



Erasmus University Rotterdam

**MSc in Maritime Economics and Logistics**

*2023/2024*

The Influence of Resource constraint Factors on The Decision-Making Process of Vietnamese Shipowners for Green Alternative Fuels.

By

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## ACKNOWLEDGEMENTS

As my time enrolling in Master of Science – Maritime Economics and Logistics has gradually come to an end, I would like to dedicate this huge and proud achievement to many individuals that has, either directly or indirectly, contributes to this once-in-a-lifetime achievement. First and foremost, I want to express my deepest gratitude and respect to my thesis supervisor, Mrs. Elvira Haezendonck. Thank you for your unwavering support and guidance throughout my thesis's journey. To all the MEL staff, Renee, Martha and Felicia, thanks for the dedication you give.

Second, I want to give the huge credit to my beloved parents and brother, who have flew all the way from Vietnam and through 17-hour-flight to support me on my Graduation day. I cannot get to where I am today and see the places that you have not got chance to see without using the money that you worked hard to earn. I still remembered when I was in grade 12, crying when Dad told me that I have to study for my Master's and now I am here, on a random Saturday evening, shouting out to my cool parents that their constant support has fueled me with strength to complete this Master programme. Thanks Mom and Dad a lot, 'Con sẽ làm Bố Mẹ tự hào'.

For my hidden hero, Hoai Tran, you have been always by my side since the first day I stepped foot in Europe. Even from 10,000km away, you make our relationship alive with your sincere and most pure love that I ever experienced. Thanks for the love and support to make my huge dream come true. I will forever cherish us and our next chapter together.

Looking back to my memories in MEL, one year passes so fast. I would like to send my gratitude to all my classmates and our memories together will be missed. As the only Viet and a Gen-Z baby in our class, I hope that I have brought you guys with a nice touch of Viet culture. And Bei He, thanks for being the "Duo" in our class with me, thanks for the online shopping during class time and thanks for giving me advice on my long-distance relationship.

A big shoutout to my girls. Thanks Ly for the daily gossips for the last 12 years. Thanks Hanh for your cursed TikTok videos, you make my TikTok messages less boring and fill my lonely life here with laughters, cheers to our slay girlhood.

Finally, I believe this work will be a testament to my relentless efforts to pursue my big-girl dream, be a strong proof of my mindset of 'Smart is the new beauty' and be a culmination of countless late study nights. And to every girl out there: 'Life is a buffet, so eat whatever you want'.

## **ABSTRACT**

The Vietnamese shipping sector is projected to undergo a fuel transition in the future decades because of increased regulation and a determination by certain shipowners to lessen their environmental effect. If shipping is to reduce greenhouse gas emissions so that the industry can meet the IMO's zero emission target of 2050, as well as the Vietnam National Energy Development Plan, urgent action is required in terms of environmentally friendly technology adoption and operational measures based on alternative fuels. While some research has arisen in the previous decade on different alternative marine fuels targeted at decreasing emissions for shipping, there has been less attention on how resource constraint factors can impact the choice of alternative fuel and the correlation between factors in decision-making process of shipowners. This research intends to analyze the relationship between resource constraint factors such as economics and scalability and two other elements utilized in the selection process of the green marine fuel: application and environmental factors, thereby examining five types of maritime fuels: LNG, LPG, Methanol, Hydrogen, and Ammonia's performance on each parameter. Through the development of a survey questionnaire from Vietnamese stakeholders based on their expertise which factor has the most significant impact during the selection process and process the data through Confirmatory Factor Analysis and multi-group Structural Equation Modeling, the paper shows that environmental factors have the highest impact on fuel selection process, followed by applicability factors, scalability and economics. With such impact level of four factor group, the results have indicated hydrogen tends to be the next green marine fuel for Vietnam's shipping sector with its suitable characteristics for Vietnamese fleet.

**Keywords:** Green Marine Fuels, decision-making process, Vietnamese shipowners, selection factor correlation, resource constraint factors, applicability factors, environment factors, economics factors, scalability factors, hydrogen.

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## LIST OF ABBREVIATIONS AND ACRONYMS

2S	Two stroke
4S	Four stroke
CO <sub>2</sub>	Chemical compound for carbon emissions
FC	Fuel Cell
GHG	Greenhouse gases
H <sub>2</sub>	Chemical compound for Hydrogen
ICE	Internal Combustion Engine
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NG	Natural Gas
NH <sub>3</sub>	Chemical compound for Ammonia
NO <sub>x</sub>	Nitrogen Oxides
PM	Particulate matter
SO <sub>x</sub>	Sulfur Oxides
T-t-P	Tank-to-Propeller Emissions
VOCs	Volatile Organic Compounds
W-t-W	Well-to-Wake Emissions

# 1. CHAPTER 1: INTRODUCTION

## 1.1. Background

Shipping is critical to Vietnam's economy since it offers a key source of revenue and creates a huge number of employments. Ships transport over 90% of Vietnam's import and export cargo volumes, making them the country's major source of transportation (Nguyena, 2024). As of December 2023, the Vietnamese shipping fleet consisted of 1,863 ships with a total DWT of around 8.176 million, accounting for approximately 1.98 percent of the total DWT worldwide. In terms of ship tonnage, Vietnam's shipping fleet ranks fourth out of ten ASEAN countries, trailing only Singapore, Indonesia and Malaysia, proving the efficiency of this transport mode in Vietnam and globally (UNCTADStat, 2024).

Given that the Vietnamese shipping sector has a huge and quickly rising fleet size, utilizes the dirtiest fuels available, and has a direct influence on coastal and marine life, sustainable shipping objectives and programs are critical to reducing the industry's negative environmental impact (Nguyenb, 2024). Therefore, simply enhancing the ship's energy efficiency will not suffice. Considering the EU, in line with the European Green Deal objectives, seeks to cut emissions overall by 55% in 2030 compared to 1990 and have a climate neutral economy by 2050, a transition from fossil fuels to zero-carbon fuels for shipping is necessary (European Commission, 2019).

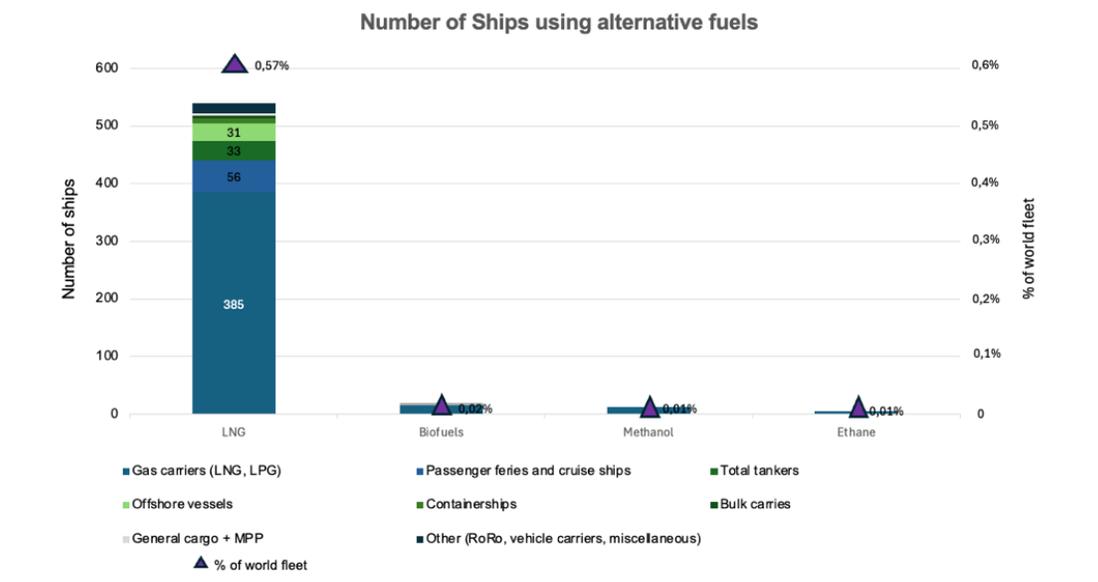


Figure 1-1: Number of ships using alternative fuels (reproduced from Clarksons Research, 2020).

The UNFCCC Paris Agreement targets for climate action were established at COP21 in 2015 and encompass all GHG emissions, including shipping. The Paris Agreement and the 2030 Agenda for Sustainable Development pave the path for sustainable, low-carbon, and resilient development in the face of climate change (United Nations, 2015). In this regard, the marine regulatory agency, the IMO, announced an updated GHG reduction strategy in 2023, identifying four goals: 1) to reduce CO<sub>2</sub> emissions by at least 40% by 2030, compared to 2008 levels; 2) to use zero or near-zero GHG emission technologies, fuels, and/or energy sources to represent at least 5% of the energy used by shipping by 2030; 3) to reduce ship carbon intensity through energy efficiency improvements for new incoming ships; and 4) to achieve net-zero GHG emissions by 2050 (IMO, 2023). The sustainable shipping program also includes existing IMO restrictions on the sulphur cap of marine bunker fuels and emission control areas. Countries announce plans to accomplish the specified IMO goals (IMO, 2023). Vietnam's Power Development Plan 8, or National Energy Master Plan (NEMP), for the 2021-2030 era is also one of the promising strategies to minimize carbon emissions from fuel and satisfy Vietnam's 'net-zero by 2050' goal, as well as ensuring the energy industry is autonomous and self-sufficient (Phung, 2023).

Despite the trend towards a net zero emission target, Vietnam's maritime fleet is having difficulty reacting to these global environmental changes, especially with the cost of this green transition. The estimated cost of complying with these regulations for the marine transport sector is over US\$3.6 billion, which is mostly due to challenges like an aging fleet or capital restriction of local shipowners (Vietnamnews, 2023). Rising above the initiatives to the green transition roadmap as a more cost-effective solution, green fuels in the maritime sector is a crucial step towards mitigating greenhouse gas emissions and addressing the environmental impacts of shipping (Le, 2024). Despite acknowledging the potential benefits of green fuels, the Vietnamese shipowners' fuel selection process remains complex due to the lack of a unified framework. Specifically, Vietnamese shipowners face the challenge of determining the relative importance of various considerations, such as fuel availability, cost, infrastructure development, technological maturity, and environmental performance (Nguyen & Gang, 2022). This leads to the consequence of not sufficiently weighting factor groups in decision-making and potentially suboptimal choices, hindering the adoption of green fuels.

## 1.2. Problem Identification

Private financial constraints are the most significant impediment to the Vietnamese marine industry's shift to green fuels. Renewable energy sources, such as hydrogen or ammonia, are more expensive than traditional fossil fuels like diesel, posing a substantial economic challenge (Nguyen, 2024). Furthermore, the infrastructure required to generate, store, and transport green fuels is yet undeveloped, resulting in significant capital expenses. Specifically, green fuel choices are typically more expensive than traditional marine fuels. Furthermore, the cost of building new ships that run on clean fuels with low emissions is around \$10 million higher than that of traditional ships (Mai, 2023). Vietnamese shipping companies must conduct a thorough cost-benefit analysis, taking into account not only fuel economy but also significant infrastructure costs and the possibility of unrealized government subsidies that could encourage a shift toward a more environmentally friendly fleet. The current infrastructure at the ports also provides a barrier since it would be expensive to install new filling stations or adapt existing ones to allow alternative fuels, which might impede their widespread adoption (Mai, 2023).

Besides, national resources such as production capacity and market availability of green marine fuel is a major resource issue facing Vietnamese shipowners as a result of multiple interrelated reasons, hindering the scalability of fuel (Raihan et al., 2024). First, the construction of critical green infrastructure is hampered by gaps in information regarding green fuels. A thorough grasp of the operational and technological aspects of new green fuel is lacking, which makes it difficult to build production facilities, storage tanks, and bunkering stations on time. Second, although there has been significant improvement, the nation's capacity to produce conventional fuels is still insufficient when compared to other nations. Vietnamese shipowners are vulnerable to market swings and possible interruptions due to their reliance on outside supplies for fuel, especially as the country makes the switch to greener fuels (Urban et al. 2019).

While resource limits may play a role, particularly in terms of production capacity or fuel availability for renewable energy projects as well as energy and capital costs, the choice of alternative fuel for the maritime industry presents a complex balancing act, which requires other sustainability and applicability factors. While LNG offers immediate environmental benefits in terms of SO<sub>x</sub> and NO<sub>x</sub> reductions, its impact on CO<sub>2</sub> remains insufficient. Biofuels offer the cleanest option but face economic and logistical hurdles. Methanol and ethanol, particularly biomass-derived versions, show promise with potentially lower investment costs and a cleaner environmental profile than LNG. Hence, with these contrasts, more study is required to fully understand the interaction of

these elements and their possible influence on the green fuel transition. Therefore, in order to put a final answer on green fuel in place, factors like economic constraints, infrastructure constraints, technological immaturity, and a changing regulatory environment must be put in a comprehensive model to decide whether economic factors can have a stronger impact than sustainability factors.

Drawing from the issues below, the question remaining to answer is to what extent can resource constraint factors impact the green fuel selection considering appearance of other urgent factors like fuel applicability and strict regulations on emissions

### **1.3. Research question and objectives**

Based on the stated issue, the primary research question for this project is as follows:

***‘How do resource constraint factors influence the decision-making processes of Vietnamese shipowners regarding the adoption of green marine fuels?’***

The study's primary objective is to investigate how, in scenarios that we fairly anticipate, may emerge in the near future of whether economics and financial factors plays a stronger role than other factors like sustainability, applicability in selecting green fuels that should be used to reach the target of decarbonization. To do this, we will need to create a model that would enable us to test the correlation of a variety of parameters quantitatively, in which we identify the most suitable green energy considering the landscape of Vietnam. These findings beg the intrusive question of what factor should be selected to compare with different economics factors when selecting green fuel. Assuming that ship owners and the industry as a whole would act rationally, we will evaluate the essential criterias and see whether costs play a strongest role in a decision-making process of Vietnamese shipowners for different alternative energy.

However, apart from the resource constraint factors, we must look at other important factors when selecting alternative fuels and how they benefit society and shipowners in many scenarios that the sub-research issues identify. While they are all mutually exclusive, they all work together to fully address the primary research issue and achieve our study goals. The identified sub-research questions are as follows:

1. What are the factors affecting the choice of alternative fuels?
2. What are the current alternative fuels in use?

3. To what extent do the dimensions of resource constraint factors impact the decision making process of green fuel selection for Vietnamese shipowners?
4. Do resource constraint factors influence fuel selection directly or indirectly through mediators such as applicability or environment factors?
5. What are the best green fuels given the correlation between the decision-making factors?

#### **1.4. Research Design and Methodology**

The goal of the research is to use data gathered from multiple sources to concentrate on the quantitative assessments. A review of the literature, questionnaires with shipowners in Vietnam, and market participants involved in existing alternative fuel projects will be the main methods used to introduce some qualitative components.

A general classification of the sub-research topics into two separate but related groups can be made according to the strategy applied to provide an effective solution.

Sub-research question 1 will identify what criterias that Vietnam shipowners are looking at when choosing a green energy to implement on their ship and relationship between them by doing literature review.

Sub-research question 2 will look at different types of the existing green fuels that have been used in the Vietnam market as well as advantages and disadvantages of each fuel.

Sub-research question 3 will investigate the correlation of selected factors inside the resource constraint factors group to understand which sub-factor are contributing the highest impact towards the overall resource constraint group.

Sub-research question 4 will look at hypothesis testing of whether resource constraint factors can positively influence significantly to the fuel selection process and test their relationship with the moderating factors like applicability or environmental factors.

Sub-research question 5 will look at the impact of the factors to select out the most suitable green fuel by combining with their performance scoring of fuels from stakeholders.

##### **1.4.1. Thesis Structure**

Chapter 1 explains the issue, establishes the research questions, and sets the groundwork for the investigation based on the background of the identified problem. Chapter 2 will serve as the

literature review and theoretical foundation for this research, as we will explore academic work conducted in disciplines relevant to the setting of our investigation. We will analyze research pertinent to emissions, reduction objectives for GHG emissions, currently accessible alternative fuels for shipping, and operational and technological ways to pick green energy from Vietnamese container lines. Chapter 3 will introduce the criteria that existing container lines have used to select a viable alternative fuel for their boats and explore their importance on the green fuel selection process of Vietnamese shipowners. Next, the alternative fuels chosen for our study based on a survey of existing literature and we will explore the basic physical characteristics of these fuels, with a focus on resource constraint factors. Chapter 4 will go into the technique and data utilized to develop the model. We will discuss the essential hypothesis and connections between the variables and parameters employed in our model. Further, the model's shortcomings will be highlighted. Chapter 5 will provide the model's output and main outcomes. We shall explore how these findings may be interpreted to have practical benefits in the future. Chapter 6 will present the study's conclusions. We will describe -the important findings and explain how they relate to our research topics. Finally, we will highlight the limits of the study and recommend topics of subsequent research that have not been investigated but might add value to this research.

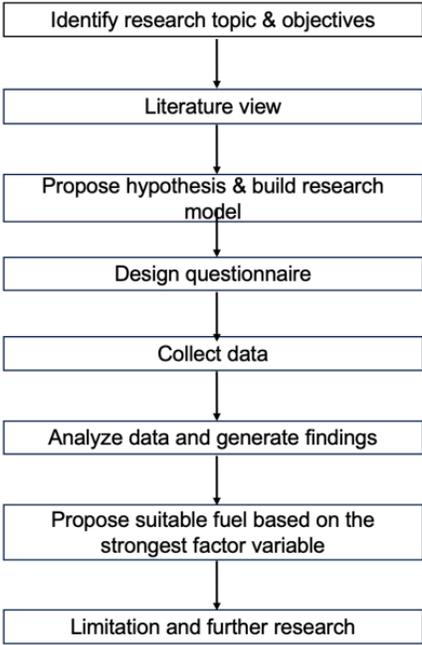


Figure 1-2: Research Process of this Paper (Author's compilation)

**1.5. Relevance of this study**

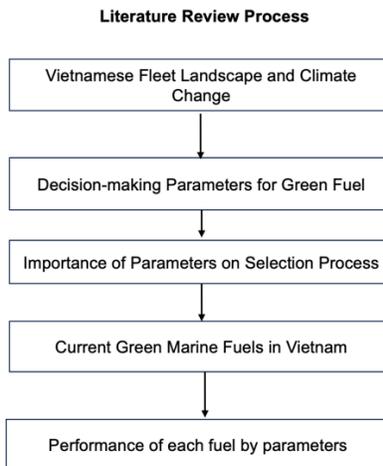
Despite being one of the least carbon-intensive modes of transport, shipping was responsible for 2.9% of all human CO<sub>2</sub> emissions worldwide in 2018. Ships produced 13.5% of the greenhouse gas (GHG) emissions from transportation, a significant decrease from road transportation's (71%), and aviation's (14.4%) totals (Soone, 2023). Southeast Asia is one of the world's most heavily frequented shipping zones, including some of the most important international sea routes for big cargo ships (Nepal, Phoumin & Khatri, 2021). Asia is the world's largest importing and exporting area, accounting for 61% of unloaded freight volume and 40% of loaded cargo volume in 2016, with rapid expansion (UNCTAD, 2023). The Straits of Malacca is an important shipping route between the Pacific and Indian Oceans. Between 2017 and 2022, the number of transits grew by 50% and the region's seaborne exports to non-ASEAN nations amounted for 74% (UNCTAD, 2023). As a result, there is a need for a better knowledge of the ASEAN region's shipping emissions and implications.

Volumes handled by port, including all cargo types such as container, liquid cargo, and dry cargo, can serve as a leading economic indicator, and Vietnamese ports cargo throughput increased by 328% to 14,733,000 TEUs in 2018, compared with 4,489,165 TEUs in 2007, resulting from the development of the Vietnamese seaport system (44 seaports with 219 terminals) (Khanh Phuong, 2024). With such a high volume of cargo and mixed fleet together with the decarbonization trend, it is apparent that Vietnamese shipowners need to choose the optimal green fuel as soon as possible. Clearly, Vietnamese ship owners are struggling to make correct decisions for SO<sub>x</sub> regulation-compliant solutions due to the technical situation of their aging and obsolete Vietnamese fleets. As a result, a study of parameters can be used in choosing green fuel as well as the advantages and disadvantages of each green alternative fuel can serve as a starting point and Vietnam may lead in the marine sector.

As far as we are aware, although studies have been made about what criteria to use when selecting alternative fuels in maritime industry, no study has examined the correlation between these factors used during the decision-making process of shipowners for alternative fuels. For this reason, both shipowners themselves and important participants in the shipping sector would find this research to be helpful when they are selecting green fuel for their firm.

