Refinery, energy, and tank storage companies are ready for hydrogen imports. Hydrogen in various forms is expected to be available by 2025, with both physical space and licenses in place. Companies are also rearranging their existing product portfolios to free up physical and/or environmental space (PortofRotterdam, 2021).

In support of decarbonization, the port of Rotterdam has put up an incentive program to assist innovative initiatives that use alternative fuels in ship-based transportation. The program began on January 21, 2019, and will run until December 31, 2022. The goal is to cut CO2 emissions significantly and offer a financial boost to initiatives that may otherwise be difficult to implement. Anyone who wants to utilize alternative fuels to lower the CO2 impact of seagoing vessels can join up. Fuel producers, suppliers, and engine makers are included in this category (ESPO, 2022).

9 The Port of Rotterdam Authority and HyNetwork Services have collaborated on a new hydrogen pipeline called HyTransPort that runs through the Port of Rotterdam. As a foundation for Rotterdam's hydrogen infrastructure, this pipeline will be essential. In the future, the pipeline will be linked to both the domestic and international hydrogen grids. Chemelot in Limburg, North Rhine-Westphalia in Germany, and other European areas will also be connected (https://hytransportrotterdam.com/en/).

4.1.2 Port of Antwerp-Bruges

An agreement has been made between the cities of Antwerp and Bruges to integrate their respective ports. The agreement between the two cities signals the beginning of a year-long unification process. The ports were named the ‘Port of Antwerp-Bruges. They are aiming by merging to increase their position in the global supply chain and pursue sustainable growth as a consequence of this combination. In addition, the unified port will be more robust to future difficulties and will lead to the transition to a low-carbon economy. First, the goal is to make the port of Antwerp-Bruges a hub for commerce, people, and environmental sustainability (PortofAnwerpBruges, 2022b).

Figure 13

Port of Antwerp map

Note. From “Port of Antwerp map” by (ontheworldmap.com).

The port of Antwerp Bruges is the world's fifth-largest bunker port for conventional fuels. By 2025, the port of Antwerp is planning to become a multi fuel port with bunkering facilities that support LNG, methanol, hydrogen, and electricity (WPSP, 2022a). Moreover, in support of decarbonization, the port of Antwerp Bruges is in the process of making an energy transition by investing in wind turbines and solar panels to generate power. They are bringing alternative energy sources such as hydrogen and transforming them into sustainable raw materials for the chemical sector at the port of Antwerp Bruges. Sustainable industry, shipping, and logistics emphasize the port of Antwerp Bruges' efforts (PortofAnwerpBruges, 2022a).

The port of Antwerp Bruges has signed a contract with the chemical company INOVYN[10] which is devoted to setting up a business in the port for hydrogen as an alternative fuel; this can only show the commitment and belief of the port of Antwerp Bruges in hydrogen as an alternative fuel. Moreover, the port has several receiving terminals for hydrogen, and substantial industrial companies use hydrogen as an energy source (PortofAnwerpBruges, 2022a).

4.1.3 Port of Hamburg

Due to its strategic location, Hamburg is Germany's most important port for international trade, thanks to its proximity to the North Sea and the Baltic Sea. Four hundred fifty million Europeans rely on Germany's largest multifunctional port, making it a critical link in the supply chain. Getting to Scandinavian and Baltic ports from Hamburg is easy due to its location in the world's busiest artificial canal, the Kiel Canal. As for the Czech Republic, the Elbe River and the Elbe-Seiten Canal are ideal for river barge transit of products (PortofHamburg, 2022).

The Hamburg Port Authority (HPA) is responsible for the whole port region and is in charge of leasing and maintaining the property. Thus, the HPA is in charge of maintaining the quays, roads, bridges and dredging the fairway, while about 1,500

10 Chemical firm INOVYN is part of the INEOS group of companies. In today's culture, its products (such as salt, PVC, and chlorine) may be found in practically every part of it. "I want to contribute to make a difference for the next generation and hydrogen has the power to bring that about," says INOVYN's Business Unit Manager for Hydrogen, Wouter Bleukx.

companies are in charge of their facilities and cranes. Moreover, the port of Hamburg's stakeholders is ready for the future. Various areas of innovation, such as sustainability, virtual reality, or underwater and aerial drone use, are now possible thanks to the HPA and port firms' digitization plan (PortofHamburg, 2022).

Regarding alternative fuels, LNG is already being used in the port region. The LNG barge "Hummel" can supply cruise ships with alternative electricity generated by LNG-driven generators. In addition, ships may use LNG to refuel while docked rather than burning fuel oil, which produces far greater emissions. The Hamburg port authority pays ships using these facilities or burning LNG on-board with a port-specific cash incentive. Ships at the port of Hamburg that perform better in terms of environmental impact receive a reduction in air-fees usage costs. Moreover, PowerPac[11] is being tested in Hamburg's port in 2018 in order to give ships with shore power generated by LNG-powered generators. From the end of 2018 onwards, a bunker barge will be ready to supply huge volumes of LNG for ships' bunkering needs. (WPSP, 2022b).

In support of decarbonization, Hamburg Green Hydrogen Hub (HGHH) is one of the first programs in the world to completely decarbonize a port's economic base as shown in Figure 14. Zero-carbon hydrogen energy is in great demand in the industrial and transportation sectors. Hydrogen manufacturing might begin in 2025 if all licenses are obtained on schedule (HGHH, 2022).

11 The Becker LNG PowerPac® is a small unit the size of two 40-foot containers that cleverly combines an LNG tank with a 1.5 Megawatt gas generator in a small area (https://www.becker-marine-systems.com/products/product-detail/becker-lng-powerpac.html).