## 2. CHAPTER 2: LITERATURE REVIEW

This chapter tries to evaluate the literature that serves as the theoretical foundation for this inquiry. We begin by discussing climate change and the need to cut GHG emissions internationally, with a focus on Vietnam. We will also discuss worldwide emission reduction objectives, the consequences of climate change, and literature on current kinds of green energy in use for marine in Vietnam. We will next review current business criteria for selecting alternative fuels based on a literature evaluation to provide the groundwork for developing methods and hypotheses.



*Figure 2-1: Literature Review Process of this Paper (Author's compilation)*

### 2.1. Vietnamese Fleet Landscape

Vietnam has around 600 ship owners from various economic sectors, with just 33 operating a fleet with a total tonnage of more than 10,000 DWT; the remainder are tiny vessel fleets of individuals and small firms based in Hai Phong, Thanh Hoa, Thai Binh, and Can Tho. Among the 33 significant ship owners, 25 belong to four major business groups: Vietnam National Shipping Lines Corporation (VIMC), Vietnam Oil and Gas Group (Petrovietnam or PVN), Vietnam National Petroleum Group (Petrolimex), and Shipbuilding Industry Corporation (SBIC). Other ship owners run modest enterprises with a small number of ships and tonnage (Dang, Nguyen & Ha, 2020). There are corporations that only possess one ship. Vietnamese firms are increasingly investing in foreign-flagged ships, particularly those with big tonnage, which will account for 37.8% of the national fleet's tonnage in 2020. In 2021, various companies have invested in specialist ships for carrying liquefied petroleum gas, huge tonnage crude oil vessels (above 300,000 DWT), aged 15 to 20, and proposed flying the Vietnamese flag (SBIC, 2023).

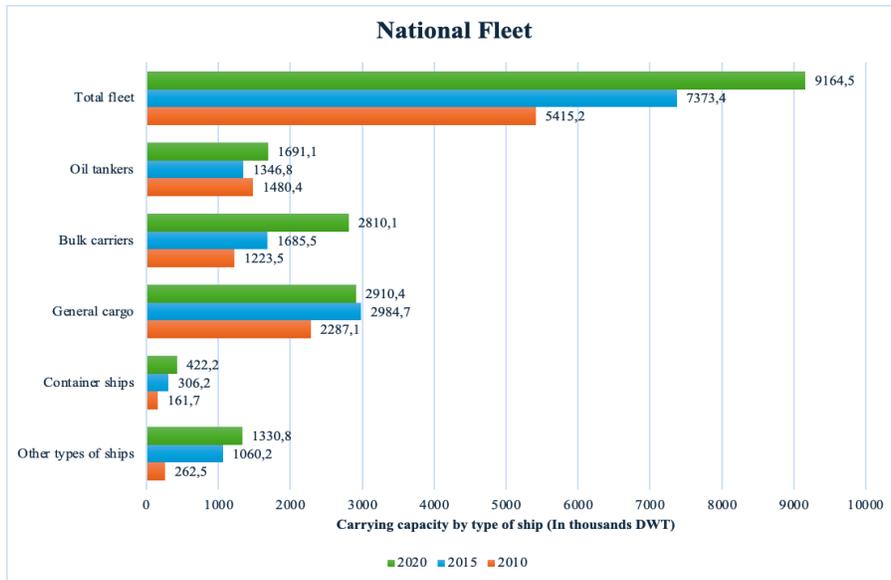


Figure 2-2: Vietnam Fleet Overview (reproduced from Dang, 2023)

However, the overall evaluation demonstrates that the Vietnamese shipping fleet has properly taken on the function of domestic transport of products, including the majority of the market share of LPG, gasoline, and oil, and now essentially controls the import and export general cargo transport market (Minh Anh, 2023). Despite the fact that the number of vessels in Vietnam's seagoing fleet is declining, its transport capacity has steadily expanded in recent years. In recent years, the fleet's overall tonnage has risen by replacing many small ships with fewer but bigger ships. The ship type component of the seagoing fleet has evolved quickly in recent years, with coastal passenger ships, LPG carriers, oil and chemical tankers seeing the highest growth rates (Nguyen, 2024). The number of bulk carriers and general cargo ships has declined. Vietnamese ship owners' fleets flying foreign flags continue to grow in size and tonnage. By 2020, several shipping businesses had overcome challenges and produced profits, so they invested in purchasing more modern ships and expanding the operation market. The majority ownership of the fleet has significantly moved from the government to the private sector (Le, Nguyen & Ha 2022). However, the facts demonstrate that the national seagoing fleet is old, particularly in the gas carrier category. Small-size bulk and general cargo ships continue to dominate. Vietnam's shipping fleet is mostly appropriate for coastal, local, or short international journeys in the region, unable to compete in the larger international shipping market with huge ships at more optimal operational costs (Nguyenc, 2023). Furthermore, the domestic fleet now focuses on domestic transit and short international journeys in Asia. In recent years, Vietnam's maritime fleet has seen a decline in its worldwide market share. The fleet structure is not as excellent as it could be, with

mostly small-tonnage ships transporting dry and bulk cargo. There is a shortage of container ships and large-tonnage ships operating on international routes (General Statistics Office of Vietnam, 2023).

*Table 2-1: Sea going ships of Vietnam split in domestic and international voyages (reproduced from Le, Nguyen & Ha, 2022)*

Year	Ships on Domestic voyages			Ships on International voyages		
	Number	GT	Deadweight (tons)	Number	GT	Deadweight (tons)
2015	848	870,407	1.418.135	566	3.401.546	5.433.035
2016	824	1.047.811	1.726.648	556	3.667.086	5.827.366
2017	807	1.091.983	1.794.518	552	3.672.897	5.805.976
2018	806	1.077.876	1.748.672	556	3.777.083	5.946.112
2019	766	1.008.432	1.617.411	555	4.061.232	6.368.520
2020	704	1.072.730	1.720.724	558	4.621.967	7.322.250
2021	671	904,313	1.465.571	594	5.889.260	9.683.518

## 2.2. GHG emissions from the Vietnamese Maritime sector

Vietnam has made a number of steps to minimize its carbon footprint. Government-led programs have focused on the shift to renewable energy sources, primarily solar and wind power. The "National Power Development Plan VIII" highlights the country's ambitious goal of dramatically increasing renewable energy capacity. Additionally, the "Feed-in Tariff (FiT) mechanism" has boosted investment in solar generating plants. To improve energy efficiency, the government has launched initiatives like the "National Energy Efficiency Program" and the "Green Credit Policy" to encourage enterprises and consumers to use energy-saving technology (Ministry of Natural Resources and Environment, 2023). The "Electric Vehicle Development Strategy" for the transportation industry seeks to encourage electric vehicles and develop charging infrastructure. While these efforts demonstrate Vietnam's commitment to sustainability, obstacles relating to grid integration, financial resources, and technical maturity remain, demanding continued policy refinement and international collaboration (Cong Quyet, 2024).

Shipping's percentage of Vietnam anthropogenic emissions has climbed from 2.76% in 2012 to 8% in 2019, with nearly 4 thousand tonnes of CO<sub>2</sub> and 60 tonnes of NO<sub>x</sub> (Lai et al., 2023). Using the vessel-based allocation of international shipping from the Third IMO GHG Study, global CO<sub>2</sub> emissions grew by 8.4% from 848 million tonnes in 2012 to 919 million tonnes in 2018. The multinational character of the shipping industry makes accounting for GHG emissions challenging. Shipping operations cause a major part of pollutants to be emitted on the high seas, outside of any country's control (Truong et al., 2022). The current ownership and operational structure of the maritime sector, which includes several operators of different nationalities, adds to the complexity. Global warming and climate change, as stated in the preceding parts, are not localized and are very much influenced, negatively, by the acts of all economic players across the world, and actions on the high seas are no exception (Jiang et al., 2014). The flag state of the vessel is responsible for maintaining compliance with numerous international rules and might be regarded as the party in charge of decreasing emissions from its fleet. Jiang et al. (2014) also investigated the burden sharing under several UNFCCC allocation alternatives for CO<sub>2</sub> emissions from shipping and discovered that they would not be in the best interests of many nations and were likely to suffer significant implementation challenges. Emissions from foreign bunker fuels are recorded in accordance with the IPCC guidelines for preparing GHG inventories and the UNFCCC yearly inventories (Mollenbach et al., 2022). However, these are recorded separately and removed from the national totals. As a result, individual countries' INDCs do not incorporate a decrease in these emissions. Including shipping emissions under the scope of the Kyoto Protocol is also not a viable

option because just 35% of the world's merchant fleet is registered in Annex I nations of the KP (UNFCCC, n.d.). Given this, regulating GHG emissions from international shipping would be best achieved through a sectoral approach. The states that sectoral and cross-sectoral approaches, in addition to national policies, to mitigation pathways and sustainable development will be necessary for the stabilization of GHG emissions. Sector-specific mitigation measures might be developed to better address impediments specific to that industry. More crucially, while national or economic policies are more cost-effective, they are difficult to implement due to political and administrative hurdles (Esmeijer, Eizen & Soest, 2020).

The IMO, as the international organization responsible for regulating international shipping, has been actively involved in researching the impact of shipping on climate change and developing measures to counteract it (IMO, 2023). In July 2023, IMO took a step forward by agreeing to new objectives for GHG emissions reductions, as well as developing and adopting a basket of measures to achieve these reduction targets by 2025. Since January 2024, the EU's Emissions Trading System (EU ETS) has been expanded to cover CO<sub>2</sub> emissions from any big ships (of 5,000 gross tons or more) visiting EU ports, regardless of the flag they fly (IMO, 2023) The scheme covers: 50% of emissions during trips that begin or end outside of the EU (enabling the third nation to decide on appropriate action for the remaining emissions), and 100% of emissions that occur between two EU ports and when ships are within EU ports. A trajectory has also been agreed upon, with indicative milestones established to reduce GHG emissions from ships by at least 20% - trying for 30% - in 2030 and at least 70% - reaching for 80% - in 2040, both in contrast to 2008 levels (IMO, 2023).

Regarding Vietnam's reduction target, the government promised to achieve substantial progress in decreasing GHG emissions from the transport sector: up to 9% with local resources alone, and 15-20% with foreign assistance and private sector cooperation (Valerie, 2023). Under the most aggressive scenario, Vietnam will reduce cumulative emissions from the transportation sector by up to 1 billion tons between 2014 and 2050. The most successful approaches are enhancing the fuel efficiency of vehicles in maritime transport and adopting the new green alternative fuel (Kim Anh, 2022). Vietnam has also shown its commitment to combating climate change and air pollution via a variety of methods. Vietnam has ratified several international treaties, including an action plan to reduce carbon emissions in transportation as part of the country's overall strategy to carry out its climate change commitments made at the 26th UN Climate Change Conference of the Parties (COP26), which aims to achieve net-zero emissions by 2050 (Fox, 2022).

In the maritime sector, the government has set goals to encourage Vietnamese ships to fully comply with the provisions of Annex VI of the MARPOL Convention on energy efficiency and the IMO strategy to reduce greenhouse gas emissions, as well as to promote the conversion of vehicles and equipment to use electricity or other forms of green energy at new and existing ports (Vietnam Register Ministry, 2020). It also ensures that vessels operating domestically fully comply with the provisions of Annex VI of the MARPOL Convention on energy efficiency. It also mandates that ships built, converted, or imported after 2035 use electricity or green energy, and that by 2050, 100 percent of ships operating on domestic routes will be converted to electricity and green energy (Vietnam Register Ministry, 2020).

### **2.3. Parameters' impacts on choosing green marine fuel for Vietnamese**

Environmental concerns over GHG emissions have driven legislative restrictions and low-carbon technical development worldwide. The pressing need to minimize the shipping industry's carbon impact as soon as possible provides a compelling motivation to take action (Nguyen, 2024a). Low-carbon alternative fuels are becoming increasingly popular in road transportation and land-based industrial sectors. Their application in shipping is still in its early stages and is being researched in Vietnam (World Bank, 2022). In this part, it is critical to investigate the link between the examined variables to draw plausible conclusions to support this research. As a result, the following paragraphs contain existing and up-to-date debates and contributions about the relationship of crucial factors during the decision-making process. Next, we will talk about existing alternative fuels and how they perform in each parameter. We will restrict the discussion to fuels that are currently in use in other energy sectors, have considerable abatement potential, are flexible for use with present marine engines, and whose availability is not a major hurdle to widespread adoption in a growing coastal country like Vietnam.

#### **2.3.1. Selected Assessment parameters**

A total of ten parameters have been identified for examination. These features are divided into four primary categories: application, economics, environment, and scalability. The appropriate category is informed by Deniz and Cinyir's (2016) research on alternative marine fuels, which split the criteria into environmental and economic components. Their selected comparison criteria are produced by taking into account ship safety, global usage, bunker capability, durability, simplicity of application, rules and regulations, engine performance and emissions, influence on engine components, and commercial issues. In addition, Brynolf (2014) evaluated and compared the

usage of green alternative fuels based on cost-related factors, CO2 emissions, and global energy competitiveness. DNV (2019) also populated their literature study with applicable factors based on energy density and technological sufficiency, but Hannson (2017) considers safety and impending regulations and policies for alternative fuels as essential factors. In terms of scalability and sustainability, Gilbert et al. (2018) and Munim et al. (2023) emphasize the need of taking into account the production capacity and availability of each green fuel, as this will affect fuel efficiency. As a consequence, a comparison of fuel technology routes based on current literature evaluations will be conducted on each of the defined parameters, as indicated in the table below:

*Table 2-2: Summary of Selected Parameters in Green Fuel Selection (Author's compilation)*

<b>Factor Group</b>	<b>Parameters</b>	<b>Source</b>
Applicability	<ol style="list-style-type: none"> <li>1. Energy density</li> <li>2. Technological maturity/Infrastructure sufficiency</li> <li>3. Flammability and toxicity</li> <li>4. Government policy</li> </ol>	DNV (2019); Hannson (2017); Ren et al. (2013).
Environment	<ol style="list-style-type: none"> <li>1. GHG emissions - well-to-wake</li> <li>2. Local emissions - SOx, NOx and PM</li> </ol>	Brynnolf (2014); Chryssakis & Stahl (2013); McArthur (2011).
Economics	<ol style="list-style-type: none"> <li>3. Energy costs</li> <li>4. Capital costs</li> </ol>	Deniz & Zincir (2016); Ren & Lutzen (2017); Gu (2014); Guerra and Jenssen (2014a), Guerra and Jenssen, (2014b).
Scalability	<ol style="list-style-type: none"> <li>1. Availability</li> <li>2. Local production capacity and locations</li> </ol>	Gilbert et al. (2018); Munim et al. (2023)

### **2.3.2. Resource constraint factors' Dimensions**

When choosing green fuels, Vietnamese shipowners face major resource constraint factors, including energy and capital expenditures. A financial burden may result from the high initial cost

of modifying old ships or buying new ships that can run on green fuels in addition to the possibility of fuel price fluctuations (Vietnamnews, 2023). In comparison to their counterparts in more developed nations, Vietnamese shipowners frequently operate with comparatively lesser margins. Consequently, it is important to carefully consider the possible long-term benefits of using green fuels, such as increased environmental reputation and compliance with new rules, against the additional costs involved.

Besides, while choosing green fuels, shipowners in Vietnam have substantial resource constraint factors due to limited fuel supply and limited local production capability. The infrastructure of the supply chain such as port infrastructure needed to enable the broad use of green fuels is still in its infancy, and the domestic market for them is still developing despite the promising plan (Nguyen 2023). Following Dang (2023), this may make it more difficult to find steady and dependable sources of green fuels, especially when it comes to the bigger volumes required for commercial transportation. Vietnam is also highly dependent on imports due to a lack of local industrial capacity, which exposes shipowners to changes in world prices and possible supply interruptions. These limitations may raise the risks and operational costs of switching to green fuels, making it harder for shipowners to defend the switch from conventional fossil fuels.

Therefore, overall combining with Tran (2022)'s studies, this paper will define resource constraint ' dimension are: economic and scalability factors. Economic feasibility is a crucial consideration for any alternative fuel. The two most important economic aspects are energy cost and capital cost, which are detailed below (Tran, 2022). Other economic factors, like maintenance expenses, are not included in this research. Furthermore, in terms of scalability, different alternative fuels/pathways will have varied possibilities of maturing and scaling up, based on factors such as cost, environmental performance, and application (Nong et al. 2020). Furthermore, scalability is governed by factors such as current consumption, availability, and global production, all of which are closely related to supply chain development and land infrastructure. These factors are explored in the following sections (Gilbert et al. 2018).

#### **2.3.2.1. Economics Factor Dimension**

Vuong (2023) reports that most Vietnamese shipowners emphasize resource constraint factors would consider economics and scalability during their decision-making process. To earn a C rating, a vessel must reduce its CO<sub>2</sub> emissions by 2% yearly over three consecutive years, from 2023 to 2026. This cannot be accomplished without engine improvements and the replacement

of alternative green fuels. Unfortunately, most Vietnamese shipowners are unable to pay the adjustments owing to the high pricing caused by significant changes in an aging fleet like Vietnamese fleet which makes the changes not practicable for Vietnamese shipowners (Vietnamnet, 2024).

#### **a. Energy costs**

First, energy prices are a critical consideration when picking green fuels for the marine industry. The economic viability of a green fuel transition is dependent on the capacity to lower operating expenses (Sadiq et al., 2023). While green fuels often need a larger initial investment, their long-term cost-effectiveness is determined by their energy efficiency and fuel costs. If the cost of green fuels surpasses that of typical fossil fuels, shipping businesses may be deterred from using them (Aydin & Esen, 2018). DNV (2019) has the same framework, which is to make a financially sustainable and ecologically responsible shift to greener marine operations, energy expenses must be carefully considered, including fuel prices and energy efficiency.

For Vietnamese shipowners, the high energy cost of green fuels poses a significant resource constraint. Vietnamese shipping businesses may face severe financial difficulties as a result of the initial capital costs involved in buying new or renovating existing ships to be compatible with green fuels as well as the continuous operating expenses related to using green fuels (Nam, 2018). In addition, the unpredictability of future energy prices and the possibility of cost fluctuations might add to the risks and complicate decision-making. All of these elements work together to make the energy cost of green fuels a significant barrier for Vietnamese shipowners looking to switch to more environmentally friendly shipping methods.

#### **b. Capital costs**

According to Solakivi, Paimander & Ojala (2022), the higher capital expenses associated with using alternative fuels generally include the cost of the converter, storage tank, and any necessary processing equipment. This paper concentrated on the converter and storage tank expenses (Solakivi, Paimander & Ojala 2022). Capital expenses are important in choosing green fuels for the maritime sector since the ability of transportation enterprises to absorb these upfront costs may influence their decision-making process. When deciding whether to invest in green fuel technology, the size of the shipping company, access to money, and government incentives are all key factors to consider. To allow a financially viable and long-term shift to greener maritime operations, capital costs must be carefully examined (Balcombe et al., 2019).

Following Nam (20218), for smaller shipping businesses with limited cash resources like Vietnamese shipowners, the significant upfront costs associated with buying new ships that are compatible with green fuels or converting existing ones can be very costly. Firm finances may also be further strained by the continuous operating costs related to green fuels, which include increased fuel prices, possible inefficiencies in green fuel technology, and the requirement for extra infrastructure despite the governments' incentives in promoting green financing (Duong, 2022). Together, these elements make the firm capital cost a significant barrier to the adoption of green marine fuels by Vietnamese shipowners, hence restricting their capacity to make investments in environmentally friendly transport methods.

### **2.3.2.2. Scalability factor Dimension**

#### **a. Availability**

The availability factor refers to how much future alternative marine fuels must be available on the market to ensure adequate adoption (Gilbert et al., 2018). This is a key factor when selecting solutions for the Vietnamese maritime industry. A stable and consistent supply chain is necessary to ensure the uninterrupted operation of vessels. While certain green fuels, such as LNG, have established infrastructure in specific places, others, such as hydrogen and ammonia, may have production, storage, and distribution challenges (Trinh & Le, 2018). The availability of green fuels in Vietnam will be directly limited by domestic production capacity, import infrastructure, and the establishment of local supply chains. As a result, evaluating the availability of green fuels in the Vietnamese market is crucial to ensure the successful and sustainable transformation of the maritime sector (Doan et al., 2023).