Figure 14

HBHH project plan

Note. From Port of Hamburg [Drawing], (HGHH.eu).

4.1.4 Port of Amsterdam

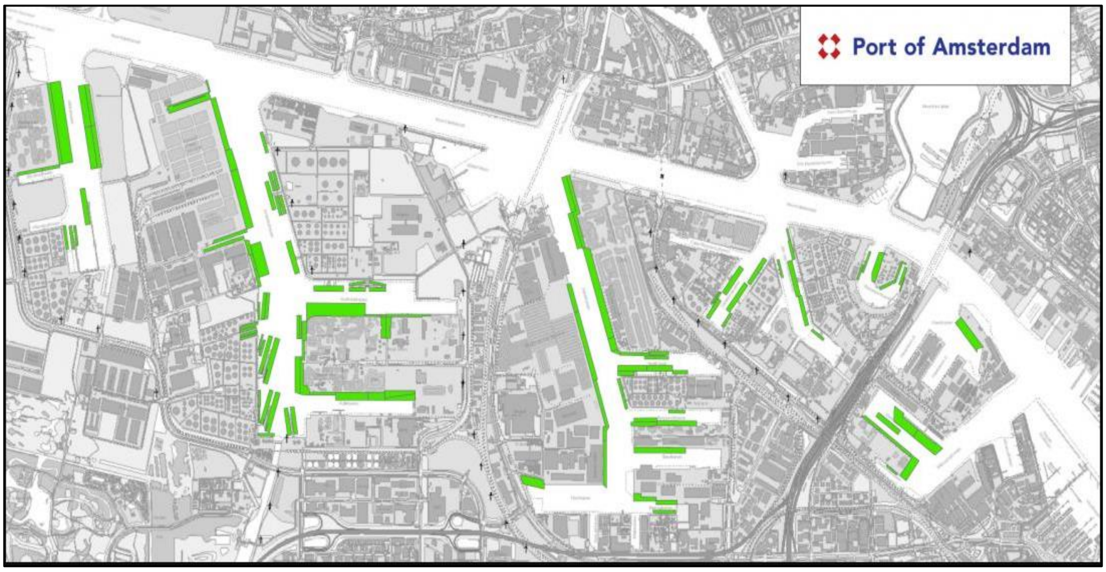
Port of Amsterdam is one of the ports that is trying to adapt to lower emissions worldwide, alternative fuel bunkering for seagoing vessels is part of Havenbedrijf Amsterdam N.V.'s long-term sustainability plan. The port of Amsterdam has already made ship-to-ship LNG bunkering viable as shown in Figure 15 (PortofAmsterdam, n.d.-c). The Titan FlexFueler[12] is housed in a specifically built facility certified by the

12 A new name, Titan, has been given to Titan LNG. All of Titan's fuels, including liquefied biomethane (LBM), as well as any hydrogen-derived green fuels in the future, are better represented by the new name, Titan engages in offering clean fuel solutions for transportation and industry. Project management, physical supply and delivery, risk management, and price hedging are all part of this package. This means Titan may cooperate with other providers of low carbon and carbon neutral marine fuels to ensure dependable supply wherever in the globe because it is an independent clean fuel firm. (Titan, 2022).

environment agency. At this point, barges may berth in order to fill up with LNG. Ships up to 180 meters long can berth here for LNG bunkering if on-site bunkering is not possible (PortofAmsterdam, n.d.-d). DNV has also conducted a study for the port of Amsterdam on the safety distance comparison for alternative fuels (LNG, Methanol, Ammonia, Hydrogen); the object of this study is to determine the distance when bunkering on the ship-to-ship method and compare it with the safety precautions of LNG (DNV.GL, 2021).

Figure 15

LNG bunkering at a fixed bunker location in port of Amsterdam



Note. From Port of Amsterdam [Map], (https://www.portofamsterdam.com).

Hydrogen is also used in the port of Amsterdam. There are several uses for hydrogen both for the port's benefit and that of the city and surrounding area. Green hydrogen, for example, may be utilized as a transportation fuel, a domestic fuel, a commercial raw material, a sustainable industrial raw material, and as a form of energy storage in place of traditional battery storage devices. The port will be able to create and store green hydrogen as soon as possible. Besides being turned into finished goods, it may also be used as a raw material. As an illustration, consider synthetic fuels, plastics, and fertilizers (PortofAmsterdam, n.d.-b).

Biofuels are also available in the port of Amsterdam. Storage, transshipment, and mixing of biofuels are all possible with the current infrastructure. Its location in the ARA hub provides excellent maritime and hinterland connectivity. This mixing is already happening in Amsterdam because it is the world’s largest gasoline port. Because of its considerable experience and competence in oil and gasoline, the port is well-suited to assist in importing and exporting biofuels. The port of Amsterdam has many biodiesel facilities in operation. Port infrastructure, such as jetties, tanks, storage, transshipment, and mixing, are already provided to biofuel consumers by existing tank storage companies. Several locations are available near or on existing tank storage terminals (PortofAmsterdam, n.d.-a).

4.1.5 Port of Bremen-Bremerhaven

Bremen and Bremerhaven are covered by Bremen’s twin ports. Bremerhaven handles containers, vehicles, refrigerated produce, and wind farm components, whereas Bremen-City handles typical breakbulk and heavy-lift goods. The Bremen ports signed the World Ports Climate Declaration in 2008, pledging their support for efforts to improve air quality (WPSP, 2022d).