#### **b. Local production capability**

Finally, local production capability and the location of green fuel plants are critical to the Vietnamese marine sector (Dang, 2023). A robust domestic production base may minimize reliance on imports, alleviate supply chain risks, and perhaps lower fuel prices. Consistently, Inal and Deniz (2020) investigated the proximity of fuel producing plants to major shipping ports can improve logistics and save transportation costs. Vietnam's green fuel transition may be made more economically viable and sustainable by emphasizing local manufacturing and strategically situating fuel plants. In DNV (2019)'s methodology for accessing the local production capability, the alternative fuel industry is worldwide, with production in Asia, North and South America, Europe, Africa, and the Middle East. Except for LNG (and LPG), the current supply of alternative

fuels does not match the marine industry's complete energy needs. They concluded a rapid growth in demand would entail substantial investment in production capacity and infrastructure. The worldwide production of alternative fuels has a significant upscaling potential since fuels may be manufactured from different energy sources, such as electrolysis powered by renewables or by reforming natural gas, oil, or coal (DNV, 2019).

### **2.3.3. Importance of Applicability and Environment Factors on Fuel Selection Process**

#### **2.3.3.1. Importance of Applicability factors on Fuel Selection Process**

Applicability criteria assess the energy density, chosen safety variables, technical maturity, international regulation, and class norms to decide the use of various fuel alternatives (Ren et al. 2013).

##### **a. Energy density**

Moshiul & Mohammad (2023) noted the energy density derived from a fuel may be described in two ways: volumetric energy density (energy content per volumetric unit) and gravimetric energy density, in which volumetric energy density refers to how much energy can be packed into a given space. This parameter is crucial in instances when space is limited, such as fuel tanks on seagoing vessels. Gravimetric Energy Density is a measure of a substance's or system's energy per unit mass. As a result, high volumetric and gravimetric densities suggest that the fuel takes up less space and has a smaller mass, which is advantageous for storing the fuel onboard a vessel (Moshiul & Mohammad 2023). A fuel's energy density determines its suitability for various ship types and operations. However, Strantzali, Livanos & Aravossis (2023) said this only covers the fuel properties; when storage tanks and accompanying systems are considered, the picture changes substantially for some fuels. This is especially true for fuels that require refrigerated/cryogenic or pressurized storage, such as H<sub>2</sub> (e.g., gravimetric densities lower than 10 MJ/kg for LH<sub>2</sub>, compared to ~120 MJ/kg for the fuel only) and LNG (gravimetric and volumetric densities of ~25 MJ/kg and ~13 MJ/l including storage systems, respectively, compared to ~50 MJ/kg and ~21 MJ/l for the fuel only) (DNV, 2019).

##### **b. Flammability and toxicity**

There are various aspects to the safe usage of alternative fuels on ships. In this section, we look at a few key fundamental properties of fuels that influence safety. Yang et al. (2023) describes the flash point of a chemical substance as the lowest temperature at which a liquid may ignite in

air near the surface, which indicates how easily a material may ignite. Materials with high flash points are less flammable or hazardous than those with low flash points. Similarly, Asharfi (2022) concluded that a lower flash point suggests that gasoline may ignite at lower temperatures, and in the absence of additional safety procedures, this signifies a bigger risk. The autoignition temperature is the minimum temperature required to ignite a gas or vapor in air in the absence of a spark or flame. It is critical to underline that regulation modifications for marine use of alternative fuels must be expected to be based on the same safety principle, and growing risk levels (frequency x consequence) will most likely be prohibited (Ashrafi, Lister & Gillen, 2022).

### **c. Technological maturity**

Following Ren et al. (2013)'s analysis on how technological sufficiency affects to green marine fuel decision-making process, technological maturity refers to the current status of engine technology and systems. Technological maturity is an important aspect in choosing green fuels for the marine sector. The author mentioned the dependability, safety, and efficiency of green fuel technologies have a direct impact on their feasibility for broad adoption. Similarly, in Moteno-Muterez (2019), mature technologies, such as those for LNG and methanol, have proven beneficial in marine applications. However, new fuels like hydrogen and ammonia require more development and testing to assure safe and efficient use, according to Mai (2023). Besides, the technical development of a green fuel also influences its infrastructural needs. For example, a more mature technology may have established supply chains and bunkering infrastructure, which reduces shipping firms' initial investment and operations expenses. Therefore, while evaluating green fuel choices, the industry must thoroughly analyze each candidate's technological preparedness to enable a seamless and sustainable transition (Mai, 2023).

### **d. Government Regulations**

Government regulation considerations in the selection of green marine fuels include laws, regulations, and incentives imposed by governments to promote the adoption of sustainable maritime activities (Ren et al., 2016). These rules have the potential to greatly affect the economic feasibility and environmental effect of green fuel alternatives. Government constraints influence the maritime industry's transition to renewable energy. Regulatory frameworks provide standards for lowering emissions, increasing fuel quality, and upgrading infrastructure, offering maritime companies and technology vendors a clear way ahead (Deniz & Zincir, 2016). Stricter regulations can promote the use of ecologically friendly fuels by charging fines on vessels that exceed

emission limits or fail to meet fuel quality criteria. In contrast, enabling legislation, such as subsidies, tax breaks, or infrastructure upgrades, can hasten the development of green fuel technologies. Government restrictions are vital in ensuring the safety and environmental compatibility of new fuels (Deniz & Zincir, 2016). Authorities can mitigate the hazards involved with the implementation of new technologies by defining standards for fuel management, storage, and transportation. To summarize, government rules provide a crucial foundation for the maritime sector to handle the transition to green fuels by encouraging innovation, protecting safety, and promoting environmental sustainability (Ren et al., 2016).

### **2.3.3.2. Importance of Environment Factors on Fuel Selection Process**

Mestemaker (2020) defined many of the alternative fuels under consideration for usage in the shipping industry have the potential to enhance environmental performance in some or all emission categories, making them attractive options for ship owners looking to comply with current and future environmental legislation. The next parts address two critical environmental issues: greenhouse gas emissions and local emissions (SO<sub>x</sub>, NO<sub>x</sub>, and PM). Other environmental factors, such as oil leak risk and noise, are not considered.

#### **a. Well-to-wake GHG emissions**

The well-to-wake GHG emissions include those from each fuel's manufacture, shipping, and storage, as well as combustion/conversion to mechanical energy on board the boats. The resulting measure for well-to-wake emissions is the mass of CO<sub>2</sub> equivalent emissions per unit of shaft output energy (Hua, Wu & Chen, 2017). Together with Balcombe (2019), this implies that the well-to-wake emissions within each of the energy carrier and converter routes will vary greatly, depending on how and where the energy carriers are produced, manner of transit and storage, and onboard system performance.

Besides, this factor is of significant importance since to accomplish the IMO's environmental goals, many solutions were incorporated into the GHG reduction plan. Beginning January 1, 2023, all ships must compute the obtained Energy Efficiency Existing Ship Index (EEXI) in order to assess energy efficiency and gather data for the reporting of yearly operating Carbon Intensity Indicator (CII) and associated CII rating. Such a rating will be included in Part III of the SEEMP (Ship Energy Efficiency Management Plan), which is essential for ships starting in 2013. The Carbon Intensity Indicator measures ship emission performance over a calendar year and is defined as the mass CO<sub>2</sub> emissions to equivalent transport work ratio. According to the current definition,

only the vessel's Well-to-Wake (WtW) emissions are considered, that is, the emissions from fuel consumption aboard (IMO, 2022).

## **b. Local emissions - SO<sub>x</sub>, NO<sub>x</sub>**

Following Hansson et al., (2019) studies, ships emit sulphur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM) depending on the fuel and engine/converter utilized (Hansson et al., 2019). To explain further, in addition to greenhouse gases (GHG), marine ships release significant amounts of pollutant pollutants such as NO<sub>x</sub> and SO<sub>x</sub>, which are also substantial contributors to air pollution (Kim and Seo, 2019). This even proves its importance when the IMO (2023) has introduced stronger measures to prevent air pollution from ships, known as Emission Control Areas (ECAs). These ECAs necessitate large reductions in SO<sub>x</sub> emissions, emphasizing the need for cleaner fuels. Additional rules targeting NO<sub>x</sub> and PM are expected. Many nations and areas have established their own air quality standards, which are typically harsher than IMO requirements. Alternative fuels with reduced SO<sub>x</sub>, NO<sub>x</sub>, and PM emissions will be more compliant and have a wider range of applications. Moreover, Ren et al. (2013) with studies on environmental sustainability and green alternative fuel stress when choosing alternative fuels, it's important to consider not only carbon emissions but also SO<sub>x</sub>, NO<sub>x</sub>, and PM (...) (Ren et al., 2013). Even if a fuel has lower CO<sub>2</sub> emissions during combustion, its production process may still produce high levels of SO<sub>x</sub>, NO<sub>x</sub>, or PM, making it less competitive. Mohd Noor et al. (2018)'s investigation even makes this criterion even more important when selecting green marine fuel because the most recent maritime agreement on oil pollution (MARPOL), which was announced on January 1, 2020, reduced the allowed sulfur content in gasoline from 3.50% to 0.50%. This is primarily addressed by fuel optimization, an innovative strategy for reducing emissions at the source and improving fuel efficiency (Mohd Noor et al., 2018)

### **2.3.4. Relationship between Resource constraint factors and Applicability and Environment Factors**

#### **2.3.4.1. Relationship between Resource constraint factors and Applicability Factors**

Following Jeong et al. (2018)'s opinions, economic issues, such as energy and capital costs, can have a considerable impact on the choice of green marine fuels since they affect application. They explained that high energy costs can make fuels with lower energy density less economically appealing since they require more frequent refilling and may raise operational costs. In contrast, fuels with higher energy density may be more enticing, despite potentially higher initial prices.

Besides, Basurko and Mesbahi (2014) looked into methodology between resource factors and investment in green marine fuel, noting that capital expenses, particularly those associated with the development of new infrastructure and technology, might hinder the adoption of various green fuels. For example, if the initial investment for a new fuel technology is excessively expensive, it may be less enticing to shipping businesses, even if it yields long-term cost advantages. Furthermore, economic factors can impact government policies such as subsidies, tax breaks, and restrictions. Governments may be more inclined to promote green fuels that provide economic benefits, such as job development or less reliance on foreign energy supplies. To summarize, the interaction of economic and applicable issues is critical in creating the future of green marine fuels, and thorough evaluation of both aspects is vital for making educated decisions.

#### **2.3.4.2. Relationship between Resource constraint factors and Environmental factors**

Deniz and Zincir (2016) conduct a comparative analysis of eleven environmental and economic parameters pertaining to four potential marine fuels: hydrogen, LNG, fossil methanol, and fossil ethanol. Using multi-criteria decision analysis (MCDA), they conclude that LNG is the best alternative fuel for the shipping industry, followed by hydrogen (which could replace LNG). This has proven that environmental variables such as well-to-wake emissions (including NO<sub>x</sub> and SO<sub>x</sub>) may be heavily influenced by economic considerations like energy prices, capital costs, and local manufacturing capacity. Li et al. (2022) when studying the correlation between green transition and economic growth has concluded higher energy costs connected with the production of renewable fuels, for example, may encourage the development of more efficient emission-reducing devices. Lower energy costs, on the other hand, may raise demand for green fuels, putting a pressure on production capacity and increasing emissions if supply cannot keep up. However, there is limited studies on whether resource constraint factors can influence the environmental factors when selecting the green fuel process. Hence, this study will develop environmental factors as moderating factors to test this hypothesis.

#### **2.3.5. Hypothesis Development**

Since all these factors according to the literature review mentioned above all have effects on the fuel selection process, this technique uses resource constraint factors aspects as center to assess its relevance in the fuel selection process considering the budget constraint of most local shipowners. The applicability and environmental factors will have a mediating function in this study approach. Lastly, due to the importance of the fuel selection decision-making process, it

will be employed as the outcome variable in this study. As a result, this study identifies the variables that Vietnamese shipowners value when selecting green fuel, and this ranking may be used to pick the fuel based on their performance in the literature research. Overall, the purpose of this study is to determine which selection factors have the greatest influence on Vietnamese shipowners' fuel selection processes in the maritime industry, as well as to test the mediating role of the applicability and environmental factors in the relationship between resource constraint factors and fuel selection processes. The conceptual model of this study is provided as follows:

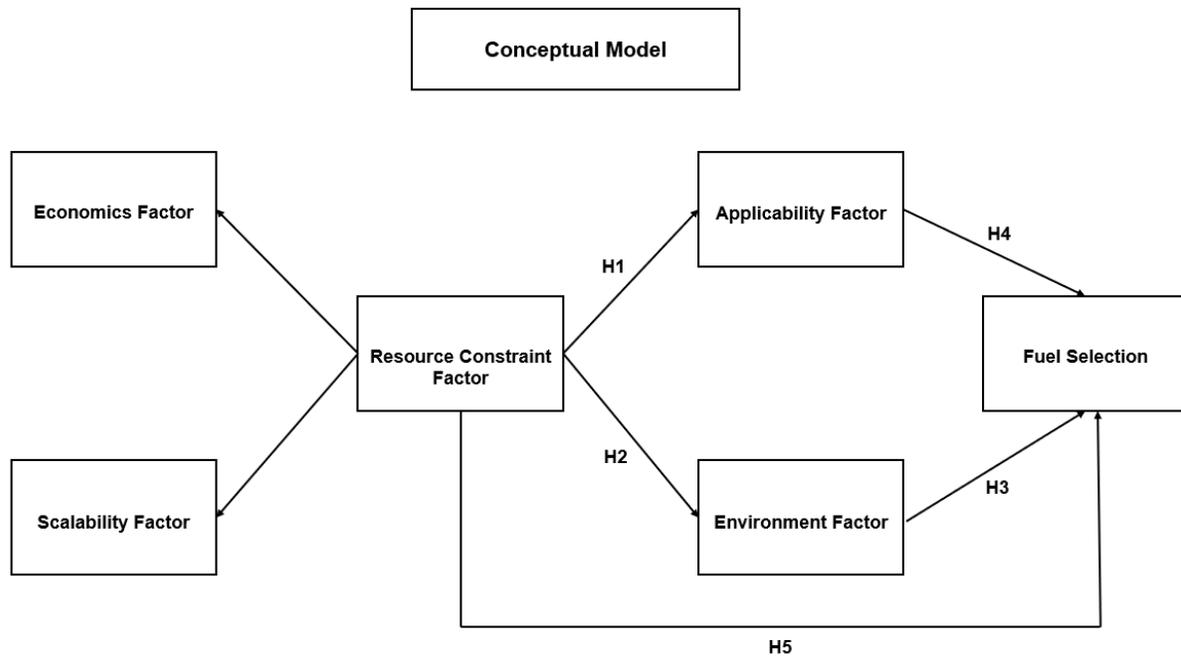


Figure 2-3: Conceptual Model of Research (Author's compilation)

Table 2-3: Proposed Research Hypothesis (Author's compilation).

<b>Hypothesis 1 (H1)</b>	Applicability is positively associated with resource constraint factors
<b>Hypothesis 2 (H2)</b>	Environment factor is positively associated with resource constraint factors of the fuel
<b>Hypothesis 3 (H3)</b>	Environment factor has a positive significant association with fuel selection
<b>Hypothesis 4 (H4)</b>	Applicability factor has a positive significant association with fuel selection
<b>Hypothesis 5 (H5)</b>	The resource constraint factors directly and positively influence the fuel selection of shipowners

### 2.3.6. Current types of alternative fuels available in Vietnam market

Many different alternative fuels can help to create ships with low or zero emissions, but their use is currently limited owing to application, cost, and availability. Figure 6 shows how the ship's direct emissions (tank to propeller) vary based on the fuel or energy carrier. For example, when utilized in low-pressure engines, LNG dramatically decreases SOx and PM emissions while also cutting greenhouse gas (GHG) emissions by around 10% and NOx emissions by 85-90%. When hydrogen and energy are utilized, no emissions go from the tank to the propeller. Given the large regional disparities in life cycle emissions reported for various maritime fuels, life cycle emissions should be investigated alongside alternative marine fuels.

	Biodiesel	Biogas	LNG	Hydrogen
CO2	Green	Green	Orange	Green
NOx	Orange	Light Green	Light Green	Green
SOx	Green	Green	Green	Green
PM	Yellow	Green	Green	Green
Noise	Red	Red	Red	Green

Figure 2-4: Potential for significant emission reduction using specific low- and zero-emission fuels and technology (emissions from the tank to the propeller).

High potential is indicated by green. Low potential is shown by red (adapted from DNV, 2019).

Together with the green marine fuels that are being investigated by other ASEAN countries, we decide to look at 5 alternative fuels including LNG, hydrogen, ammonia, methanol, and LPG. This chapter's main objective has been to assess alternative marine fuels' operational and commercial viability utilising recent research and business materials. The shipping industry must make the difficult choice to invest appropriately now in order to allow ships to remain competitive while complying with both short-term local emissions regulations (such as the IMO 2020 sulphur cap) and long-term GHG emission regulations that will be adopted by the IMO. DNV GL has gathered data for this paper regarding the performance of different alternative fuels in relation to LNG, which serves as the benchmark for comparison. The initiative aimed to gather and display statistics for the most recent years. But as it became clear, there is a dearth of data for 2030, therefore it was chosen to focus on any year between 2020 and 2023. The section's main goal has been to evaluate alternate marine fuels' operational and commercial viability using current scholarly and industrial material. The method evaluates the performance of the five chosen green fuels following ten parameters listed above. Relevant converters, such as internal combustion engines, fuel cells, and battery-electric systems, were assigned to each of these fuels.

### 2.3.6.1. LNG

Since the 1960s, LNG has been utilized as a supplemental maritime fuel aboard LNG carriers, largely for the purpose of boiling off gas. Currently, LNG may be utilized in specialist mono-fuel engines based on the Otto Cycle or in diesel engines employing the dual fuel process. These dual-fuel engines are known as gas engines (Pavlenko, 2020). LNG is created by the liquefaction of natural gas, which mostly contains methane. The development of ECA for SO<sub>x</sub> and Tier III NO<sub>x</sub> requirements has driven increasing interest in LNG, which is a very favorable fuel vis-a-vis these pollutants (Pavlenko, 2020). In terms of GHG emissions, it does promise savings of up to 25% when compared to HFO; nevertheless, even modest amounts of methane slip, a present operating norm, can dramatically boost GHG emissions. It is projected that a methane slip of 5.5% would bring the GHG emissions from LNG to parity with those from MDO. Nonetheless, with optimum operational procedures, meaningful reductions of 10-20% over traditional oil-based fuels are possible (Chryssakis et al., 2015).

Table 2-4: LNG technology options and properties (reproduced from DNV, 2019)

Converter	ICE 4-stroke Lean Burn Spark Ignition / Dual Fuel Low Pressure (4S LBSI/LPDF)	ICE 2-stroke Dual Fuel Low Pressure (2S LPDF)	ICE 2-stroke Dual Fuel High Pressure (2S HPDF)
Components	Engine	Engine	Engine
	Storage tanks	Storage tanks	Storage tanks
	Process system	Process system	Process system
			NO <sub>x</sub> reduction system (EGR/SCR)
Key Challenges	Methane slip for some of the ICE's		
	Cryogenic materials needed		
	Fuel storage tank 2-3 times larger than for petroleum-based fuels		

### 2.3.6.2. Hydrogen

Currently, hydrogen is typically generated using steam methane reforming (SMR) or autothermal reforming (ATR) of natural gas (Mohamed, 2023). In 2021, 62% of hydrogen was generated from natural gas, 19% from coal, 0.7% from oil, 0.04% from electricity (water electrolysis), and 18% as a byproduct of naphtha reforming at refineries. Hydrogen derived from fossil fuels is known as 'gray' hydrogen. When CO<sub>2</sub> emissions from the conversion of natural gas are caught and stored, they are commonly referred to as 'blue' hydrogen. Blue hydrogen represented just 0.7% of worldwide hydrogen production in 2021 (IEA, 2022). Blue hydrogen generation still produces greenhouse gas emissions. Methane (a much more potent GHG than CO<sub>2</sub> - 82.5 times on a 20-year global warming potential (GWP) basis and 29.8 times on a 100-year basis, according to the Intergovernmental Panel on Climate Change's AR6 (n.d.) report, has the potential to leak at the

production plant or at any point along the natural gas distribution chain. Additionally, the efficiency of CO<sub>2</sub> collection from the reforming processes (SMR and ATR) is less than 95%. Furthermore, the generation of blue hydrogen relies on fossil fuels. Given the foregoing, green hydrogen, derived from renewable energy sources, is often regarded as the ultimate answer for decarbonizing hydrogen production and use.