The port’s administration chose to assist the development of LNG as a maritime fuel alternative when it adopted its 'green ports' ideology. The port's fleet uses LNG as a fuel source. The port's infrastructure management business, BREMENPORTS, will show the technical, operational, and economic viability of LNG-fueled engines in its newest hopper barge, in addition to facilitating shore-side infrastructure. For the transportation of dredging materials, Bremen ports has developed a new type of hopper barge, which it claims to be the first of its kind in the world; the company hopes to have its whole hopper barge fleet powered by LNG (WPSP, 2022d).

4.2. PESTLE/SWOT analysis

When conducting SWOT/PESTLE analysis, each port will have its own strength and weaknesses. In this part, we will discuss and analyze the SWOT/PESTLE analysis for ports overall to decide how to make the right decision regarding adopting alternative fuels in ports.

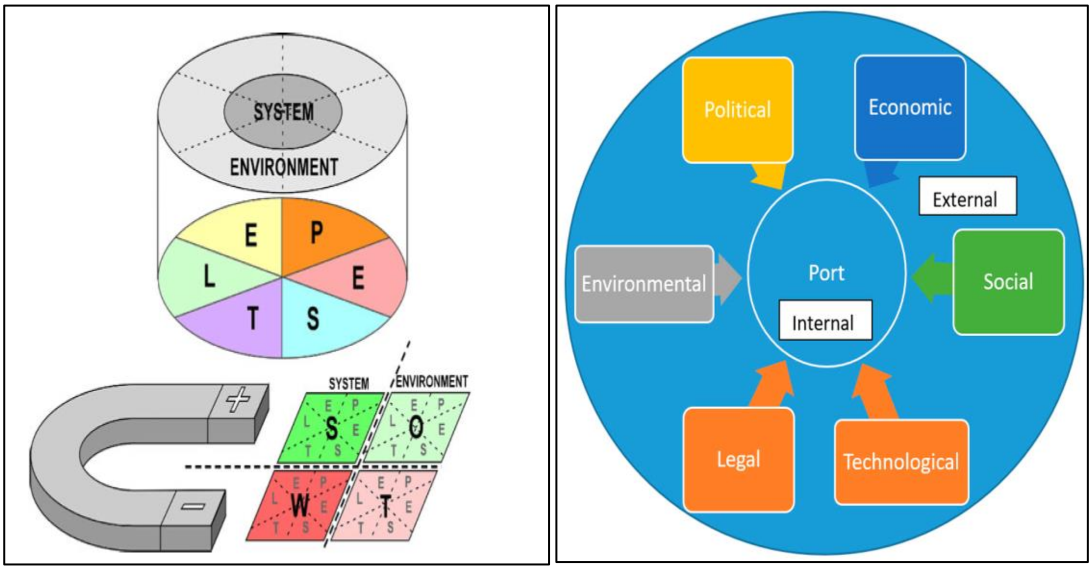
In order to recognize the main internal and external factors that can have an impact on the decision-making to adopt a specific type of alternative fuel, a SWOT/PESTLE analysis is used in this study. Moreover, according to Evangelinos and Nikolaou, analyzing a port's strengths and weaknesses, as well as its opportunities and threats from implementing a plan, is a helpful tool for environmental management strategic planning (Nikolaou & Evangelinos, 2010).

An assessment of the elements impacting the deployment of a port plan when it comes to alternative fuels may be done using a SWOT analysis, which divides the internal (strengths and weaknesses) and external (opportunities and threats) parameters. Many variations have been proposed to the SWOT/PESTLE analysis, which is the most common circumstance when the systems evaluated are complicated, and the external variables must be extensively analyzed (Clark et al., 1999; Hill & Westbrook, 1997).

It is crucial for port strategic planning that gives a deliberate parameter for analyzing the external forces that affect a port. Port uses it to assess the potential influence of the surrounding environment on a project. Using the acronym PESTLE categorizes a variety of external criteria into a single factor category. It will also allow us to identify the internal factors and their categorization into the many PESTLE categories. A PESTLE Analysis is frequently used in conjunction with a SWOT Analysis. The main advantage of adopting a SWOT/PESTLE theory is that it gives us the opportunity to combine the internal and external elements that could influence a project as shown in Figure 16, mainly because the latter are outside the control of the business and are more challenging to uncover (Srdjevic et al., 2012).

Figure 16

SWOT/PESTLE analysis

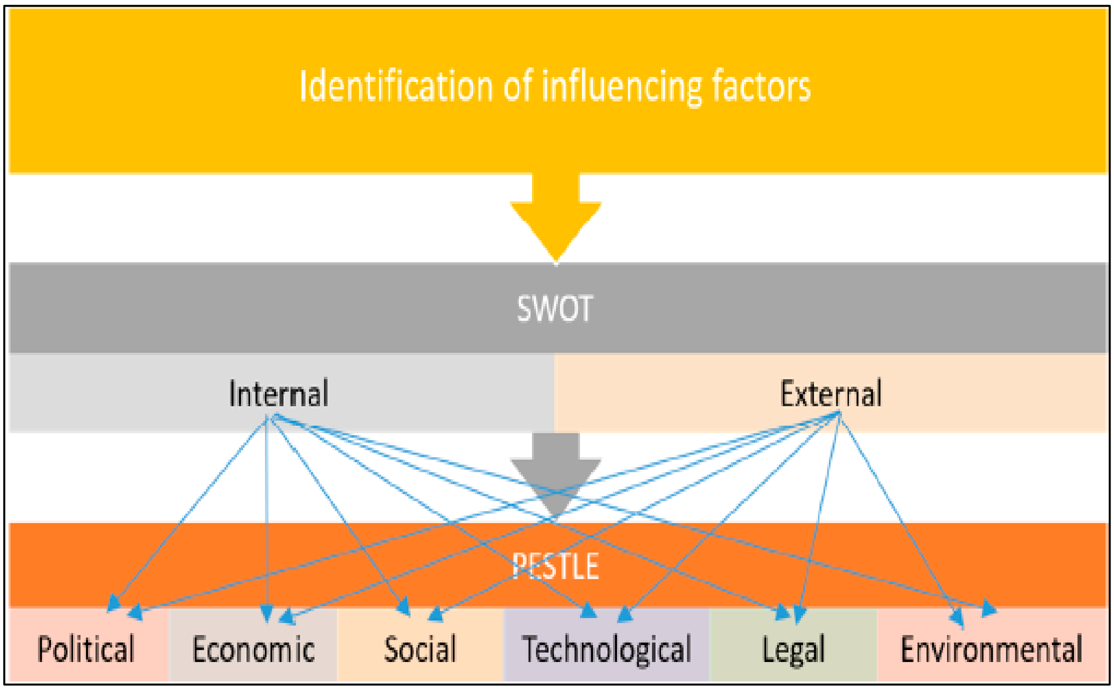


Note. From "Identifying the Main Opportunities and Challenges from the Implementation of a Port Energy Management System: A SWOT/PESTLE Analysis", by Anastasia Christodoulou and Kevin Cullinane. Copyright 2019 by Sustainability & from "Identifying the Criteria Set for Multicriteria Decision Making Based on SWOT/PESTLE Analysis: A Case Study of Reconstructing A Water Intake Structure" by Zorica Srdjevic, Ratko Bajcetic & Bojan Srdjevic. Copyright 2012 by Springer International Published.

A port alternative fuel adoption strategy evolution in connection to the port's internal and external environment may be examined using the synergy between SWOT and PESTLE analysis because of the port's complex and multidimensional environment. An internal and an external cluster of elements are utilized in this study to divide the factors that play a crucial role in the effective adoption of alternative fuel in ports into two groups based on the domain in which they have an impact on the adoption. To classify these variables, we use a PESTLE analysis that breaks them into six groups as shown in Figure 17 based on the degree of their effect on the system as a whole (Srdjevic et al., 2012; Vorthman, 2008).

Figure 17

Identification of the factors that impact the decision-making of adaptation of alternative fuels in ports



Note. From "Identifying the Main Opportunities and Challenges from the Implementation of a Port Energy Management System: A SWOT/PESTLE Analysis", by Anastasia Christodoulou and Kevin Cullinane. Copyright 2019 by Sustainability.

4.2.1External factors

4.2.1.1 The competitive advantage

Strength: Implementing an alternative fuel management strategy and adopting a particular alternative fuel for operation and bunkering, such as LNG or hydrogen, shows the commitment to the sustainable development goals, which gives the port a better competitive edge in its region by portraying itself as a socially responsible port committed to sustainable development.

Weakness: The lack of energy management strategy and alternative fuel bunkering can show the lack of commitment of the port to the support of shipping decarbonization and thus lose the competitive edge in the marketplace.

4.2.1.2 The influence of stakeholders

Strength: The governments and regional authorities significantly impact port operations and their decisions on investing in alternative fuels and policies on energy consumption. According to Fenton, when it comes to a port's capacity to deal with the climate change consequences of shipping and ease the decision-making process for alternative fuel investment, cities should play an active role in the activities that are aimed at reducing air emissions from ship-and-port operations. (Fenton, 2017).

Weakness: The influence of the stakeholders could be negative for the port if they did not support the port's decisions to adopt alternative fuel in operation and bunkering.

4.2.1.3 Profitability

Strength: Investing in alternative fuels earlier may help the port to become a step ahead among others in the region; this will help gain the market and reduce the cost of operations in the port, thus improving the profitability of the port.

Weakness: Ports with a highly competitive location and low investments and stakeholder support can lead to less profitability, which may result in loss of investments.

4.2.1.4 Regulations related to alternative fuels

A port alternative fuel management strategy can help ports fulfil future international, national, and regional laws. OPS and LNG filling stations are required in all EU ports by the end of 2025 under European Directive 2014/94/EU, which aims to create an infrastructure for alternative fuel and boost LNG usage. We can see from Section 4.1 that all European ports already have LNG bunkering (Acciaro et al., 2014); thus, having a regional regulation is a strength for all countries of the regions. On the other hand, other regions lack this type of regulation which can be considered a weakness for the port.

4.2.1.5 Funding

Strength: The support of all stakeholders is crucial at this point. It is imperative to have enough funding to support adopting alternative fuels. Rich countries with massive financial capabilities will have this as a strong point.

Weakness: Countries with low financial capabilities will find it hard to invest in alternative fuels, especially since investing in alternative fuels and ports often demands significant initial expenses and funding, as well as external finance that comes with substantial business risk. Thus it is critical to know what alternative fuel will be used in the future ship-owners to make the right decision.

4.2.1.6 Financial investments

Strength

Ports can better prepare for financing possibilities by implementing a port alternative fuel management strategy. Poseidon Med LNG Bunkering Project is an EU project that shows the energy effort in that region. Designing an LNG supply and distribution network and infrastructure, which includes bunkering in the East Mediterranean, is a European Union-funded project that receives 50 percent EU funding assistance (Christodoulou & Cullinane, 2019). These extra funding possibilities can help ports in alternative fuel projects.