Table 2-5: Hydrogen technologies options (reproduced from DNV, 2019)

Converter	FC	ICE
Components	Fuel cell Storage tanks Process system Electric propulsion system Reformer Battery	Engine Storage tanks Process system
Key Challenges	Fuel storage is more massive and requires more space than petroleum-based fuels Cryogenic materials needed for LH <sub>2</sub>	

### 3.6.3. Ammonia

The safety and legal problems, as well as the space and weight issues associated with storing huge amounts of hydrogen on ships, have sparked interest in researching alternate hydrogen-based energy carriers. Several investigations have identified ammonia (NH<sub>3</sub>) as a possible transportation fuel (Mounaïm-Rousselle, 2021; Lhuillier et al., 2019). Ammonia, sometimes known as 'the other hydrogen', is carbon-free and liquefies at a greater temperature than hydrogen (-33°C against -253°C). Besides, Ammonia combustion has been shown to provide more power than standard fuels or hydrogen and has difficulties as a fuel in combustion engines, such as very high auto-ignition temperature, poor flame speed, high heat of vaporization, limited flammability limits, and toxicity (Lhuillie et al., 2019).

Table 2-6: Ammonia technologies options (reproduced from DNV, 2019)

<b>Converter</b>	FC	ICE
<b>Components</b>	Fuel cell Storage tanks Process system Electric propulsion system Reformer Battery	Engine Storage tanks Process system NOx reduction system (EGR/SCR)
<b>Key Challenges</b>	Fuel storage is more massive and requires more space than petroleum-based fuels	

### 3.6.4. Methanol

Methanol, having the chemical formula CH<sub>3</sub>OH, is the simplest alcohol, containing the least carbon and the most hydrogen of any liquid fuel (Wissner, 2023). Methanol is a liquid between 176 and 338 K (-93°C to +65°C) at atmospheric pressure, making storage less costly than LNG, H<sub>2</sub>, and NH<sub>3</sub>. According to DNV (2019), when manufactured from natural gas, a mixture of steam reforming and partial oxidation is commonly used, with an energy efficiency of up to around 70% (measured as energy stored in the methanol vs energy delivered by natural gas). Natural gas generation was chosen as the energy source for the methanol pathway since it is the most common technique to produce methanol. Furthermore, internal combustion engines are the only practical methanol solutions in Vietnam in the near to medium future. Thus, ICE is the preferred converter for the methanol route. Whether the engine is a 2-stroke or 4-stroke has not been defined, however there are mostly 2-stroke engines in use, therefore data used mostly refers to this engine type (Chevron, 2022).

Table 2-7: Methanol technologies options (reproduced from DNV, 2019)

<b>Converter</b>	ICE 2-stroke Dual Fuel High Pressure
<b>Components</b>	Engine Storage tanks Process system NOx reduction system (EGR/SCR)
<b>Key Challenges</b>	Fuel storage tank 2-3 times larger than for petroleum-based fuels

### 3.6.5. LPG

Following the research of Yeo, Kim and Lee (2022), Liquefied petroleum gas (LPG) is defined as a liquid combination of propane and butane. Specific butane-propane mixes are employed to produce the necessary saturation, pressure, and temperature properties. Propane is gaseous under normal circumstances, having a boiling point of -42°C. It may be handled as a liquid by

applying modest pressure (8.4 bar at 20 °C). Butane comes in two forms: n-butane and isobutane, with boiling temperatures of -0.5°C and -12°C, respectively. According to Ashok, Ashok and Kumar (2015), because both isomers have greater boiling temperatures than propane, they may be liquefied under lower pressures. Propane tanks used for land-based storage include safety valves that maintain the pressure below 25 bar. LPG fuel tanks are 2-3 times bigger than oil tanks because of the lower volumetric energy density of LPG and volume inefficiencies for C-type tanks. LPG is derived from two primary sources: oil and gas production byproducts and oil refinery byproducts. It is also feasible to make LPG from renewable sources, such as a byproduct of renewable diesel manufacturing. There are three major ways to use LPG as ship fuel: in a two-stroke diesel-cycle engine, a four-stroke, lean-burn Otto-cycle engine, or a gas turbine (DNV, 2019).

Because the most prevalent means of producing LPG are as a byproduct of oil and gas production or as a byproduct of an oil refinery, they have been combined and characterized as a fossil energy source for LPG production in this study. The selected engine is not stated as a 2-stroke or 4-stroke engine, but because only 2-stroke engines are currently accessible, the data will apply to this engine type.

Table 2-8: LPG technologies options (reproduced from DNV, 2019)

<b>Converter</b>	ICE
<b>Components</b>	Engine Storage tanks Process system NOx reduction system (EGR/SCR)
<b>Key Challenges</b>	Fuel storage tank 2-3 times larger than for petroleum-based fuels

Therefore, the green alternative fuels pathways that this paper is going to investigate is summarized in this table 9:

Table 2-9: Research Green Marine Fuel Pathways (Author's compilation)

<b>Fuel</b>	<b>Pathway</b>
<b>LNG</b>	Pathway 1: NG – LNG – ICE – 4S LBSI/LPDF Pathway 2: NG – LNG – ICE – 2S LPDF Pathway 3: NG – LNG – ICE – 2S HPDF

<b>Hydrogen</b>	Pathway 1: NG – H2 – FC Pathway 2: NG – H2 – ICE Pathway 3: Renewable - H2 – ICE Pathway 4: Renewable – H2 – FC
<b>Ammonia</b>	Pathway 1: Renewable – NH3 – ICE Pathway 2: Renewable – NH3 – FC
<b>Methanol</b>	Pathway 1: NG – Methanol – ICE
<b>LPG</b>	Pathway 1: Fossil – LPG – ICE

**2.3.7. Performance of each alternative fuel based on the assessment parameters**

**2.3.7.1. Applicability**

**a. Energy density**

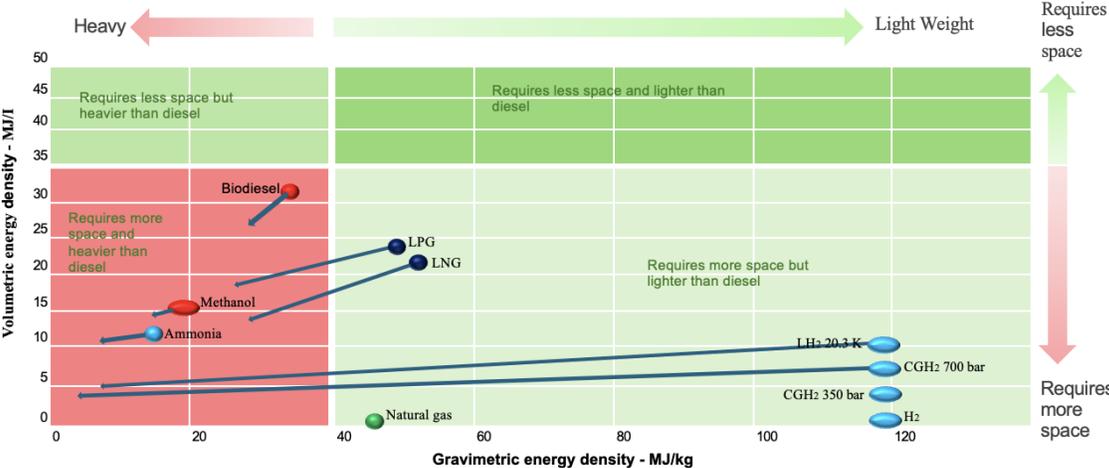


Figure 2-5: Energy densities for different energy carriers (Author’s compilation inspired by DNV, 2019; Shell (2017; MariGreen (2018))

The graphic shows that LNG has around 40% lower volumetric energy density than biodiesel, which is nearly the same as LPG. When accounting for the storage mechanism, LNG has a volumetric density that is around 40% lower. Liquid hydrogen, ammonia, and methanol have even lower volumetric energy density (about 40-50% of LNG), however the extra space required for methanol storage is smaller (Nieman et al., 2019). Ammonia is often kept in pressurized type C tanks, which have a comparable influence on real ship space usage as LNG when accounting for

storage systems while LPG is now kept in both prismatic (refrigerated) and cylindrical (pressurized) tanks, similar to LNG (Shell, 2017). As a result, the volumetric energy density ratio of ammonia and LPG to LNG provides an accurate picture of what it means to transition from LNG to these fuels (MariGreen, 2018). When considering the storage system for hydrogen, it becomes clear that this affects the practicality because the density is substantially lower than the other potential fuels. Biodiesel has a substantially greater volumetric energy density than LNG, with levels comparable to diesel.

### b. Flammability and toxicity

According to Jo and Kim (2012), the flammability limits provide the range of vapour concentrations of a certain chemical, stated in volume percent, across which a flammable combination of gas or vapour in air may be ignited at 25°C and atmospheric pressure. A broad range (such as for hydrogen) suggests a fuel that is flammable in a variety of situations, implying a higher danger in the absence of extra safety precautions. All characteristics are presented at atmospheric circumstances (25°C, 1 atmosphere) (Kenneth et al., 2019).

Table 2-10: Overview of flammability and toxicity of different fuels (Author's compilation)

Fuel	Flash point (Degree Celsius)	Autoignition temperature (Degree Celsius)	Flammability Limits (volume % in air)	Toxicity	Sources
LNG	-188	537	4-15	Not toxic	Fernandez, Gomez & Insua (2017)
Hydrogen	Not defined	500	4-74.2	Not toxic	Mohamed (2023); Dang (2023)
Ammonia	132	630	15-28	Highly toxic	Mounaïm-Rousselle et al. (2021)
Methanol	11-12	470	6.7-36	Low acute toxicity (dangerous for humans)	Bos (2019)
LPG	-104	410-580 (depending on the composition)	1.8-10.1	Not toxic	Yeo, Kim & Lee (2022)

According to Bos (2019), a broad range of flammability limits denotes a fuel that can catch fire in a variety of circumstances, which, in the absence of further safety precautions, suggests a higher danger. As summarized in Table 10, Ammonia, Hydrogen and Methanol has the highest flammability limits, indicating the highest danger of these fuels. Worse flammability and toxicity scores should be expected to convert into adequate risk mitigation measures, with a corresponding impact on e.g. costs and operational constraints (Dang, 2023). According to the

existing research, ammonia appears to be the most harmful fuel that shipowners should consider when deciding on a green marine fuel.

### **c. Technological maturity**

A maturity level of 1 denotes high maturity and a commercially accessible technology, while 4 implies poor maturity and a technology that is not even in the pilot stage. The technological maturity level is judged based on today's state. Interpretation of technological maturity levels: (1): Measures that are off the shelf and commonly used on new ships; (2): Measures that are commercially available but not fully mature; (3): Measures that are in the piloting stage and/or have only a few commercial applications; and (4): Measures that have not been tested in full scale and have no piloting or full-scale testing underway. Table 11 shows that the fuel cell systems are often immature. Furthermore, the technological maturity of methanol and ammonia systems is poor.

Table 2-11: Overview of technological maturity of different fuels (Author's compilation)

Fuel	Converter	Components	Maturity	Sources
LNG	ICE 4-stroke Lean Burn Spark Ignition/Dual Fuel Low Pressure (4S LBSI/LPDF)	Engine Storage tanks Process system	1	Boretti (2020); Bakar et al. (2012)
	ICE 2-stroke Dual Fuel Low Pressure (2S LPDF)	Engine Storage tanks Process system	1	
	ICE 2-stroke Dual Fuel High Pressure (2S HPDF)	Engine Storage tanks Process system NOx reduction system (EGR/SCR)	1	
Hydrogen	FC	Fuel cell Storage tanks Electric motor & reformer Battery	2	Tang & Wang (2023)
	ICE	Engine Storage tanks Process system	3	Wrobel et al. (2022)
Ammonia	FC	Fuel cell Storage tanks Process system Electric motor & reformer Battery	3	Langella et al. (2022)
	ICE	Engine Storage tanks Process system NOx reduction system (EGR/SCR)	3	Ghasem (2024)
Methanol	ICE 2-stroke	Engine Storage tanks	2	Verhelst et al. (2019)
LPG	ICE - 2-stroke	Engine Storage tanks Process system NOx reduction system (EGR/SCR)	2-3	Hashem (2023)

#### d. Government policy and shipping regulations

The Vietnamese government's strategy on marine fuels demonstrates a purposeful transition toward cleaner alternatives while recognizing the ongoing relevance of traditional options.

**Liquefied Natural Gas (LNG):** Under Vietnam's Power Development Plan 8 (PDP8), LNG is prioritized as a critical marine fuel, with a goal of contributing significantly to power generation by 2030. This translates into favorable policies for LNG import infrastructure development, as demonstrated by projects such as the Thi Vai LNG Storage facility (Le & Nguyen, 2024). Furthermore, the government actively promotes research and application of science and technology in research, building, repairing, and converting ships, and continues to exempt import

tax and reduce 50% of tonnage fees when ship owners buy and operate container ships of 1,500 TEUs or more, or ships running on clean energy such as LNG, H2, and LNG tankers until the end of 2030 (Vietnam International Trade Administration, 2023).

**Liquefied Petroleum Gas (LPG):** LPG regulations are primarily concerned with assuring safety throughout the supply chain, which includes transportation and storage. While rules may not explicitly encourage its marine usage, its proven position in the domestic energy mix shows that it has the potential to be used in the maritime sector indefinitely (DNV, 2019). Similarly in Vietnam, which is holding the 5th Asia Pacific LPG Expo, is taking a proactive approach to energy security by creating a new regulation to assist the LPG sector according to Vietnamnews (2023).

**Hydrogen and Ammonia:** Vietnam's government aggressively pushes renewable energy options such as hydrogen and ammonia. Yep and his colleagues (2024) noted the Hydrogen Energy Strategy was created using the National Energy Development Master Plan, which establishes the groundwork for the Vietnamese energy sector, encompassing oil and gas, coal, electricity, and renewable energy, from 2021 to 2030, with a vision of 2050. The primary purpose of the Hydrogen Energy Strategy is to develop the different stages of Vietnam's hydrogen energy ecosystem, such as production, storage, transportation, distribution, domestic usage, and export (Yep et al., 2024; Huld; 2024). Similarly, Vietnamenergy (2024) also stresses that the government promote the use of green hydrogen energy and hydrogen-origin fuels in all energy-consuming sectors to decarbonize the economy and significantly contribute to achieving the net-zero emissions goal by 2050, including transitioning gas-fired and LNG-fired power plants to use hydrogen and coal-fired power plants to use ammonia in accordance with the National Power Development Plan.

**Methanol:** There is currently no clear policy direction in Vietnam governing the use of methanol as a marine fuel. The lack of large-scale local manufacturing and limited existing laws indicate that it might not be a significant priority in the foreseeable future.

Overall, based on the existing policy environment, LNG has the most favorable position for Vietnamese marine applications. Existing complementary infrastructure development plans, as well as compatibility with the government's energy policy, reinforce its supremacy. However, in the long term, despite no progress being made, as Vietnam promotes clean energy transition, future rules may favor renewable choices like hydrogen and ammonia, necessitating continuous monitoring of policy changes in these sectors.

### **2.3.7.2. Economics**

#### **a. Energy cost**

Data on energy prices were gathered from public sources and translated to USD/MWh shaft output, allowing for a direct comparison of costs across different energy carriers. The conversion method is inspired by DNV (2019), which took into account both system efficiency and the fuel's specific energy content. According to the analysis of Mohamed (2023) on hydrogen, the generation of hydrogen and ammonia from renewable sources is heavily influenced by electrolyser load factors (number of running hours per year) and energy costs. This analysis used a 50% load factor and power costs ranging from \$20 to \$60 per megawatt hour. At load factors below 50%, the price rises dramatically following DNV (2019). The electricity utilized in production must come from renewable sources if the hydrogen and ammonia routes are to be powered by them (Mounaïm-Rousselle et al., 2023). For some of the paths, just the commodity price is provided, not the price of supplied gasoline, which is the case with hydrogen, ammonia. When the cost of liquefaction/compression, distribution, storage, and bunkering facilities, as well as mark-up, is taken into account, the price of supplied fuel is clearly greater than that stated for the relevant paths. According to DNV GL (2018), the distribution cost of LNG from LNG terminals to the receiving ship generally ranges between 40-120 USD/m<sup>3</sup>, which is about 15-40 USD/MWh shaft output. In any given instance, the cost of carrying ammonia should be about equivalent to that of transporting LNG, measured per volume (Bicer & Dincer, 2018). Adjusting for ammonia's reduced energy content, this corresponds to around 20-70 USD/MWh, in addition to the figures shown below. Transport costs for LPG would be somewhat cheaper than for LNG due to the slightly higher energy density, and LPG ships are often less expensive than equivalent LNG carriers (Ashok, Ashok & Kumar, 2015). A distinction between liquefied and compressed hydrogen has not been made, however according to Vedhuis, Richardson and Stone (2007), liquid hydrogen is around 30% more costly than compressed hydrogen.

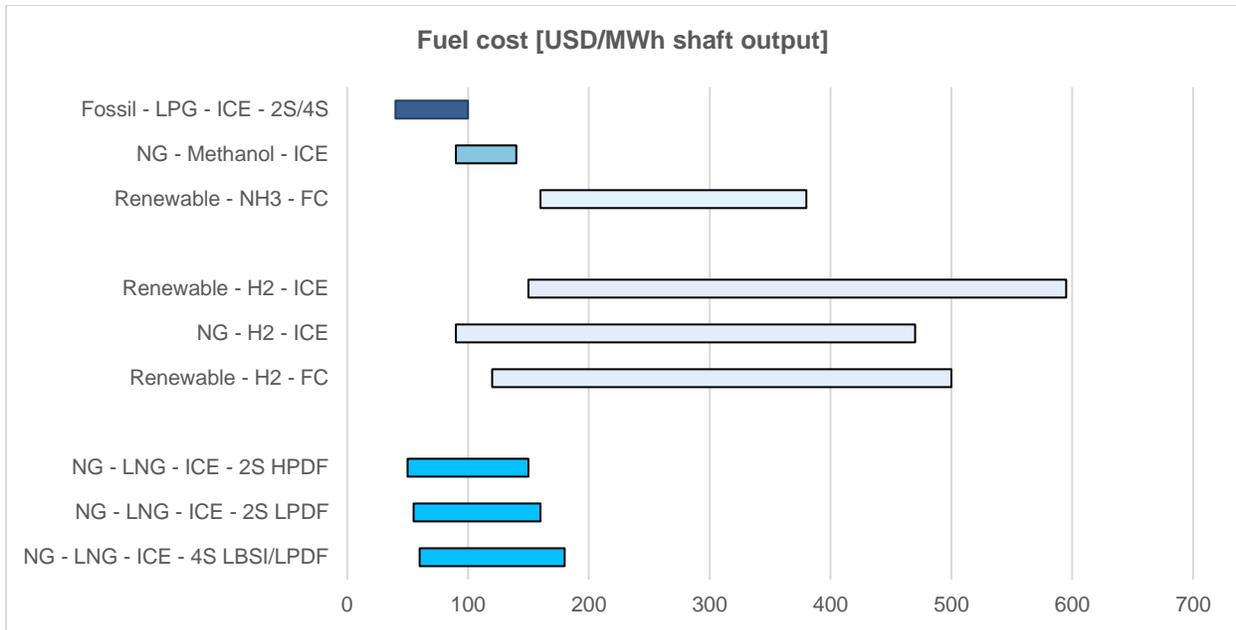


Figure 2-6: Fuel cost of different fuel pathways (Author's compilation)

From Figure 2-6 it is clear that LNG, methanol and LPG are competitive in terms of energy costs, while hydrogen and ammonia are also far more expensive, and the large cost range indicates a significant uncertainty in terms of pricing. Also, the figure may give the impression that hydrogen produced from renewables is likely to be cheaper than when produced from natural gas. However, there are few available sources and only IRENA (2021) gives prices for both, suggesting that hydrogen from renewables is 50% more expensive. Besides, Bos (2019) clearly shows that LNG, methanol, and LPG are comparable in terms of energy costs, however hydrogen and ammonia are significantly more expensive, and the wide cost range suggests substantial volatility in price.

### b. Capital costs

It was discovered that the cost for the process system is generally not stated in the accessible literature, thus in the following, just the cost of the converter and storage system are included.