4.2.1.7 Alternative fuels framework

Strength: A well-defined set of standards for a port energy management system and alternative fuel operation and bunkering use would help ensure that new technologies are monitored and accurately measured. This might be a catalyst for the creation of new technological innovations.

Weakness: The lack of framework for using alternative fuel can lead to risks like safety and security risks, which will result in the loss of port position in the market as an alternative fuel user and provider.

4.2.1.8 Air pollution reduction

Strength

The implementation of alternative fuels in operation and bunkering implies that the undesirable effect of port daily operation on people's health as well as climate change will also be decreased, resulting in a reduction in the external expenses of port operations. To endorse the use of alternative fuels, the port alternative fuel strategy mandates the construction of port operations and the supply of LNG refuelling points. Building infrastructure and producing power for alternative fuels from renewable energy sources will reduces the air pollution in port areas because of the influence of fuel type on air emissions (Christodoulou & Cullinane, 2019).

4.2.1.9 Integration of ports activates in using alternative fuels

Strength

An effective port alternative fuel management plan might assist ports in incorporating the concept of reducing energy consumption and lower GHG emissions into all aspects of port operations and culture, therefore including management as well as employees, and making them a part of the process of change is a critical phase when taking decision.

4.2.1.10 Mismanagement in implementing alternative fuel plans in ports

(Weakness)

The main danger of a port alternative fuel adoption strategy is if it is implemented incorrectly or in the wrong way. Organizational change, such as incorporating energy management into daily operations, is typically met with opposition from both management and employees. Many management systems (ISM Code, SEEMP) in the maritime sector have not been effectively implemented because of a lack of training and participation of management and workers (Bazari & Longva, 2011). Table 5 summarizes the external parameters that can affect investing in alternative fuels in ports.

Table 5

External parameters affecting investing in alternative fuels in ports

SWOT/PESTLE	External Factors
Political	• The influence of Stakeholders on Ports • Financial Investment
Economical	• Profitability improvement • Competitive advantage over others • Funding
Social	• Mismanagement in implementing alternative fuel plans in ports. • Integration of port activities in using alternative fuels.
Technological	• Helping in developing new energy efficiency technologies.
Legal	• Meeting all current and future regulations in order to reduce GHG emissions
Environmental	• Achieve the future goal of decarbonization

Note. Own elaboration based on data of sources above in this chapter

4.2.2 Internal factors

4.2.2.1 Location

Can be a strength or weakness depending on the country

Location is one of the most critical factors that can affect the decision-making of having alternative fuels as a good port location is a strength that will increase the number of visiting ships; thus, having an LNG bunking will help all the ships that operate with this type of alternative fuel which will lead to more profitability and capital return. On the other hand, a competitive location can be a weakness and lead to fewer visiting ships and high market competitiveness.

4.2.2.2 Port strategic plan

Strength

The creation of a strategic port plan that supports the adoption of alternative fuel in operation and bunkering must be tailored to a particular port's needs. The port's key characteristics and operations must be considered, as ports can vary significantly in size, services supplied, energy consumption, and bunkering needs.

4.2.2.3 Clear port alternative fuel policy, management objectives, and goals

Strength

The construction of a port alternative fuel management strategy relies heavily on establishing particular objectives and goals in a well-defined port energy policy. Consequently, the attainment of these goals will be compared to the outcomes of adopting the plan, indicating whether or not the plan has been successfully implemented.

4.2.2.4 Existing policies, standards, and regulations compliance

Weakness

The port alternative fuels decision plan must consider all applicable international, national, and regional legislation and standards since any inconsistencies in such regulations and policies might jeopardize the plan's success. Unfortunately, there is a lack of international regulations regarding alternative fuels; for example, for the time being, alternative fuels bunkering safety regulations are only done by classification societies such as DNV for a specific port upon request.

4.2.2.5 GHG reduction

Strength

Improved energy performance and reduced air emissions are the most significant factors when developing an alternative fuel strategy. The port's energy efficiency and the source of its energy generation are used to measure the port's energy performance. GHG emissions in ports can be lowered if the port's energy demands can be met more efficiently through improved energy performance and renewable energy sources (Alamoush, Olçer, et al., 2022).

4.2.2.6 Cost of investment

Weakness

The cost of investment, especially at this time when no one knows what type of alternative fuel will be used in the future, is the primary obstruction when deciding.

4.2.2.7 Top Management Commitments

Can be a strength or weakness

An alternative fuel strategy for the port must include an explicit declaration from top management regarding their commitment to invest in alternative fuels and improve the port's energy efficiency. For port management and personnel to adopt and implement an energy conservation strategy, the top management must be unambiguous about their commitment to reducing GHG emissions (Karcher & Jochem, 2015; Moroni et al., 2016).

4.2.2.8 Staff training

Can be a strength or weakness

For the successful adoption of an alternative fuel strategy, it is crucial for staff to have tailored training in all aspects of alternative fuel, such as safety and security in bunkering. ISM code experience demonstrated that the lack of training, as well as the engagement of employees, was a crucial difficulty in executing a safety management strategy (Pun et al., 2003).

4.2.2.9 Performance monitor system

Strength

There should be a framework to evaluate and compare the energy efficiency and alternative fuel measures, as well as the reduction in GHG emissions from ports that have been implemented with the targets established in the port's policy. In this method, the port's administration may be alerted of variances in performance.

4.2.2.10 Periodic management review

Strength

In order to maintain a high level of performance in the port, a formal management review should be part of every port management strategy. As a result, it is necessary to identify current shortcomings and instances of non-compliance with established objectives. Both serve as valuable input for changing alternative fuels policy or adjusting the targets set.

Table 6 summarizes the internal parameters that can affect investing in alternative fuels in ports.

Table 6

Internal parameters affecting investing in alternative fuels in ports

SWOT/PESTLE	Internal Factors
Political	• Port strategic plan • Clear port alternative fuel policy as well as management objectives and goal • Location
Economical	• Cost of investment
Social	• Top management commitment • Staff training
Technological	• Performance monitor system • Periodic Management Review
Legal	• Existing Policies, Standards, and Regulations Compliance
Environmental	• GHG reduction • Reduction of energy consumption

Note. Own elaboration based on data of sources above in this chapter

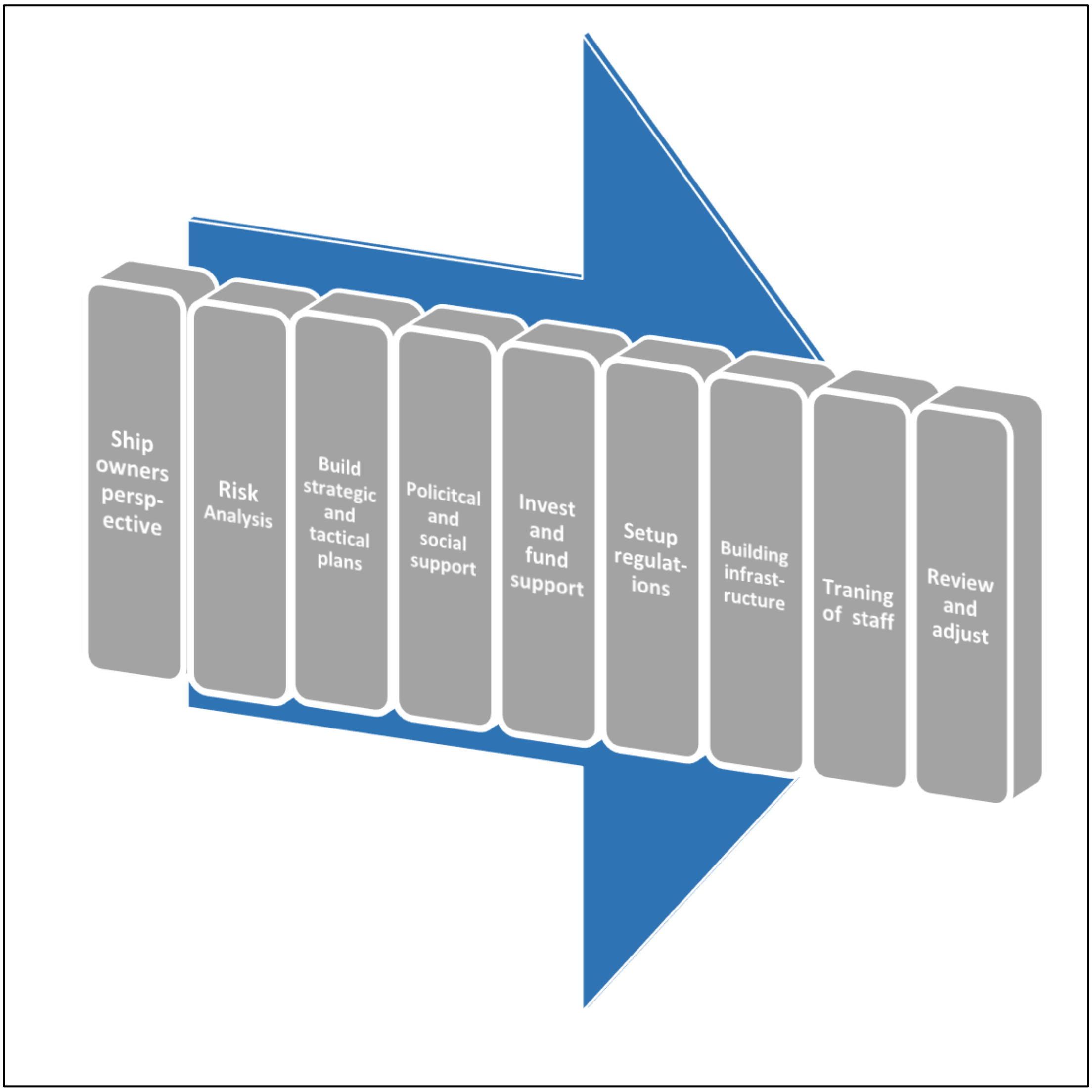
4.3. Roadmaps of port's solutions to overcome the limitation of adopting alternative fuel for bunkering and operation

Adopting an alternative fuel strategy in ports is a tough decision as it depends on many factors. We can divide alternative fuels in ports into two categories. The first category is the bunkering for alternative fuels, and the second is alternative fuels as a power source for ports. For the time being, LNG looks like the safest type of fuel to invest in. Moreover, other alternative fuels, such as methanol and hydrogen, are also promising. However, the ports still have to wait and see the general orientation of the maritime industry. Hydrogen and ammonia are used in ports as a power source alongside wind turbines. In this category, the ports' environmental, economic, technological, and social aspects are the key factors that affect the type of alternative fuels chosen for the specific port.

Based on the result of the review, which focused on alternative fuel bunkering and limitation in port, including the operation, table 7 below presents these limitations and the recommended solutions to overcome these limitations. Additionally, these solutions serve as opportunities for ports to adopt alternative fuels as this increase their competition and position them well strong in the supply chain of decarbonization (Alamoush, Ballini, & Dalaklis, 2021; Alamoush, Ballini, & Ölçer, 2021a). Further visualization of the Road Map is presented in Figure 18 below, which includes steps that should be taken while ports mitigate the limitations.