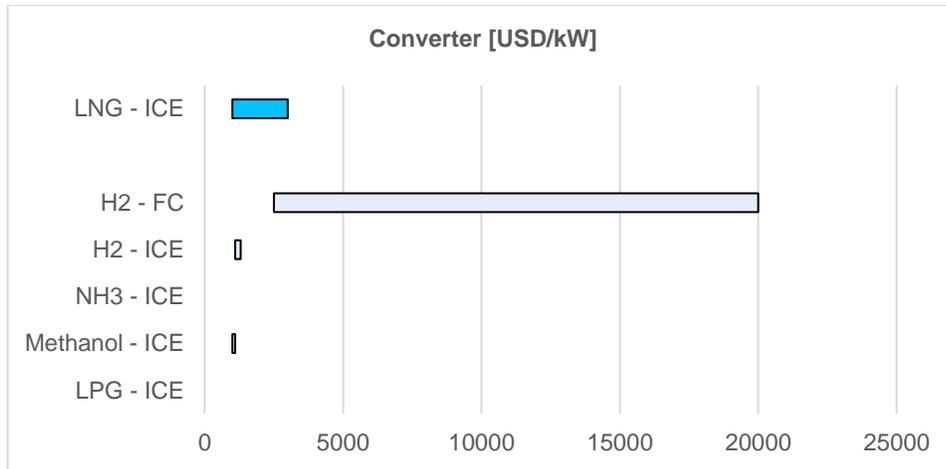


Figure 2-7: Converter expenses for the selected fuel pathways (Author's compilation)

Figure 2-7 shows that fuel cells are currently far more costly than internal combustion engines. Furthermore, the wide range in cost for fuel cells shows a high level of uncertainty. This is most likely owing to the low maturity of fuel cells, which has resulted in poor sales volume in today's marine business (Hashem et al., 2023). Another factor that is not included in the indicated capital cost for fuel cells is the fuel cell stack's life expectancy, which indicates that it must be replaced after a certain amount of time of operation (Mohamed, 2023). The available data about the number of operating hours before a cell stack replacement is needed varies significantly. Brynolf (2018) provides a range of 10,000 to 90,000 hours, with a sample lifespan of 47 500 hours. This would normally imply stack replacement every ten years for primary engines on deep sea vessels (depending on ship type and market conditions). According to Shell (2017), the life expectancy for the two most promising fuel cell technologies is 60 000 hours for proton-exchange membrane (PEM) fuel cells and up to 90 000 hours for solid oxide (SO) fuel cells. The cost of replacing the cell stack is reported by Raucci (2017) as 60% of the fuel cell's capital cost, but DNV GL (2018) operates at 50% of the fuel cell cost. Although there is no data on particular expenses for ammonia technology, the same study reveals that biofuel incurs no additional investment expenditures when compared to traditional vessels. Installing LPG systems on a vessel is around half the cost of installing LNG systems, as long as pressurized type C tanks are utilized (DNV, 2018). Besides, Mounaïm-Rousselle et al. (2022) stated that ammonia is transported by multi-cargo gas carriers that can also transport LPG, so equipment and costs for transporting ammonia can be estimated based on the cost of LPG, taking into account energy content, system efficiency, storage system utilization, and storage system lifetime [USD/kg LNG equivalent].

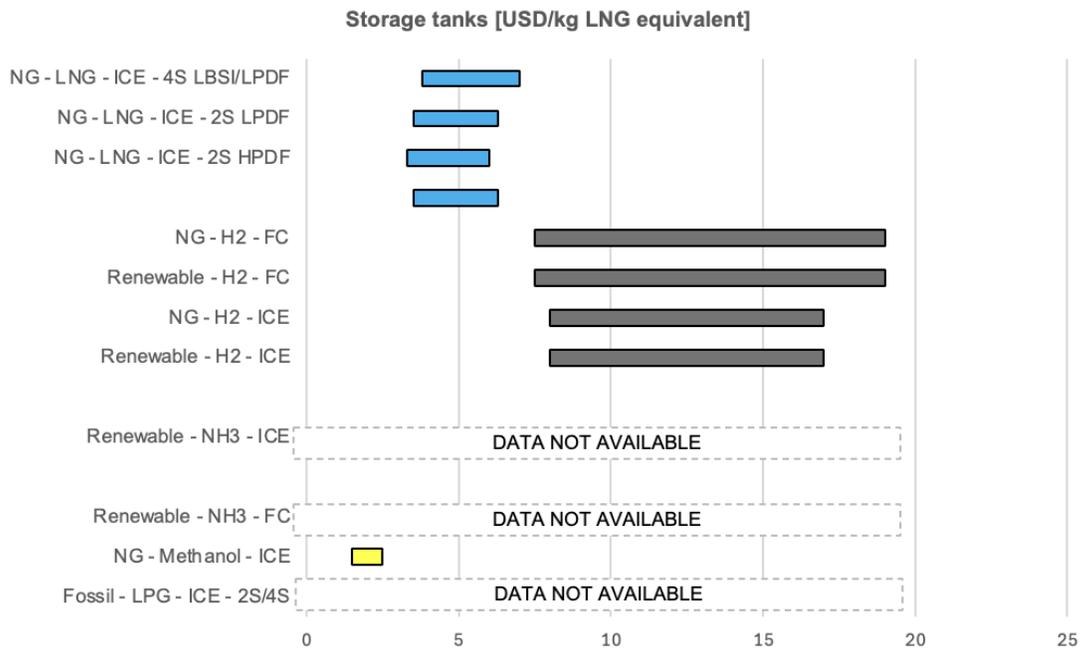


Figure 2-8: Storage tanks expenses for the selected fuel pathways (Author's compilation)

When comparing storage costs, the converter efficiency, tank storage utilization factor, and storage longevity were all evaluated. This is why the price of LNG tanks varies significantly depending on engine type (and fuel cell). Following Basurko and Mesbahi (2014), adjusting for battery storage lifespan (assumed to be 1/3 of fuel tanks) has a major influence on findings, but is somewhat offset by almost double the system efficiency of ICEs. When compiling statistics for hydrogen, no distinction was made between liquefied vs. compressed hydrogen because sources sometimes do not clarify which technique the cost is supplied for. However, tanks for liquid hydrogen are substantially more expensive due to lower storage temperatures, better insulation quality, and limited maritime uses (Mohamed, 2023). With current technology, hydrogen appears to be confined to short-sea ships because of tank costs and range limits caused by its low density.

### 2.3.7.3. Scalability

#### a. Fuel Availability in Vietnam market

When LNG arrives at its destination (import terminal), it is often re-gasified and delivered via gas networks, similar to gas from pipelines. Despite Vietnam's rising interest in LNG as a cleaner fuel option for its marine sector, the number of operating LNG-powered ships is limited. The country's first LNG facility started operational in July 2023, indicating the early stages of LNG adoption. Furthermore, with only one terminal now serving the Cai Mep - Thi Vai port, infrastructural

restrictions likely limit the broad deployment of LNG-powered vessels at the moment (Valerie, 2023).

On the other hand, hydrogen is now receiving much attention from the Vietnamese government; the use of hydrogen in transportation is currently small, although various projects are being developed to employ both liquid and compressed hydrogen (Hoang et al., 2023). The anticipated uses are for the short sea portion. While Vietnam understands the limitations of existing marine fuels and investigates alternatives, hydrogen's development as a feasible solution is in its early stages with expected potential upcoming projects.

Osman (2024) notes that ammonia is not currently used as a fuel in transportation, although the industry is beginning to consider it for usage in combustion engines and fuel cell applications. Similar with methanol when Dincer I (2024) found that there are now 12 methanol-powered ships in service or on order worldwide; however, Vietnam currently has minimal specialized bunkering facilities for ships.

A huge network of LPG import and export ports exists across the world, but the development of ship bunkering infrastructure remains a hurdle to the fuel's usage. The existing infrastructure might be leveraged to extend the distribution and bunkering of LPG as a maritime fuel (Doan, 2023). Bunkering can be provided by trucks or bunker boats from LPG terminals. However, in comparison to alternative fuels like hydrogen or ammonia, there is little investment and pilot technology in the development of LPG-fueled ships. Furthermore, Vietnam's green shipping policies focus on large emission reductions. While LPG burns cleaner than other fuels, it nevertheless emits greenhouse gas (Nguyenb, 2024)

Overall, future alternative marine fuels must be accessible on the market in order to ensure adequate adoption. Dang (2023) concluded that except for LNG and hydrogen or ammonia in Vietnam, the existing supply of alternative fuels is insufficient to meet the maritime industry's current energy requirements. Furthermore, most fuels have inadequate or restricted infrastructure. This is not the situation with LNG, where extensive regional LNG bunkering infrastructure has already been built (LNG terminals, truck loading facilities, and LNG bunker tankers). Rapid advancements in LNG infrastructure are seen at several critical bunkering locations, enabling LNG-fueled deep-sea transport. Following Valerie (2023), significant LNG infrastructure was originally developed at the Cai Mep-Thi Vai port. In principle, a conversion to

LNG for the whole world fleet is feasible, as existing LNG production surpasses the maritime industry's present energy requirements, and more production capacity is being created.

#### **b. Local production capacity and locations**

For hydrogen, China Huadian Engineering Co. Ltd., a subsidiary of one of China's largest power generators China Huadian Corp., and Vietnam's Minh Quang JSC met officials of the central province of Quang Tri to invest \$2.39 billion in a green hydrogen project. The project will comprise a 1,200 MW wind power plant, an 800 MW solar power plant and a water electrolysis plant for hydrogen production, along with storage and transport infrastructure, the companies said. Its initial phase will have a green hydrogen plant alongside a 200-MW solar farm (Vietnamnews 2023). Besides, Tra Vinh Green Hydrogen project in the coastal province of Tra Vinh, Vietnam's first green hydrogen plant in the Mekong Delta, with production capacity of 24,000 mt/year and construction timeline of two years at a cost of \$327.7 million. While present production capacity is modest, with no large-scale facilities functioning yet, Vietnam is making tremendous efforts in developing a hydrogen and ammonia economy, as described in their national policy, which aims for 100,000-500,000 tons of pure hydrogen generation per year by 2030 (Le, 2022). This emphasis on clean manufacturing methods complements Vietnam's renewable energy boom, presenting it as a possible future player in the global clean hydrogen and ammonia industries. Similarly, Hoang (2023) stressed that additional project developments in the following years will offer a clearer picture of Vietnam's real production capability and trajectory within this expanding clean energy sector.

Vietnam's natural gas sector distinguishes between liquefied petroleum gas (LPG) and liquefied natural gas (LNG). While local LPG production meets a fraction of national demand, LNG currently depends primarily on imports to fill the shortfall (Tran, 2023). Regarding LPG, Vietnam has limited local manufacturing capacities. Existing refineries account for around 30% of the country's overall LPG consumption. Imports account for the remaining 70%. This reliance on external supplies emphasizes the necessity for prospective exploration and production development in Vietnam. On the other hand, Vietnam's LNG infrastructure is rapidly developing. The country's Power Development Plan 8 (PDP8) promotes LNG as a primary fuel source, aiming for a 24-29% share of overall energy output in 2030 (Nguyena, 2023). To accommodate this transformation, facilities such as the Thi Vai LNG Storage, which has a phase 1 capacity of 1 million tonnes and a projected phase 2 extension to 3 million tonnes, demonstrate Vietnam's commitment to LNG import and usage (Cong Quyet, 2024).

On the other hand, Vietnam's methanol manufacturing capability remains mostly unmet despite previous ambitions. Proposals for domestic methanol factories with annual capacities ranging from 600,000 to 1.3 million tonnes have been explored, but no large-scale facilities have emerged (Shi, 2023).

Overall, Vietnam has the largest domestic capacity for LNG and hydrogen, while being largely reliant on imports. Domestic production capacity for LPG and methanol remains limited. However, it is noteworthy to note that Vietnam is shortly switching from LNG to Hydrogen in the long term, with the bulk of projects concentrating on manufacturing hydrogen (Cong Quyet, 2024).

#### **2.3.7.4. Environmental**

##### **a. Well-to-wake GHG emissions**

Figure 11 provides a summary of well-to-wake GHG emissions. For each pathway, a range of lowest and maximum values is provided, as well as an average of averages for the studied data. It is crucial to note that the assumptions and circumstances on which the findings are based, such as production, mode of transportation, and vessel specifications, are not equal. Brynolf (2014) suggests that the use-cases themselves reflect a diverse range of well-to-wake scenarios, and so the different route emission levels are not directly comparable. However, this work attempted to collect data from possible use-cases to provide a depiction of realistically comparable GHG well-to-wake emissions. Hwang and Joon (2012) investigated in addition to variances in use-cases and scenarios, there will be significant uncertainty in predicting life-cycle emissions for various energy carrier and converter routes. This must also be considered when comparing Figures 11 since in this paper some routes have limited, if any, literature on GHG emission statistics and it has to show these paths without ranges.

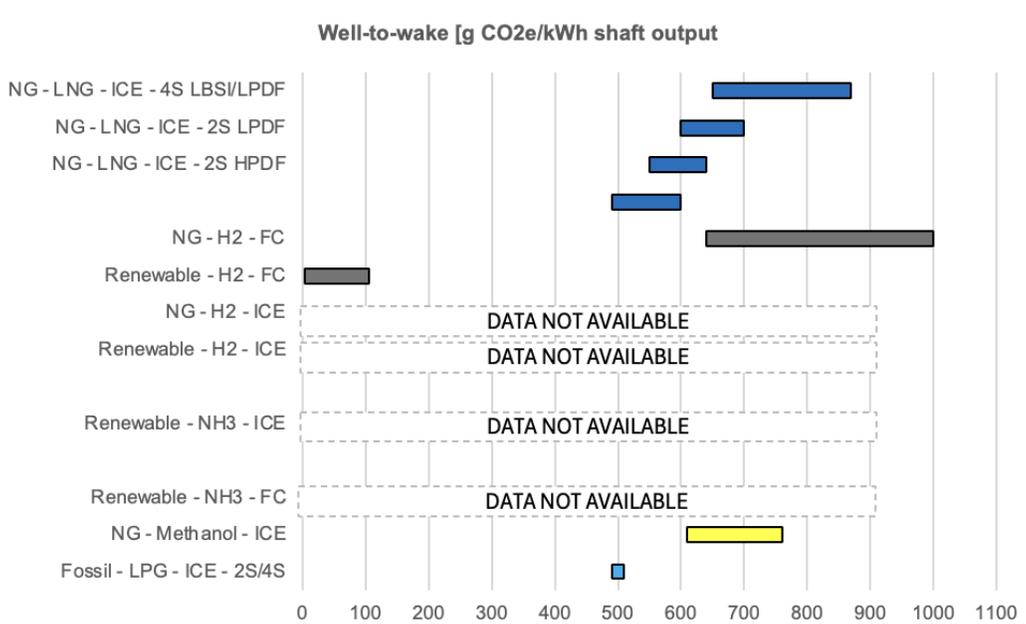


Figure 2-9: Well-to-wake emissions for fuel/technology pathways, taking into account energy content of fuel and system efficiency [g CO<sub>2</sub>e/kWh shaft output]

There are very few studies on the expected or assumed potentials for lifecycle emission reductions in any of the routes. Thus, this research solely shows the current picture of well-to-wake emissions. In accordance with worldwide drivers for essential future emission reductions in the marine industry, incentives to reduce other aspects of the lifetime route emissions are projected to be implemented (Kim & Seo, 2019). The results reveal vast ranges of probable lifecycle emissions for some of the routes, indicating major variability in modes of production, transportation, and storage, or simply that there is tremendous uncertainty when modeling life cycle fuel emissions (Balcombe et al., 2019). In general, renewable energy routes or those derived from biomass are associated with lower well-to-wake GHG emissions than those originating in fossil fuels. Hydrogen production and storage need a significant amount of energy, hence its competitiveness in terms of GHG emissions is heavily dependent on low-emission energy generation (Hansson et al., 2019).

### b. Local emissions - SO<sub>x</sub>, NO<sub>x</sub> & PM

The emissions of sulfur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM) from ships are determined by the fuel used and the engine/converter employed (Strantzali, Livanos & Aravossis 2023). Figures 12 to 15 below summarizes onboard emissions from various fuels and converters. Only on-board emissions are accounted for. Many sources only give relative reduction factors when compared to HFO/MGO, hence the following baseline values were presumed to be

able to convert to g/kWh for comparative purposes: NOx: Baseline is Tier II limit at relevant rpm, SOx: HFO sulfur content 3.5%, MGO sulfur content 0.1%, SFOC 175 g fuel/kWh, and PM 7.6 kg/tonne fuel (Dalsøren et al., 2009). The next three graphs depict the tank-to-propeller NOx, SOx, and PM emissions for the various fuels. Notice that for many of the fuels of interest, there is minimal data available.

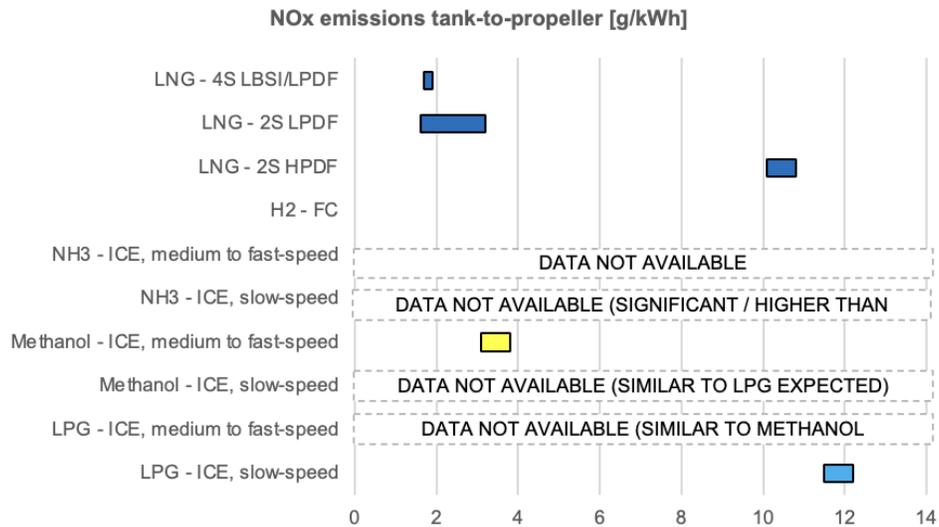


Figure 2-10: NOx emissions Tank-to-Propeller of selected fuel pathways (Author's compilation)

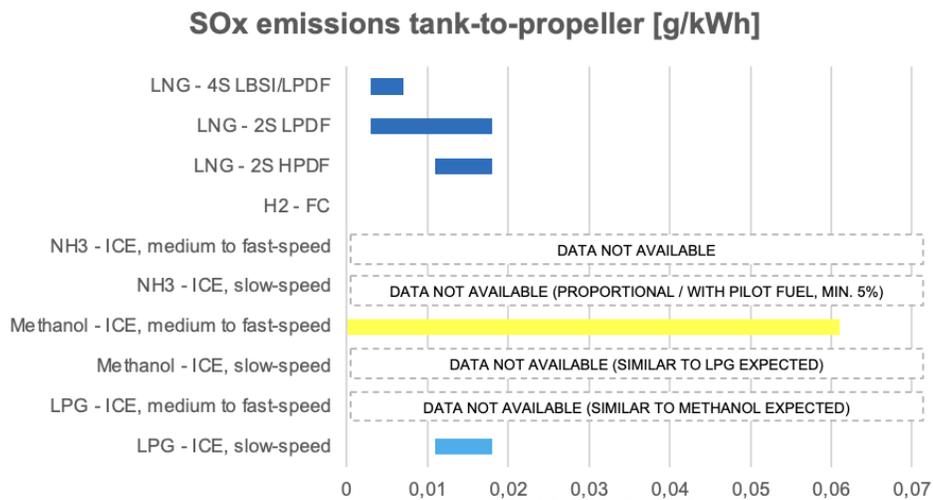


Figure 2-11: SOx emissions Tank-to-Propeller of selected fuel pathways (Author's compilation)

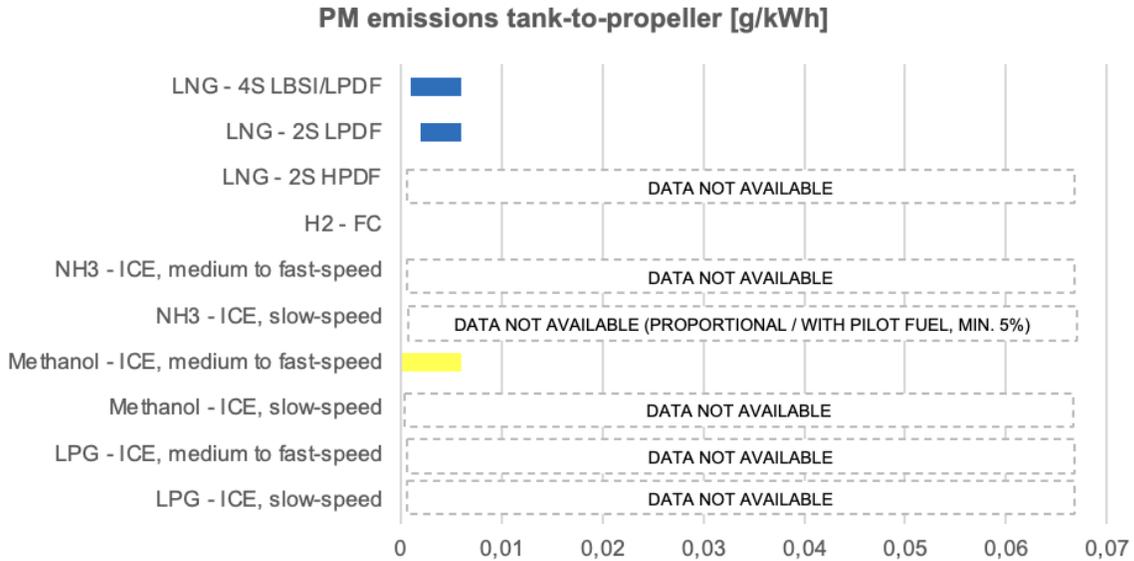


Figure 2-12: PM emissions Tank-to-Propeller of selected fuel pathways (Author's compilation)

Converters that use the Otto combustion concept have very low emissions of local pollutants and, independent of fuel source, fulfill the current toughest emission criteria, such as the IMO Tier III NOx limit (Ren et al., 2013). Diesel cycle (high pressure) converters often emit more local pollutants than converters that use the Otto combustion concept. For SOx and PM, the somewhat higher emission levels relate to the greater fraction of pilot diesel fuel required to ignite the gas, however it is crucial to stress that both approaches minimize such emissions by more than 95% (Brynolf, 2014). McArthur (2011) explained that the increased NOx emission levels are due to the Diesel combustion principle, and exhaust gas after treatment is required to meet with Tier III (usually standard solutions with SCR or EGR).