Figure 18

Road map for adopting alternative fuels in port



Note. Own elaboration based on data of sources above in this chapter

Table 7

Solutions to adopt alternative fuels in port

Limitations	**Solutions to adopt Alternative fuels in port**
Economics (require funds)	• Budget and funds from the government
Lack of use of electricity based on renewable energy (solutions), they still use fossil fuel to generate and produce AF	• Harnessing renewable energy in AF production
Environmental issues (methanol slip, increase in energy consumption, life cycle emissions increase,	• Life cycle analysis of emission of alternative fuels, • The cost-benefit ratio of adoption
Security issues (i.e. explosion by terrorists) & Safety issues (i.e. fire, explosion)	• Security and safety plans • Training • Certification • Risk analysis • Inclusion of alternative fuels in ISPS code
Lack of regulations	• Government and port authorities to enact regulations for legalizing alternative fuels bunkering and ships reception
Sustainability issues natural resources consumption e.g. biofuel	• Port to invest with the cooperation of other stakeholders and the city (port city integrations) to ensure the sustainability of resources. They also can invest in panting algae or other biomass materials etc.
	• Cooperation, collaboration, coordination with other stakeholders (feedback from the city, ship-owners, ship operators, shipping agencies etc.

4.3.1 The Road Map

4.3.1.1 Ship owners' perspective

For bunkering, ports will have to depend on what ship-owners decide to use as alternative fuels for their vessels. On the one hand, the first and most essential factor is to know among all these alternative fuels which one will be chosen to be the one the ship-owners will use for their ships (Aronietis et al., 2017). Suppose ship owners desire to use LNG, the development of LNG bunkering infrastructures must be supported by the ports. There must be an understanding of what kind of demand there is for LNG before any port authority can invest in this infrastructure (Aronietis et al., 2016). For the time being, LNG is the most excepted type of alternative fuel to be used worldwide.

4.3.1.2 Planning

The port authority needs to set up or adjust the strategic plan that includes all the actions needed to adopt the selected alternative fuel. The plan must include the capital needed, infrastructure, and training plans.

4.3.1.3 Risk analysis

The ports must adjust their safety and security plans to the new threats emerging from these alternative fuels. The port must conduct a risk analysis for the adjustment of the plans. Moreover, continuous training and certification are crucial; it is recommended to include alternative fuels in the ISPS code.

It is imperative for port authorities to conduct a risk analysis to know their strength and weakness and whether it is the right choice to invest in alternative fuels and build all the necessary infrastructure or not. The analysis will show the port's strengths and weaknesses in the market and the opportunities and threats that will help the decision-makers make the right decision.

4.3.1.4 Political and social support

It is vital to get political and public support to adopt alternative fuels as this type of decision must have a high investment to succeed. The political and social support can be challenging for emerging countries to invest in alternative fuels. In comparison, they need the money to invest in the health and education sector, which people in these countries consider more important. Moreover, the port needs to look at the competitive ports in its region, especially in regions where ports are close to each other's as the competition will be much higher and will affect the profitability of the port. The port needs to study the ship movement in its region and the type of bunkering needed for that amount of movement. Furthermore, the safety of alternative fuels is an issue as a new safety regulation is needed for these types of alternative fuels.

4.3.1.5 Regulations

The new challenges include the bunkering of these new alternative fuels. For instance, instead of requiring a specific technology, the IGF Code empowers the ports to choose what works best. According to the IGF Code, any standardization of the bunkering interface will be necessary if gas-powered ships seek to bunker at multiple ports, particularly in different countries/continents. In this context, SGMF and the International Standards Organization (ISO) are developing a publication on the best practices in this field (SGMF, 2019).

4.3.1.6 Building infrastructure

When deciding to use alternative fuels, the port authorities must build all the infrastructure needed to support adopting the selected type of alternative fuel. Knowing the exact type, size, and capacity of infrastructure is crucial. An example is knowing the amount of bunkering capacity the market needs in the specific region.

4.3.1.7 Training

Adopting new types of alternative fuel will introduce a new type of risk at the port. Training is the most crucial step when it comes to risk mitigation; thus, it is essential to set up all plans and issue certificates needed for these types of training.

4.3.1.8 Review and adjustment

To have a successful adoption, the port must continuously review all the steps and adjust when needed. The port must always continue its evolution to stay relevant, advanced, and competitive. The continued review will help the port recognize all the opportunities available in the market. On the other hand, the adjustment will help the port take advantage of these opportunities.

Chapter 5: Conclusion and Recommendation

Summary of research

In this dissertation, a comprehensive systematic literature review analysis methodology was utilized to address the research problems raised by this project. A systematic review methodology was guided by phases and steps suggested by (Denyer & Tranfield 2009; Petticrew & Roberts, 2008; Snyder, 2019). The goal was to identify and discuss the Ports' steps necessary to prepare and adopt the shipping of alternative fuels in support of decarbonization. In order to find relevant research, it was necessary to begin the search with a well-defined query with a clear response; the four-phase method mentioned in chapter two was conducted. In the first phase, an electronic database search was conducted to locate the most complete source or a combination of sources. We have selected the journals and articles to research and the period in which they were analyzed. The second stage evaluated the papers based on their relevance to the review topic. A first search was undertaken to determine the criteria for rejecting non-related items. The next step was to analyze the papers for relevance to the review topic. After establishing the parameters for removing irrelevant content, the preliminary search was conducted. After that, the next stage was to obtain and use relevant information to investigate the review questions further. An in-depth review of the relevant literature was conducted in the third step of this process. The review is only completed after all of the findings of a previous study are thoroughly examined.
The systematic literature review accounted for five promising alternative fuels, i.e.
LNG, ammonia, biofuel, methanol, hydrogen. The review includes their abatement potential and limitations and also suggests various solutions.