### 2.3.7.5. Summary of Performance of Each Fuel based on 10 parameters

Table 2-12: Summary of Performance on Each Fuel (Author's compilation) based on previous studies

Energy source	Fuel	Fossil			Renewable	
		LNG	Methanol	LPG	Ammonia	Hydrogen
- Energy density		Green	Red	Yellow	Orange	Green
- Technological maturity		Green	Red	Yellow	Orange	Green
- Local emissions		Green	Red	Yellow	Orange	Green
- GHG emissions		Green	Red	Yellow	Orange	Green
- Energy cost		Green	Red	Yellow	Orange	Green
- Capital cost	Converter	Green	Red	Yellow	Orange	Green
	Storage	Yellow	Red	Yellow	Orange	Green
- Fuel availability		Green	Red	Yellow	Orange	Green
- Flammability		Green	Red	Yellow	Orange	Green
- Toxicity		Green	Red	Yellow	Orange	Green
- Government Regulations		Green	Red	Yellow	Orange	Green
- Local production capacity		Green	Red	Yellow	Orange	Green

	Highest performance
	Proper performance
	Moderate performance
	Poor performance
	Worst performance

According to Table 2-12, hydrogen has the highest performance in environmental factors and applicability factors with the proper performance in scalability factors groups, except the worst performance in the economics factors since hydrogen's energy costs are the highest. However, since hydrogen lies in the government's energy development plan, the government will provide incentives which reduce the costs of using hydrogen for shipowners in Vietnam (Nguyen, 2023). Following hydrogen is LNG, which seems to be the second-potential green marine fuel: with proper performance in applicability factors like energy density or toxicity, however, regarding the development roadmap Vietnam will move from LNG to Hydrogen, in the future, LNG may receive less preference from the government. On the other hand, LPG and Ammonia rank the third with moderate performance in the factors according to previous studies. Last, Methanol seems to be out of the league from this paper's result and will not be included in any of Vietnam's green maritime initiatives. However, it is note that the information is gathered mostly from generic studies, in which the particulars of the situation being analysed, such as ship specifications have not been taken into account when considering alternative fuels. Therefore, the results may differ based on vessel types or specifications.

### **3. CHAPTER 3: QUANTITATIVE RESEARCH METHOD**

**The ground method** for this paper would be the multi-group Structural Equation Modeling (SEM) with the support of Confirmatory Factor Analysis (CFA) to test the suggested hypotheses in section 2.3.5 to find and verify the correlations between the research constructs. However, before testing the correlation in SEM, the measuring scale's reliability and validity to validate the observed variables is necessary to confirm if a collection of selected variables can be categorized into underlying factors or latent constructs. This was evaluated using methods such as Cronbach's Alpha testing and CFA. After all the variables are valid and confirmed by Cronbach's Alpha and CFA, the links between the constructs were tested using Structural Equation Modeling (SEM).

Sub-research Question 3 will be answered through CFA analysis since the results of CFA will point out which resource constraint factors, either economics or scalability contribute the highest contribution to resource-constraint factor in general. Sub-research question 4 will be answered through SEM analysis since the result will point out whether the proposed hypothesis is accepted, which is whether the resource constraint factors directly or indirectly affect the green fuel selection of Vietnamese shipowners in Vietnam. Besides, the impact level pointed out by SEM will also act as an indication for which factor to prioritize. Therefore, based on this, together with score of each 5 fuels on 10 parameters given by survey, will indicate the answer for Sub-research Question 5.

In this study, data was acquired from 2-part questionnaire survey sent to Vietnamese shipowners. To conduct analysis for the above methods, data first went through the data checking process. Then grouped into the descriptive analytics to see who is the stakeholders and types of vessels that results of this paper most illustrates. The data is then handled using IBM SPSS and AMOS to conduct CFA and SEM. To be more explicit, quantitative research on this issue involves the following steps:

#### **3.1. Data checking**

The key data obtained during the survey will be processed using Excel software. Surveys that do not match the conditions will be eliminated prior to quantitative analysis. Data cleansing in Excel includes the following tasks:

- Checking for missing or incomplete information: Surveys that have more than 30% missing data will be removed.

- Surveys with only a single rating for all observable variables will be eliminated to prevent altering correlation coefficients, standard deviations, and medians.
- Following the data processing stage, the data will be imported into SPSS 22.0 for descriptive statistics analysis, with the goal of determining the mean values and key features of the observed sample. The key data obtained during the survey will be processed using Excel software. Surveys that do not match the conditions will be eliminated prior to quantitative analysis.

### **3.2. Descriptive statistics**

First, the frequency and statistical average are calculated, providing an overview of the gathered samples. Sociodemographic factors are examined to determine the distribution of the sample group's characteristics. Because the target respondents in this study are Vietnamese shipowners, demographic data such as vessel type, route, age of vessels and DWT of vessels will be considered. The replies are then summarized and visualized to determine which is the main group of stakeholders this result is describing.

### **3.3. Reliability measurement**

The scale's reliability is then assessed using the Cronbach's alpha coefficient. Each group has three or four things, which are stated by a five-point Likert scale question. Cronbach's Alpha reliability coefficient is often used by academics to test the reliability of scales. Cronbach (1951) developed the coefficient to assess the reliability of measuring scales for conceptual entities in research. This approach does not compute the reliability of individual observed variables, instead the corrected item-total correlation is utilized to assess the degree of relationship between an observed variable and the remaining variables. According to Nguyen Dinh Tho (2013), a scale with a minimum Cronbach's Alpha value of 0.6 and a maximum value of 0.95, as well as an item-total correlation larger than 0.3, is reliable. When the Cronbach's Alpha coefficient surpasses 0.95, the observed variables are essentially identical. Based on these criteria, scales with Cronbach's Alpha values between 0.6 and 0.95 and observed variables with item-total correlations over 0.3 will be chosen for future investigation.

### **3.4. Confirmatory Factor Analysis**

Confirmatory Factor Analysis is used to ensure the validity of the theory construct employed in the investigation. In research, hypotheses are suggested based on the author's knowledge of the

ideas, and this analysis is used to determine if that understanding and the measurements of observed variables are compatible with one another (Price, 2023). In CFA, first-order constructs are directly measured by smaller observed variables while second-order constructs are indirectly measured through first-order constructs, in which the second-order constructs are the representative of broader concept or features that comprises multiple first-order constructs. In this paper, first-order construct are economics factors, scalability factors, applicability factors and environment factors and fuel selection since it is directly measured through the observed variables in [table 3-1](#). The second-order construct are resource-constraint factor since it comprises the first-order construct, which are scalability and economics factors.

It is noted that this paper will employ CFA for second-order constructs. The process of creating CFA models for second-order constructs usually entails 2 steps: first, the relationships between observed variables and first-order constructs are analysed, and then the relationships between the second-order construct and first-order constructs are analysed (Price, 2023).

Particularly, in step 1, First-order construct will test and validate 5 first-order constructs: scalability factors, economics factors, environment factors, applicability factors and fuel selection process with its observed variables in [table 3-1](#). In step 2, Second-order construct analysis will validate the relationship between the observed variables [table 3-1](#) inside first-order constructs scalability and economics factors, namely energy costs, capital costs, fuel availability and local production with the second-order construct: resource-constraint factors. Hence, the sub-research question 3 will be answered through this second-order construct CFA analysis.

These phases aim to evaluate four characteristics of the assessment scale: (1) unidimensionality, (2) convergent validity, (3) discriminant validity, and (4) reliability.

To evaluate unidimensionality, researchers must consider the compatibility of the proposed model with market data, which means that the observed variable set is unidimensional (Hoyle, 2000). To solve this issue, the Chi-square test is used in conjunction with significant indices like as RMSEA (Root Mean Square Error Approximation), TLI (Tucker-Lewis Index), CFI (Comparative Fit Index), GFI (Goodness of Fit Index), and the Chi-square/df ratio. A strong model fit is achieved when the Confirmatory Factor Analysis results match the following criteria:  $\text{chi-square/df} \leq 2$ ,  $\text{CFI} \geq 0.9$ ,  $\text{GFI} \geq 0.9$ ,  $\text{TLI} \geq 0.9$ , and  $\text{RMSEA} \leq 0.06$ . Furthermore, it is still suitable in a particular scenario with less good indices, such as  $\text{chi-square/df} \leq 5$ ,  $\text{CFI} \geq 0.8$ , and  $\text{RMSEA} \leq 0.08$  (Hoyle, 2000).

According to Tavakol and Dennick (2011), researchers use metrics like CR (Composite Reliability), MSV (Maximum Shared Variance), and AVE (Average Variance Extracted) to assess the assessment scale's reliability, discriminant validity, and convergent validity. Specifically:

(1)  $AVE > 0.5$  and  $CR > 0.7$  show strong dependability,

(2)  $AVE > 0.5$  shows strong convergence validity, and

(3)  $AVE > MSV$  and  $\sqrt{AVE} >$  the correlation coefficient between constructs indicate excellent discriminant validity.

The Stats-Tools-Package calculates CR, AVE,  $\sqrt{AVE}$ , and MSV values.

### 3.5. Linear Structural Equation Modeling (SEM) Analysis

SEM (Structural Equation Modeling) is used to discover the connections between constructs due to the intricacy of the interactions in the theoretical model. SEM enables for the simultaneous testing of several regression equations (Hair et al., 2016). The analysis includes the following major steps:

- **Model fit assessment.** This stage tests the structural model's compatibility with actual research data using measurements such as Chi-square/df, RMSEA, CFI, TLI, and GFI. These measurements help discover potential inaccuracies in the model.

- **Testing the significance and adequacy of relationships in the structural model:** This stage seeks to establish the links between constructs based on the original hypothesis. Statistically significant associations are defined as  $p < 0.05$ . The route coefficients are also checked for appropriateness. Path coefficients should be in the range of -1 to +1 (Hair et al. 2016).

- **Testing the role of mediator variables:** According to Hair et al. (2016), one should look into the statistical significance of both direct and indirect effects in order to assess the role of mediator factors. In the event that the indirect impact reaches statistical significance ( $p < 0.05$ ), a partial mediator will be included in the study model. A direct impact is referred to as a partial mediator if it continues to be statistically significant. On the other hand, the direct influence is categorised as a complete mediator if it is not statistically significant. To evaluate the mediation role, the bootstrap approach is commonly employed (Shrout & Bolger, 2002). This method is supported by AMOS 24.0 software.

### 3.6. Questionnaire design

#### 3.6.1. Sampling method

A survey is performed to acquire data from Vietnamese maritime stakeholders that choose green marine fuel. Due to limited resources, convenience sampling is used rather than real random samples. The goal of this study is to investigate Vietnamese stakeholders' green fuel preferences, thus the survey is disseminated directly to local firms who operate their own fleets and want to transition to green fuel to achieve the IMO's aim. In addition, the survey is circulated by email, personal messaging, or networks. An online survey was constructed using Google Forms, and the data was gathered in 19 days.

While the study provides interesting insights, it is crucial to note that the findings may be biased owing to the use of convenience sampling methods. Volunteer bias, in which those who freely participate vary from those who do not participate, is a possible cause of bias in the results. Furthermore, the sample may not adequately represent other demographic features, such as years of experience in the sector or geographical region.

Hachter (1994) suggests a sample size that is at least five times the total number of variables observed on the scales. In this study, the questionnaire included 12 observed variables for factor analysis. As a result, the minimal sample size for this study is 12 multiplied by 5, which is 60 units. This survey is given to 60 Vietnamese enterprises with their own fleet, and each company will have 3-4 managers in charge of the sustainability program to respond.

#### 3.6.2. Questionnaire

The survey question sets (table 3-1) comprise rating questions for each type of green fuel to ascertain respondents' preferences when selecting an alternative fuel for their firm. This article will create the questionnaire with the previously mentioned parameters, which were selected based on the literature investigation in Chapter 2. The questionnaire will have 10 criteria presented in the table below, asking about the importance of each factor during the decision-making process.

*Table 3-1: Questionnaire set of survey sent to stakeholders (Author's compilation)*

<b>First-order Constructs</b>	<b>Observed Variables</b>	<b>Acronyms</b>	<b>Question</b>
-----------------------------------	---------------------------	-----------------	-----------------

Applicability	Energy density	AP1	I will select green fuel based on: How much energy the fuel contains per unit volume or weight.
	Technological maturity/Infrastructure sufficiency	AP2	I will select green fuel based on: How developed the fuel technology is and whether there's enough infrastructure (like fueling stations) to support its use
	Flammability and toxicity	AP3	I will select green fuel based on: How easily the fuel catches fire and how harmful it is to people and the environment.
	Government policy	AP4	I will select green fuel based on: Regulations, incentives, or restrictions related to the fuel's use in the Vietnamese shipping industry.
Economics	Energy costs	ECO1	I will select green fuel based on: The price of the fuel itself.
	Capital costs	ECO2	I will select green fuel based on: The expense of modifying or replacing engines and other equipment to use the fuel
Environment	GHG emissions - well-to-wake	EN1	I will select green fuel based on: The total greenhouse gas emissions produced, from fuel production to its use on the vessel.
	Local emissions - SOx, NOx and PM	EN2	I will select green fuel based on: The amount of sulfur oxides, nitrogen oxides, and particulate matter

			released when the fuel is used, which affect local air quality
Scalability	Availability	SCA1	I will select green fuel based on: How easy it is to obtain the fuel when and where it's needed
	Production locations	SCA2	I will select green fuel based on: How it is fuel
Fuel Selection	Selection of fuel	FS1	Will use these factors to select green fuel for the company
	Recommendation for others	FS2	Will recommend these suggested factors for colleagues to use

Because all the variables are latent, the questionnaire has a series of questions designed with the Likert scale (1932), a prominent method of measurement in scientific research. The Likert scale is a hypothetical evaluation tool that incorporates individuals' or groups' viewpoints, opinions, and attitudes on a specific topic. It is commonly used as a 5- or 7-point scale, ranging from strongly disagree to completely agree, with a neutral middle. The author of this study employed a 5-point - 2-pole Likert scale, in which respondents will rank in a scale of 1 to 5.

*Table 3-2: Summary of Ranking Scale for 2 parts of survey based on Liker scale (Author's compilation)*

Survey Part 1: Importance of Factor during Decision-making process	1-Not Suitable, 2-Poorly Suitable, 3-Moderate, 4-Highly Suitable, 5-Optimal.
Survey Part 2: Performance of Each fuel based on selected criteria	1-Bad, 2-Somewhat satisfied, 3-Moderate, 4-Good, 5-Excellent.

## 4. CHAPTER 4: RESULTS

### 4.1. Descriptive Statistics

The survey collected from 115 respondents from 56 Vietnamese companies that are developing green fuel long-term strategy for their vessels. The demographics statistics of the respondents are summarized as below:

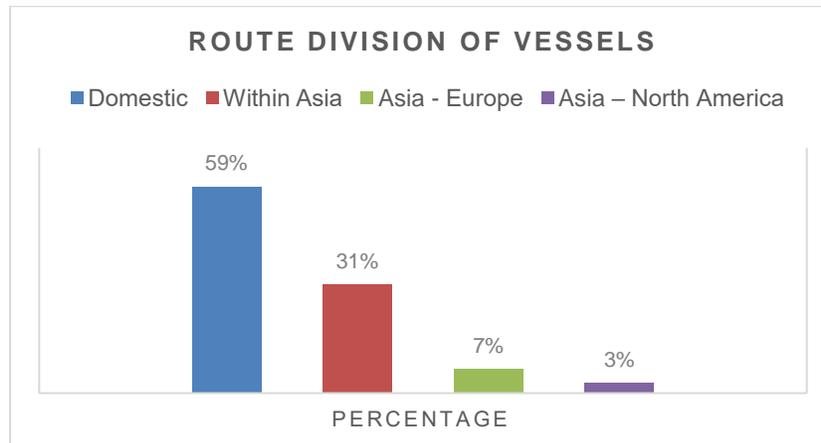


Figure 4-1: Route division of survey participants' vessels (Author's compilation from survey result)

There are 5 main routes that Vietnamese shipowners are targeting to transform their fleet to green fuel: Domestic, Asia - Asia, Asia - Europe and Asia - North America, in which short-sea shipping operates in domestic routes account for the highest percentage of 59%, following by vessels operating internal Asian routes.

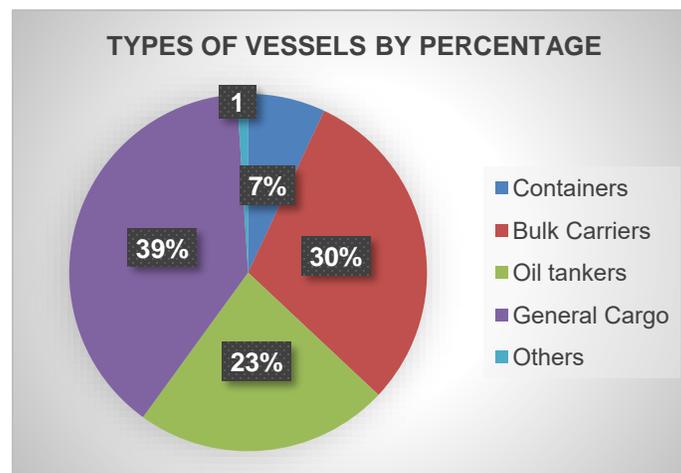


Figure 4-2: Vessel types of survey participants' vessels (Author's compilation from survey result)

There are 4 main vessel types after collecting the survey result, which is container vessels, bulk carriers, oil tankers and general cargo, in which general cargo has the highest percentage of

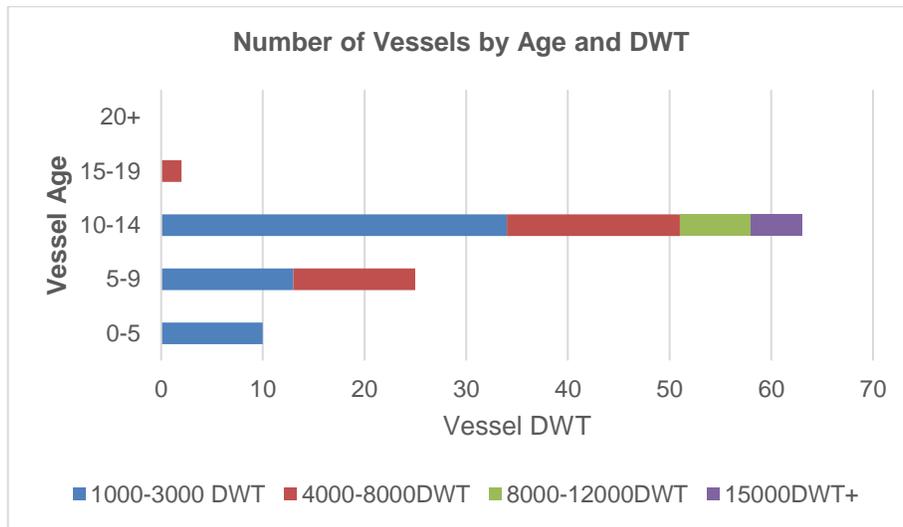


Figure 4-3: Vessel Age of survey participants' vessels (Author's compilation from survey result)

The average vessels fall into the age group of 15-19 and have small DWT of mostly from 1000-3000 DWT and 4000-8000 DWT. There is a limited number of above-20 year old vessels and there are not many Vietnamese shipowners who own 15000+ DWT vessels.

#### 4.2. Measurement Scale Reliability Assessment

For each collection of scales, the Cronbach Alpha analysis approach is used to assess their reliability. Cronbach's Alpha analysis is used to determine the convergence of observed variables within a measurement scale. A measuring scale is deemed trustworthy if the Cronbach's Alpha coefficient is more than 0.7 and the item-total correlation of the observed variables is greater than 0.3 (Bonnett, 2014). A total of 5 measurement scales and 12 observable variables are examined consecutively.

Table 4-1 shows the Cronbach Alpha values for the conceptual construct measuring scales, which show that all the scales have Cronbach's Alpha coefficients of 0.70 or higher. Cronbach's Alpha coefficients range from 0.807 (for the Economics-related Factor) to 0.905 (for the Environment Factor). There is no need to eliminate any variables to increase Cronbach's Alpha. Furthermore, all measured variables show item-total correlations of 0.30 or above. Thus, the measurement scales for the study constructions satisfy the dependability criteria.

Table 4-1: Cronbach Alpha Summary for Tested Constructs (source: SPSS Output)

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
<b>1. Economics factor: <math>\alpha = 0.807</math></b>				
EC1	3.88	0.812	0.676	
EC2	3.73	0.761	0.676	
<b>2. Scalability factor: <math>\alpha = 0.858</math></b>				
SCA1	3.81	0.552	0.751	
SCA2	3.77	0.574	0.751	
<b>3. Applicability Factors: <math>\alpha = 0.863</math></b>				
AP1	11.27	4.936	0.661	0.845
AP2	11.29	4.545	0.783	0.795
AP3	11.40	4.813	0.640	0.856
AP4	11.25	4.791	0.769	0.803
<b>4. Environment Factor: <math>\alpha = 0.905</math></b>				
EN1	3.82	0.830	0.827	
EN2	3.80	0.794	0.827	
<b>5. Fuel Selection: <math>\alpha = 0.867</math></b>				
FS1	3.49	0.950	0.768	
FS2	3.69	0.789	0.768	

### 4.3. Confirmatory Factor Analysis (CFA)

#### 4.3.1. First-order CFA analysis

- Evaluating the overall fit of the model

To assess the discriminant validity of the research constructs in the study model, a first-order constrained model was built, with the research constructs freely connected to one another.

The CFA findings revealed that the first-order constrained model (only 1st order constructs) has 44 degrees of freedom. The chi-square test resulted in a value of 46.792 with a p-value of 0.359. The chi-square/df ratio was 1.063, which met the criteria of <2. Furthermore, the model fit indices showed a satisfactory fit with the market data (GFI=0.963, CFI=0.998, TLI=0.997, meeting the criteria of >0.9), and the RMSEA was 0.018, which was less than 0.08. Therefore, we can infer that the model displayed an acceptable overall fit.

Except in circumstances when measurement errors of the observed variables are linked, the model fit with the market data provides us with the necessary and sufficient conditions for the observed variables to demonstrate unidimensionality (Nguyen Dinh Tho, 2011). The study's findings revealed that the model had a reasonable overall fit, with no association between the observed variables' measurement errors. Thus, the first-order structures in the model were unidimensional.

Table 4-2: Model fit indices (source: AMOS output)

Model fit indices	Cmin/df	CFI	GFI	TLI	RMSEA
Recommended value	< 2.0 or < 3.0	> 0.9	> 0.9 or > 0.8	> 0.9	< 0.08
Obtained	1.063	0.998	0.963	0.997	0.018

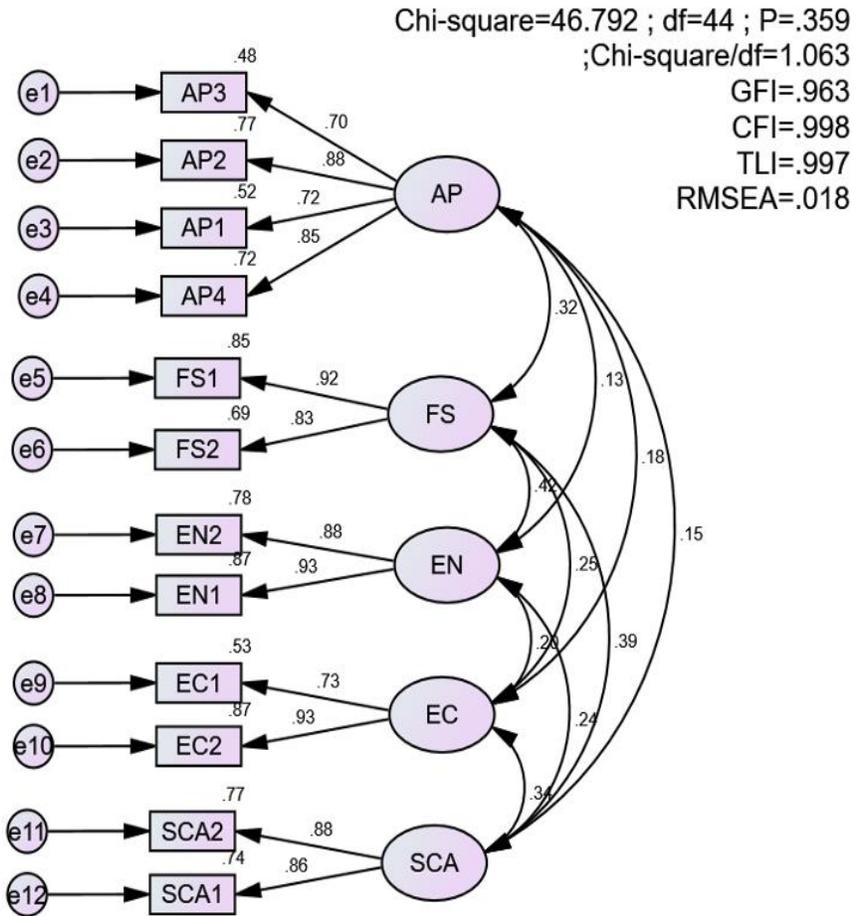


Figure 4-4: The results of the standardized first-order CFA model (source: AMOS output)

- Evaluation of the composite reliability (CR) and average variance extracted (AVE)

Table 4-3 's reliability testing shows that the components' extracted variance ( $\rho_{vc}$ ) and composite reliability coefficients ( $\rho_c$ ) match the requirements. The composite reliability coefficients ( $\rho_c$ ) vary from 0.819 to 0.906, satisfying the condition of  $\geq 0.70$ . Additionally, the total variance extracted ranges from 62.4% to 82.8%, meeting the criteria of  $\geq 50\%$ . This shows that the measuring scales are dependable.

Table 4-3: Evaluation of measurement scale reliability (source: AMOS output)

Code	Construct	Cronbach	CR	AVE
AP	Applicability Factors	0.863	0.868	0.624
FS	Fuel Selection	0.867	0.871	0.772
EN	Environment Factor	0.905	0.906	0.828
EC	Economics factor	0.807	0.819	0.697
SCA	Scalability factor	0.858	0.858	0.752

- *Convergent validity assessment*

All variables have standardized regression weights above 0.6 (with the lowest being  $\lambda_{AP3} = 0.696$ ) and are statistically significant ( $p < 0.001$ ), suggesting convergence of the scale's observed variables.

Table 4-4: Factor loadings of observed variables (standardized)

				Estimate
AP3	<---	AP		.696
AP2	<---	AP		.879
AP1	<---	AP		.720
AP4	<---	AP		.848
FS1	<---	FS		.922
FS2	<---	FS		.833
EN2	<---	EN		.885
EN1	<---	EN		.935
EC1	<---	EC		.726
EC2	<---	EC		.931

SCA2	<---	SCA	.875
SCA1	<---	SCA	.859

- **Discriminant validity assessment**

Discriminant validity illustrates a construct's uniqueness or distinctiveness in relation to other constructs in the model. According to Fornell and Larcker (1981), discriminant validity occurs when the square root of the average variance extracted (AVE) for each latent variable is greater than the correlations with other constructs.

Table 4-5: Discriminant validity assessment (following Fornell & Larcker (1981) (source AMOS output)

	CR	AVE	AP	FS	EN	EC	SCA
AP	0.868	0.624	0.790				
FS	0.871	0.772	0.323***	0.879			
EN	0.906	0.828	0.127	0.415***	0.910		
EC	0.819	0.697	0.180*	0.246**	0.203*	0.835	
SCA	0.858	0.752	0.155†	0.393***	0.238**	0.343***	0.867

The diagonal values are the square roots of the AVE (average variance retrieved) for each component. The numbers below the diagonal reflect the correlations between the model's relevant constructs (ranging from 0.79 to 0.910). Discriminant validity is attained when the diagonal values exceed the values in their corresponding rows and columns. Table 4-5 shows that discriminant validity has been attained for all five first-order components in the study model.

#### 4.4.2. Second-order CFA Analysis

- **Evaluation of the overall model fit**

Resource constraint factors is a second-order construct quantified using first-order constructs such as Scalability (SCA) and Economics (ECO). In this second-order CFA analysis, we re-evaluate whether the Resource constraint factors' component measurement scales are appropriate for the survey data. Figure 19 shows the findings of the second-order CFA for resource-constraint factors.

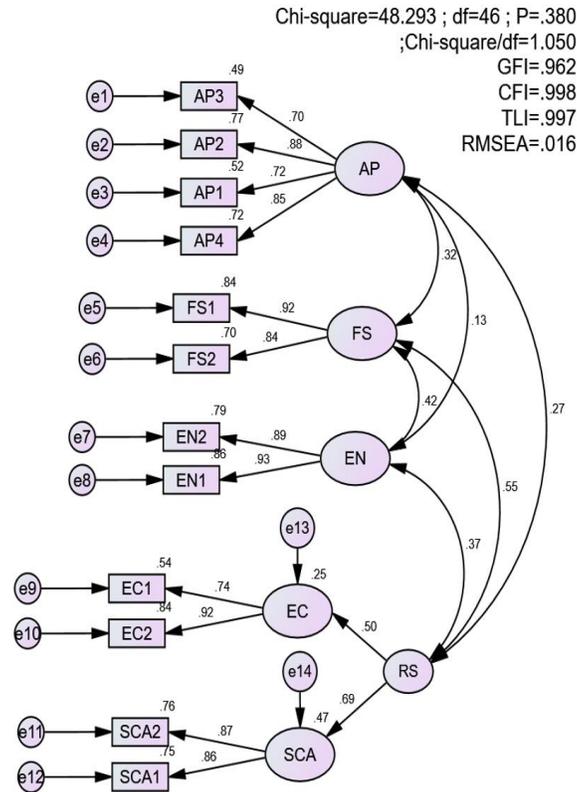


Figure 4-5: SEM Results of the Standardized Research Model (source: AMOS Output)

Figure 4-5 shows the results of the limited measurement model's second-order CFA, which revealed the following findings: The model has 46 degrees of freedom, a Chi-square value of 48.293 with  $p = 0.000$ , a CMIN/df of  $1.050 < 2$ , and goodness-of-fit indices of  $GFI = 0.962$ ,  $TLI = 0.997$ ,  $CFI = 0.998 (> 0.9)$ , and  $RMSEA = 0.016 (< 0.08)$ . As a result, we can conclude that the model fits the market data.

- **Convergent validity assessment**

The observed variables' factor loadings on their respective factors in the second-order restricted model vary from .659 to .916 (as shown in Table 4-6), showing that they meet the criteria of being more than .50. As a result, we may conclude that the component measurement items in the second-order model have good convergence.

Table 4-6: Convergent validity assessment in the second-order constrained model (source: AMOS output)

			Estimate
SCA	<---	RS	.687
EC	<---	RS	.501
AP3	<---	AP	.696
AP2	<---	AP	.877
AP1	<---	AP	.721
AP4	<---	AP	.849
FS1	<---	FS	.919
FS2	<---	FS	.836
EN2	<---	EN	.889
EN1	<---	EN	.930
EC1	<---	EC	.738

EC2	←---	EC	.916
SCA2	←---	SCA	.870
SCA1	←---	SCA	.864

- **Convergent validity assessment for the Resource constraint constructs**

The results in Table 4-6 reveal that the standardized factor loadings of the first-order constructs are all more than 0.5. As a result, all four components significantly contribute to the explanation of the resource constraint factors construct.

According to the table, the standardized factors of Scalability (SCA) are higher than Economics Factors (EC) ( $0.687 > 0.501$ ), showing that SCA has a greater impact on Resource constraint factors (RS). As a result, Vietnamese shipowners might place a higher priority on SCA than EC. Specifically, EC2 has a higher standardized factor than EC1, implying that factor EC2 may receive greater priority than factor EC1. Similarly, SCA2 has a larger standardized factor than SCA1, indicating that it should be prioritized.

#### 4.5. Testing the research model and hypotheses

The ML estimate findings in Figure 4-6 reveal that the evaluated research model comprises four elements (constructs): Applicability elements (AP), Fuel Selection (FS), Environment Factor (EN), and Resource-constraint factors. In that, resource-constraint factor is a second-order construct that combines two first-order constructs: the Economics-related factor (EC) and the Scalability-related factor (SCA).

The linear structural analysis performed with the ML estimation method reveals that the model has 47 degrees of freedom. Although the Chi-square value is  $p = .415$  (Chi-square = 48.419), the adjusted Chi-square divided by degrees of freedom (CMIN/df) is 1.030, which meets the criteria of being less than 2.00. Furthermore, the other fit indices match the requirements: GFI = 0.962, CFI = 0.999, TLI = 0.998, and RMSEA = 0.028 (all above .90). Thus, we may conclude that this model is appropriate for the data collected from the market.

The SEM model testing supports all the study model's hypothesized associations. Table 4-7 shows the estimated (standardized) parameters for the main effects. The model's weight matrix indicates that the variables' direct effects are statistically significant ( $p < .05$ ). **Thus, all five hypotheses (H1-H5) are accepted.**

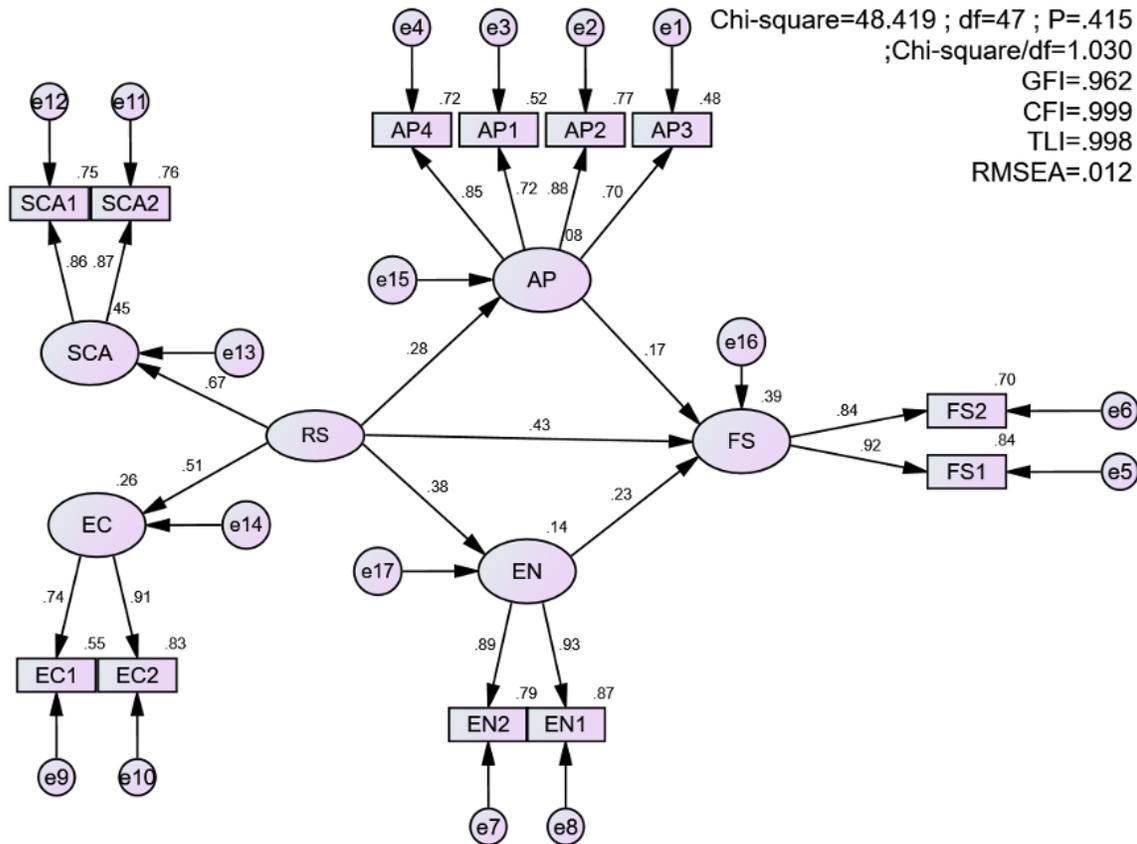


Figure 4-6: SEM Results of the Standardized Research Model (source: AMOS output)

Table 4-7: Results of Hypothesis Testing in the Research Model (Author's compilation)

Hypothesis	Unstandardized regression coefficient.	P value ( $p < 0.05$ )	Standardized regression coefficient	Hypothesis testing

H1	Applicability is positive influenced by resource constraint factors	.401	.019	.281	<b><i>Accepted</i></b>
H2	Environment factor is positively influenced by resource constraint factors of the fuel	.702	.005	.377	<b><i>Accepted</i></b>
H3	Environment factor has a positive significant association with fuel selection	.236	.008	.234	<b><i>Accepted</i></b>
H4	Applicability factor has a positive significant association with fuel selection	.229	.031	.174	<b><i>Accepted</i></b>
H5	The resource constraint factors directly and positively influence the fuel selection of shipowners	.799	.008	.427	<b><i>Accepted</i></b>

#### **4.6. Score matrix**

In table 4-8, the average score of each fuel based on survey answers are summarized below in the scale of 1 to 5. The score is calculated by taking the average of scores that participants score each green fuel based on the parameters defined in the literature review sector.

Table 4-8: Score matrix of Research fuels (source: Author's calculations based on survey results)

	LNG	LPG	Methanol	Hydrogen	Ammonia
Energy density (AP1)	4,00	5,00	4,00	4,00	3,00
Technological maturity/Infrastructure sufficiency (AP2)	5,00	4,00	2,00	5,00	3,00
Flammability and toxicity (AP3)	4,00	3,00	3,00	4,00	3,00
Government policy (AP4)	4,00	3,00	3,00	5,00	4,00
Energy costs (EC1)	3,00	4,00	3,00	3,00	3,00
Capital costs (EC2)	3,00	4,00	3,00	3,00	4,00
GHG emissions - well-to-wake (EN1)	3,00	5,00	3,00	5,00	5,00
Local emissions - SO <sub>x</sub> , NO <sub>x</sub> and PM (EN2)	4,00	3,00	3,00	5,00	4,00
Availability (SCA1)	4,00	4,00	2,00	4,00	3,00
Production locations (SCA2)	4,00	4,00	2,00	4,00	3,00

The highest performance fuel in the Environmental factors group is Hydrogen, highest in Applicability factors is LNG and Hydrogen while Methanol seems to be the least favourable fuel. For resource constraint factors, LPG is the highest performance fuel, followed by Hydrogen.

## **5. CHAPTER 5: DISCUSSION**

This study introduced the concept of Resource constraint factors as a hierarchical and multidimensional construct. It is revealed that resource constraint factors can be viewed as a higher-level construct comprising four distinct dimensions that relate to various factors: energy costs, capital costs, availability and production capacity. This hierarchical structure allows for different levels of abstraction, enabling the assessment of resource constraint factors as a whole as well as the examination of individual resource constraint domains. The overall assessment of resource constraint factors provides insights into shipowners' fuel selection process, while the individual resource constraint factors offer a more detailed understanding of how each domain influences the fuel selection process of Vietnamese shipowners.

### **5.1. Descriptive statistics**

The majority of companies participating in the survey are local Vietnamese shipowners, in which most of the vessels that they are targeting to transform to use the green fuel is general cargo, followed by oil tankers and bulk carriers.

The DWT of the vessels in the plan of transformation are less than 10,000DWT, this aligns well with the fact that only 5% of Vietnamese fleet and wearing Vietnamese flag has DWT above 10,000DWT. These vessels often operate in more localized routes. The route of the vessel also reflects the reason why there are a majority of below 10000 DWT vessels since nearly 60% of the vessels mostly operate in domestic routes and 30% operate within Asia. Ha (2023) also explains this because Vietnamese fleet has not had enough large vessels that can run on longer routes, however, the tendency to run to Europe, where the strict regulation about emission has to be met, is rising. Hence, this report will mostly be from the perspective of shipowners whose vessels are small and operate on a short-sea route.