Importantly, we found that adopting alternative fuels in ports as a source of power or for bunkering will not only help reduce GHG emissions but will also support the global efforts to reduce ongoing vessels (OGVs) and land transport GHG emissions. It is not easy for the port decision-makers to decide which type of alternative fuel to invest in. On the one hand, when it comes to bunkering, LNG is the safest alternative fuel to invest in. All the prominent ports in Europe have some sort of LNG bunkering. On the other hand, hydrogen can come into the equation alongside LNG when it comes to alternative fuels as a source provider for power in ports.

Another important finding of this study is the identification of drivers for adopting alternative fuel bunkering. Regarding alternative fuel drivers, every type of fuel has its drivers (mentioned in Table 3), but all of them share the characteristic of having less pollution than fossil fuels.

On the other hand, limitations of alternative fuels, such as the lack of regulation, the emerging security and safety threats, and the high investment needed for adoption, can affect the stakeholders' decision to adopt alternative fuels in ports for bunking or operation.

Ports such as Rotterdam already have LNG in place. They have a strategic plan to use and distribute hydrogen in the north and central Europe by 2030, aiming to significantly reduce carbon emissions by vast spreading the use of hydrogen in the industry (Pekic, 2022). Moreover, the port of Hamburg has one of the first programs in the world to decarbonize a port's economic base completely. Hydrogen manufacturing plans are to begin production in 2025 (HGHH, 2022).

Regarding other types of alternative fuels in ports, such as ammonia, biofuels, and methanol, European ports still find the decision hard to invest in these types of alternative fuels, especially for bunkering, as they need to see the commitment of ship owners to build or modify their ships to be operated by alternative fuel source of power.

A vital result of this research is building a road map to overcome the limitations of alternative fuel bunkering and its use in port operations. The road map steps start with the knowledge of the future alternative fuel the ship-owners will use. After that, the port must conduct a risk analysis, set up and adjust strategic plans, gather political and social support, allocate investments and funds needed, set up regulations, build infrastructure, set up training plans and programs, and finally review and adjust. It is essential to mention that due to the complexity of ports, there is no general policy that fits all ports worldwide. Every port must tailor its own policy for the support of decarbonization. Moreover, when it comes to the financial part, ports must consider the amount of capital used to adopt alternative fuels and forecast the possible profit. Competition, loan interest rates, political issues, and port location can all affect the port's financial situation.

Limitations

Finding the port preparations for alternative fuels in bunkering or operation was challenging. When researching this subject, we only found some reports by recognized organizations discussing the forerunner ports' preparation for alternative fuels. On the other hand, we did not find any relative documents discussing alternative fuel preparations in ports in emerging countries for bunkering or operation.

Contribution

This work helps to global climate change mitigation efforts. In particular, it adds to the sustainability performance of the port. In addition, the study has consequences for port authorities and maritime administrations preparing for the future, i.e. gaining knowledge and decision support regarding what is necessary for future bunkering and reception of ships carrying alternative fuels. Notably, the study contributes to the body of knowledge because few studies have addressed this issue.

Recommendations for port authorities and operators

Ports worldwide, especially in emerging countries, it is considered challenging to decide to invest in alternative fuels. Emerging countries, therefore, will need to analyze all the possibilities and establish national and political support before investing in alternative fuels as a source of power or for bunkering. It is also essential to lower the competitiveness in the port region by agreeing with the neighbouring countries on which type of alternative fuel to invest in bunkering for each country; this will help decrease the competition in ports between the neighbouring countries.

Overall, in order to adopt alternative fuel in ports, for the time being, the recommended alternative fuel for bunking is LNG, as it is already used as a source of power for ships in the maritime industry. Moreover, hydrogen is also recommended alongside LNG for operations in ports. The port of Rotterdam can be taken as an example of a port planning to adopt alternative fuel strategies for operation and bunkering.

Ports need to overcome the limitation of these alternative fuels by having all the stakeholders' support and the national support in the country to have the required funding for this adoption. Moreover, security and safety plans, training, certification, and, most importantly, risk analysis are crucial to deal with the new security and safety threats emerging from adopting alternative fuels. Furthermore, it is recommended for countries to support the idea of the inclusion of alternative fuels in the ISPS code, which will provide the minimum standards to avoid these kinds of risks.

Finally, strategic and long-term development planning for future port operations, including environmental goals, such as climate change mitigation strategies, must be included in the port plans targeting (GHG reduction). Ports must consider sustainability from the beginning of every project, even if it is just an extension (Lam & Notteboom, 2014).

Future research areas

The scope of alternative fuel in ports is relatively new and needs further research. The essential scope to be researched is safety regulations in ports for each type of alternative fuel for bunking and operation. Furthermore, the study of the ship-owner decision on which alternative fuel to be used worldwide is a field that can attract more ports into confidently investing in the selected type of alternative fuel. This research was based on a systematic literature review; further research efforts may help advance the findings if other forms of research utilize interviews and questionnaires to establish data about the ports. Multi-criteria decision-making as a tool can be used to validate the road map structure and steps.

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