The age of the vessels in the survey ranges from 10 to 14 years old, which is also the average age of the Vietnamese fleet. However, vessels of this age present a challenge because, in the long run, enterprises' primary solution is to decommission old and non-compliant vessels and invest in rejuvenating the fleet with new-generation vessels. Furthermore, Vuong (2023) noted that achieving the EEXI index requires most current vessels to reduce their main engine power, affecting operational efficiency, particularly causing the challenge for some old vessels in securing cargo transportation contracts due to an inability to achieve the required operational speed.

## 5.2. First-order construct

Table findings show that Capital cost (EC2) has the greatest standardized loading factor of 0.916, demonstrating its significant contribution to Vietnamese shipowners' resource constraint fuel choosing procedure. Schmidt (2014); Schinko and Komendantova (2016); Komendantova et al. (2019) also state that if there is a lack of financial resources, certain energy projects may not be economically feasible owing to the high cost of capital. The author discovers that across nations, the availability of financial resources contributes to investments in more capital-intensive energy technologies (that is, technologies with a greater percentage of capital costs in total lifecycle costs). They also emphasize the influence that financial capital has on the shift from (traditional) biomass to fossil fuels, particularly in low-income (developing) nations. This can be explained by the research site, which is in Vietnam, an underdeveloped country with a limited fleet and prices.

Production capacity (SCA2) has the second highest standardized loading factor of 0.870, showing that it plays a secondary role in Vietnamese shipowners' resource constraint fuel selection processes. This observation is also consistent with Huang (2022). The economic situation of a country substantially supports its energy transition strategy. It requires investment in various energies such as power generation by wind rather than fuel, renewable energy projects, and others (X. Wu, Sadiq et al., 2021b; Xiang et al., 2021). A country with a poor economy cannot afford such a project and will be unable to carry out its energy transition strategy. Furthermore, each country's natural resources have an influence on its energy transition plan. The country is reliant on its industry and will need to consider its energy transition strategy and process. This energy revolution will also have an influence on the industrial industry, resulting in lower total energy use and costs (Lee et al. 2017). Furthermore, the survey respondents, the majority of whom are small-scale shipowners, also have an influence on these findings. Small shipowners in Vietnam may pick green fuels, of which their nation has the largest manufacturing capacity, for numerous reasons. First, local manufacturing may minimize reliance on imported goods, cutting supply chain risks and perhaps lowering gasoline costs. Furthermore, proximity to industrial facilities might improve logistics and lower transportation costs. This can be especially beneficial for smaller shipowners that have limited resources and prioritize cost-effective operations. Second, boosting local green fuel companies may boost economic growth and job creation in Vietnam, which aligns with national development objectives. Small shipowners may help make the marine sector more sustainable and self-sufficient by favoring locally generated green fuels (Xiang et al., 2021).

The fuel's availability (SCA1) ranked third, with a standardized loading factor of 0.860. Bai (2021) also have the same results of small shipowners frequently pick green fuels that are familiar in the market for a variety of reasons. First, already-available fuels have a better developed infrastructure, such as bunkering facilities, supply chains, and technical assistance, which may lower operational costs and lessen risks associated with implementing new technologies (Bai, 2021). Second, familiarity with a fuel type frequently leads to a greater pool of competent workers and experience, making it simpler to locate qualified crew members and specialists. This can lead to more efficient operations and cheaper maintenance expenses. Furthermore, proven fuels may have a more favorable regulatory environment, with clearer norms and established compliance requirements, which reduce ambiguity and potential legal risks (Bai, 2021).

The surprise finding is that energy cost (EC1) placed last with a standardized loading factor of 0.738, making the smallest contribution to resource constraint considerations in the fuel selection process. It is logical given that when they choose green fuel, energy prices are the obvious aspect that shipowners must bear throughout the green shift. According to Dang (2023), tiny Vietnamese shipowners have limited bargaining leverage as they are not large energy importers, forcing them to accept the current pricing. Furthermore, failure to absorb these costs may result in reduced profitability and a loss of market share, so they accept the trade-off. Finally, the short-term sustainability implications of rising fuel prices may be prioritized over economic considerations. Small shipowners may be more focused on preserving sustainability, which will repay the investment in capital expenses (Nguyen & Gang, 2022).

*Table 5-1: Ranking of impact level for first-order constructs (Author's compilation)*

<b>Prioritize order</b>	<b>Variable Acronym</b>	<b>Variable Name</b>	<b>Standardized Regression Factor</b>
1	EC2	Capital Cost	0.916
2	SCA2	Local Production Capacity	0.870
3	SCA1	Market Availability	0.860
4	EC1	Energy Cost	0.738

### **5.3. Second-order construct**

#### **a. Hypothesis (H1): Applicability is positively associated with resource constraint factors**

The analysis results show statistical significance (Sig. = 0.019), and the standardized regression coefficient of 0.234 suggests that resource constraint selection factor procedures have a beneficial impact on the applicability factor. Thus, the hypothesis (H1) is accepted. The standardized regression coefficient of 0.234 shows that a one-unit change in customers' CSR perceptions will lead to a 0.234-unit increase in the applicability factor, providing other components stay equal. This aligns with the findings of Xuan et al. (2022), in which high energy costs may incentivize the development and adoption of more energy-efficient technologies, while low capital costs can facilitate investments in new green fuel infrastructure. Local production capacity can reduce reliance on imports, mitigating supply chain risks and potentially lowering fuel costs. In response to these economic factors, governments may implement policies that support the development and deployment of green fuels, such as subsidies, tax incentives, or emissions regulations.

#### **b. Hypothesis (H2): Environment factor is positively associated with resource constraint factors**

The analysis results show statistical significance (Sig. = 0.000), with a standardized regression coefficient of 0.174 indicating a positive impact of the Resource constraint in Environment Factor. Thus, the hypothesis (H2) is accepted. The standardized regression coefficient of 0.174 indicates that a one-unit change in the Environment Factors by customers will result in a 0.174-unit increase in the accuracy of the Fuel Selection process, providing other factors remain constant. the pursuit of economic efficiency can sometimes lead to trade-offs with environmental sustainability. For instance, while locally produced green fuels may reduce transportation costs and support domestic industries, they may also have a higher carbon footprint if the production process is energy-intensive or relies on fossil fuels. Additionally, the initial capital costs of transitioning to green fuel technologies can be significant, potentially limiting the adoption of more environmentally friendly options.

#### **c. Hypothesis (H3): Environment factor has a positive significant association with fuel selection**

The analysis results show statistical significance (Sig. = 0.008), and the standardized regression coefficient of 0.427 indicates that environmental influences have a beneficial impact on the fuel selection process. Thus, the hypothesis (H3) is accepted. The standardized regression coefficient of 0.427 indicates that a one-unit change in customer satisfaction will result in a 0.427-unit increase in customer loyalty to the company, providing all other factors remain constant. This standardized regression analysis is highest, showing that the environment component has the most impact on the fuel choosing process. It is understandable since the green fuel transition stems from the environmental consequences and net zero emission target of IMO. Furthermore, Adomako and Tran (2022) noted that enterprises' decision-makers respond positively to the external impact of laws and regulations, changing their business models and practices to ones that are socially acceptable. Li et al. (2022) contended that rigorous environmental rules might bring long-term advantages to enterprises and their sustainability, driving the organization to adopt sustainable practices. According to studies by Hsu et al. (2021) and Li et al. (2022), environmental legislation and policies are important drivers of green innovation, as enterprises respond to regulatory bodies' pressure on GHG emissions.

**d. Hypothesis (H4): Applicability factor has a positive significant association with fuel selection**

The analysis results show statistical significance (Sig. = 0.031), with a standardized regression coefficient of 0.337 indicating that applicability considerations have a favorable impact on the fuel selection process. Thus, the hypothesis (H4) is accepted. The standardized regression coefficient of 0.337 means that a one-unit change in brand image will result in a 0.337-unit increase in customer loyalty towards the company, providing other factors remain constant. Vietnamese shipowners' fleets must explore fuels with high energy density, which provide higher efficiency while lowering fuel consumption and operating expenses. Shipowners are confident in technologically mature fuels that have demonstrated dependability and safety histories. Additionally, low-toxicity fuels reduce environmental concerns and minimize potential regulatory fines. According to Huang (2023), these features, taken together, increase the attraction of green fuels to Vietnamese shipowners looking to strike a balance between economic efficiency and environmental sustainability. Furthermore, this application does not have as great an influence as the environmental concerns because the bulk of the boats that Vietnamese shipowners seek for fuel change are short-distance vessels (mainly domestic). Domestic boats, in particular, might reduce the impact of lower energy density fuels by traveling shorter distances and refilling more

frequently. Furthermore, domestic activities frequently include smaller vessels, making fuel efficiency a less crucial factor.

**e. Hypothesis (H5): The resource constraint factors directly and positively influence the fuel selection of shipowners.**

The study results are statistically significant (Sig. = 0.008), and the standardized regression coefficient of 0.281 indicates that resource constraint factors have a favorable impact on the fuel selection process. Thus, the hypothesis (H5) is accepted. The standardized regression coefficient of 0.281 shows that a one-unit change in CSR perceptions will lead to a 0.281-unit increase in the accuracy of the fuel selection process, providing other parameters stay constant. This is the lowest standardized regression coefficient; therefore, this can indicate that resource constraint has the lowest impact on fuel selection process. This result can be due to the smaller size of the vessels (below 10,000DWT) of the respondents participating in the report (table), since they do not need such a huge investment to change vessel engines compared to bigger size ships. This contrasts with the findings of Ren and Ji (2021) when acquisition cost and economics factors receive higher importance than other factors during the decision-making process. The reason for this can be as follows: with the tighter restrictions on net zero emissions, Vietnamese shipowners have to see energy costs of the fuel as an unavoidable cost, besides, with the support of government through incentives, the funding could be the not so prioritized factors.

The standardized regression coefficient of these hypotheses shows that H3 has the strongest link, followed by H4, H5, H1, and H2. The ranking of the group of components is: Environment <- Applicability <- Resource constraint. This, together with the CFA analysis below, yields the prioritization level of characteristics to consider when selecting green fuel, in which Environmental factors group contributes the highest, followed by Applicability factors and Resource constraint factors.

## **5.6. Alternative Fuel Selection Recommendation**

According to Table 4-8, the highest performance fuel in the Environmental factors group is Hydrogen. This fuel also ranks the second in the Applicability factors and ranks the highest in the scalability factors. The only weakness hydrogen has lies in its energy costs. However, according to the findings of hypothesis testing, environmental considerations are somewhat more relevant than application criteria such as infrastructure requirements or economic ones such as energy and capital costs. In this fashion, this study prioritizes the fuel that performs well on environmental

impact factors, followed by the fuel that performs well on applicability factors, and finally the fuel that performs well in the resource constraint factors group. Besides, the high energy costs of hydrogen following the CFA analysis result has the least impact on the overall fuel selection process. Therefore, in conclusion, considering the amount of influence of each component group, hydrogen is the most viable green alternative fuel for Vietnamese shipowners to achieve their decarbonization goals, followed by LNG. This also aligns with the result from literature review in table 2-12.

This score result aligns with the characteristics of hydrogen compiled in previous studies. According to DNV (2019), The fundamental advantage of hydrogen is its potential to be an emissions-free fuel when produced from renewable sources. Furthermore, the expected move to land-based renewable power generation is ideal for future hydrogen manufacture capabilities. The two most significant barriers to hydrogen use are its high cost and a lack of bunkering infrastructure. However, the fuel's energy cost has the least influence on green fuel choices, therefore, hydrogen remains a feasible choice for Vietnamese shipowners following the survey's result.

The majority of hydrogen generated will come from natural gas until the transition to renewable power production without CCS is well advanced (as it is today). Though more expensive and likely to be adopted slowly, maritime projects that use hydrogen may ensure the use of (and contribute to the creation of) renewable hydrogen (Hoang, 2023). Another key difficulty is the feasibility of hydrogen use. This drastically limits the ship segments in which hydrogen may be employed. Given the present cost of fuel cells and tanks, as well as hydrogen's low density, it appears that its usage in transportation is limited to short-haul routes. However, according to the study of this conclusion, most Vietnamese shipowners are pursuing operations on internal routes, and within Asia (which is short-sea shipping), thereby hydrogen's problem in this sector may not be a major concern.

Moreover, this fuel result also aligns with the Vietnamese government's growth goal. No new LNG-to-power plants will be developed from now on, and LNG will be gradually converted into hydrogen (Nguyenb, 2024). After 10 years of operation, each of these projects is expected to be converted to hydrogen, providing a cost-effective choice. By 2050, most, if not all, of the country's gas-powered facilities will have completed this metamorphosis. Vietnam was taking the first moves toward transitioning from traditional to renewable, or green, energy, with the establishment of a green H<sub>2</sub> economy viewed as a crucial priority for Vietnam in the near future. According to

projections, Vietnam's total energy demand by 2050 will be around 144-170 million tons of oil, with H2 energy accounting for approximately 5.6%-6.2%. As a result, the use of green hydrogen in transportation and industry could help Vietnam eliminate approximately 324.4 million tons of CO2 by 2050, contributing to the net-zero objective in the whole energy sector. Given the abundance of renewable sources in Vietnam, the development of green H2 might begin by growing offshore wind power and solar (Hoang et al., 2023).

To achieve the goal of generating green H2 energy, the Vietnamese government published Resolution No. 55-NQ/TW dated 2020 on the orientation of the National Energy Development Strategy until the end of 2030, with a vision for 2045. Vietnam has also released a list of high-priority technologies for development, including hydrogen energy sources by 2050 (Valerie, 2023). According to the National Energy Development Strategy for 2030, with a view for 2050, the development of H2 energy was firmly targeted. Furthermore, the National Energy Plan set a target that by 2050, H2 output might reach about 25 million tons, and synthetic fuels derived from H2 would reach around 2.5-2.9 million tons. As a result, H2 fuel and H2-derived synthetic fuels were employed in power production, transportation, industry, and residential and commercial buildings to speed the energy transition and gradually decarbonize the economy (Tri, 2023). Furthermore, increasing the carbon tax should be an effective way to create a clean, green, and healthy corporate environment. According to prior reports, the carbon tax should be raised to 1275-2,55 million VND/t CO2, resulting in a green H2 pricing of 17,830-25,500 VND/kg (Le & Nguyen, 2021). Furthermore, the H2 energy development roadmap was divided into two phases: Phase 1 from 2020 to 2030 would develop small-scale H2 projects with approximately 20,000-25,000 tons, and Phase 2 from 2031 to 2050 would promote H2 production by using renewable electricity technology and coal gasification. Based on the general strategy of ASEAN, UNDP, and the Vietnam Energy Institute have laid forth three scenarios for green hydrogen development in Vietnam, based on renewable energy supply for electrolysis (Tue Anh, 2023).

## 6. CHAPTER 6: CONCLUSION

This chapter will describe the study's principal results and consequences. In doing so, we shall quickly summarize the findings in light of our sub-research topics. We will also emphasize the limits of this work and offer topics for additional research in the arena of emissions assessment and abatement from shipping.

### 6.1. Summary and Key Findings

The research findings strongly support the theoretical model and all hypotheses. The findings show that resource constraint factors have a beneficial effect on applicability and environmental factors. The primary goal of this research is to (1) clearly identify resource constraint factors dimensions from the perspective of Vietnamese shipowners, (2) explain how resource constraint factors contribute to the fuel selection process, and (3) uncover the underlying mechanism of economics, logistics, and fuel selection. According to the findings, the link between the resource constraint factors and the fuel selection process is mediated by the applicability and environmental factors.

Sub-Research Questions 1 and 2 are answered using industrial sources and a published paper on the decision-making process for selecting green alternative fuels, which are classified as resource constraint factors such as economics, scalability, availability, and environmental factors. Each is separated into ten tiny variables. Specifically, (1) economic factors include energy and capital costs; (2) scalability factors include fuel availability and local production capacity; (3) applicability factors include energy density, technological maturity, flammability and toxicity, government regulations; and (4) environmental factors include GHG emissions, local SO<sub>x</sub> and NO<sub>x</sub> emissions. This study is separated into five types: LNG, LPG, hydrogen, ammonia, and methanol.

Sub-Research Question 3 is addressed using our CFA analysis. Resource constraint factors have dimensions such as economics factors including energy costs, capital costs and scalability factors including fuel availability, and local manufacturing capability. Capital costs had the biggest influence on resource constraint variables, whereas energy costs had the least impact. This contrasts with prior research where energy costs ranked higher. Two factors were discovered to explain this disparity. First, small-scale vessels accepted the trade-off between energy costs and sustainability advantages, which in turn delivered the long-term benefit. Second, Vietnamese shipowners have limited authority to haggle energy costs; they tend to accept the price as it is.

Sub-Research Questions 4 and 5 were answered using hypothesis testing and SEM analysis, and the study also investigated the underlying mechanism between resource constraint factors and the green fuel selection process, considering the mediating factors of applicability and the environment. The study found that resource constraint considerations had a direct and indirect favorable influence on fuel choices. The indirect relationship between mediating factor and fuel selection was stronger than the one between resource constraint factors and fuel selection. This contrasts with earlier studies, which implied a strong direct association between resource constraint factors such as economics factors and fuel selection. The study found that environmental factors indeed have the strongest impact on the fuel selection process. Several rationales have been found to explain this disparity. First, firms are becoming more conscious of the significance of environmental factors than they were many years ago. Second, as the strict requirement of IMO for a net zero emission target, regardless of economics or scalability factors, shipowners have to prioritize the GHG emissions or local emissions of their fleet.

Sub-research Question 6 is a recommendation drawn from the relationship between the factors, in which points out that resource constraint factors have less impact than the mediating factors like applicability and environmental factors. Hence, this study suggests the fuel that performs well following this impact order combined with the average score on the performance given by survey respondents. It makes an important conclusion that hydrogen is the most promising green fuel for Vietnamese shipowners. Hydrogen can be the fuel with zero emissions if it is made from renewable resources. Furthermore, the projected energy shift to land-based renewable power generation in the Vietnam National Energy Development plant is well-suited to future hydrogen manufacturing capability. Besides, given the current expense of fuel cells and tanks, as well as the low density of hydrogen, it appears that the use of hydrogen in transportation is restricted to short-haul routes, which is the majority of routes that Vietnamese shipowners are targeting, making it a potential green marine fuel regarding context of small shipowners.

## **6.2. Limitations of Study**

Although all the hypotheses were validated, it is crucial to note the study's limitations, which provide opportunity for future research. To begin, the sample employed in this study comprises Vietnamese shipowners who are not geographically restricted and operate with a variety of vessel types, which may limit the research's specificity. Besides, factors that may temper these connections, such as the years of experience and decision-making level of the assessed stakeholders have not been looked at. Given that various shipowner groups may have varied

concerns and attitudes regarding resource constraint considerations, it is critical to explore how these factors impact the fuel selection process. As a result, the limited elements that are examined for connections during the decision-making process may limit the explanatory capacity of the model.

Furthermore, it became clear that there are many gaps in the available data while evaluating the various alternative fuels using the specified parameters. This relates primarily to ammonia or methanol. Therefore, it is conceivable that some of these uncertainties represent solutions that are still developing, that paves ways for R&D research and piloting programs.

### **6.3. Future Research**

To strengthen the specificity of the research, future researchers could include other players in the green fuel industry, such as energy providers or transportation intermediates, in order to compare various groups and widen the scope. Future studies can also use firm size and decision-making capacity as moderating factors to investigate their influence in the overall model. Since most of the vessels examined in the research are small and belong to small-scale shipowners, further study is required to expand our investigation of the link between resource constraint issues and the use of green marine fuel for the context of larger size firms, taking into account these new moderating variables such as market power or years of experience.

Furthermore, duplicating the study with certain types of vessels will yield more complete and specific data. This would give more insights into the more particular characteristics that are specialized for one type of vessel. Finally, based on this research, there are opportunities for deep-diving into the weight of each specific criteria such as energy cost, capital costs separately instead of considering big groups like resource constraint factors to yield more accurate results. Opportunities for research using software like MAMCA is beneficial in ranking and determining weights for each small factor and the performance of each fuel provided since this research has already tested and proven the reliability of each selected factor in the decision-making process. This would contribute to the overall picture of green marine fuel in Vietnam context and assist shipowners in selecting the suitable green fuel to aim for a sustainable maritime future.

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