Chatarina Petra Salim

Socio-technical Analysis of Green Methanol in the Shipping Industry

Socio-technical Analysis of Green Methanol in the Shipping Industry

By

Chatarina Petra Salim
5706602

Master thesis submitted to Delft University of Technology

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in **Management of Technology**

Faculty of Technology, Policy and Management

to be defended publicly on Tuesday, 9 July 2024.

Graduation Committee

Chairperson	: Dr. J.A. (Jan Anne) Annema,	Transport & Logistics (TLO), TU Delft
First Supervisor	: Dr. J.A. (Jan Anne) Annema,	Transport & Logistics (TLO), TU Delft
Second Supervisor	: Dr. L.M. (Linda) Kamp,	Energy & Industry (E&I), TU Delft
Company Supervisor	: ir. J.M. (Jurrit) Bergsma,	Sustainable Transport and Logistics, TNO
Project Duration	: January 2024 – July 2024	

Faculty of Technology, Policy and Management, TU Delft

In a research collaboration with TNO

Executive Summary

Climate change has been an urgent global issue. Maritime transport contributes to approximately 80% of worldwide trade carried out by sea, contributing up to 3% of global CO_2 emissions. Therefore, the shipping industry needs to move towards renewable energy technology, one of which is to switch to sustainable fuel. Green methanol is one of the alternative options that has been considered for the cleaner energy transition because it is readily available, has the potential to reduce significant emissions, and has a high energy density compared to other sustainable fuels. However, the research on the viability of the fuel applications is still limited. Therefore, the following research question was formulated: “To what extent is green methanol a viable option for the shipping industry?”

A structured literature review was conducted to discover the literature relevant to the research and gain an understanding of methanol transition. The insights gained from the literature review were used as the basis of this study, to formulate the interview and survey questions as well as to confirm the relevancy of the framework that will be used in this study. The study incorporates the concept of Clean Energy Technology Investment Attractiveness Scan (CETIAS) by Donker et al. (2020) to analyse the investment attractiveness from political, economic, technological, social and environmental aspects. CETIAS is chosen because it can bring a broader scope with systematic steps in evaluating the investment attractiveness of methanol with certain criteria from different aspects. Moreover, the study incorporates the concept of a list of uncertainties in the maritime fuel transition by Hajonides (2023) to analyse the investment barriers of the green methanol transition. This list of uncertainties is used because it can support analysing the most important uncertainties for certain shipping stakeholders and how the stakeholders’ engagement can help reduce the uncertainties. Both qualitative and quantitative methods are used in this study, involving semi-structured interviews with eleven shipping stakeholders and a survey with thirty-nine respondents. The qualitative data from the interviews were coded and analysed using content analysis, which aimed to discover the viability of methanol transition based on the feasibility evaluation of the PESTE aspects. The quantitative data from the survey were interpreted statistically using descriptive and correlations statistics and chi-square analysis, which aimed to discover the stakeholders’ methanol investment status and the uncertainties of methanol transition.

The results indicate that methanol is politically, socially, technologically, and environmentally feasible, and partially economically feasible. Politically, methanol aligns with the government’s net zero ambitions and is supported by various policy instruments. Socially, society has positive societal acceptance towards methanol as a cleaner fuel than fossil fuels, due to environmental benefits. Technologically, methanol enables the possibility to use existing shipping infrastructure and convert existing vessel engines to be applicable with methanol with certain modifications. Although various risks might occur during the methanol transition, it is argued that the technical risks are low compared to other fuels like ammonia, hydrogen, and LNG. Environmentally, methanol can significantly reduce emissions, and it is produced from sustainable feedstock.

Methanol is partially economically feasible because it is currently not beneficial to invest in methanol. However, it might be profitable in the long term if certain regulations are in place that limit the use of fossil fuels. The investment consideration by the shipping stakeholders is mainly for better emissions. More investment decisions are being considered for methanol, but the companies must ensure that they are confident enough to invest in methanol because it requires a big cost. Furthermore, significant opportunities arise from methanol’s superior technological performance. Compared to the other types of fuels, such as ammonia, hydrogen, and LNG, methanol is preferred by six out of eleven shipping stakeholders interviewed because methanol is easier to adopt, handle, integrate, and store, with less pollution, less space, and less toxicity. Therefore, the main competition for feasibility is with the established energy carriers, such as HFO, MGO, and LNG.

Currently, the shipping stakeholders overall are on a moderate level of investment (mean = 3.23 out of 5), with most of them in the middle stage, which relates to the feasibility assessment, and the others are mostly in the final stage of positive investment decision to methanol. Their investment decisions are mostly driven by the desire for sustainability and fulfilling customers' demands. Furthermore, it is discovered that various perspectives exist in prioritising the uncertainties of the methanol transition. While the uncertainty regarding the availability of subsidy for methanol investment is the least important for the shipowners and the shipyards, this uncertainty is highly important for the fuel suppliers. The available subsidies are mainly to produce methanol, making them highly important for the fuel suppliers to produce methanol and sell it at a more affordable price. However, the subsidies are not relevant for the shipowners that have allocated funding for the ship’s construction for long-term utilisation, and for the shipyards that cannot build their companies that depend on subsidies and their decision is based on the request of their customers.

From this study, a value network map is developed that represents the stakeholders’ relationships regarding the financial flow in the context of methanol. The map illustrates how the uncertainties for certain stakeholders can be reduced with the help of other stakeholders, promoting positive investment decisions. The value network map offers the viability evaluation of methanol from the stakeholders' side, of which powerful stakeholders support methanol. This map offers a thorough framework that will help stakeholders make well-informed decisions towards the methanol transition. The framework suggests seven control measures that specific stakeholders can take in facing a specific uncertainty. One of the recommendations is to create a contractual agreement between the shipowners and the fuel suppliers, to reduce the shipowners’ uncertainty of methanol availability and the fuel suppliers’ uncertainty of willingness to pay. The agreement is in the form of an indexed price agreement with flexibility clauses that can adjust the prices according to the specific fuel purchased, enabling the price to remain competitive in the market.

Overall, the study concludes that green methanol is a viable option for the shipping industry, based on the feasibility assessment of political, economic, social, technological, and environmental aspects; it has a favourable performance for advancements; it is supported by powerful actors; and it is deemed feasible based on the barriers assessed. The study recommends specific control measures and collaborative efforts among the main shipping stakeholders to mitigate the uncertainties for methanol transition. The shipping stakeholders are encouraged to advance green methanol as a sustainable fuel.

Keywords: green methanol, shipping, viability, socio-technical, investment attractiveness

Table of Contents

List of Figures

List of Tables

1. Introduction

The first chapter introduces the background of the study, the research questions that are aimed to be answered by the study, the relevance of the study to the Management of Technology, and the structure of the report.

1.1. Background

Climate change is an urgent global issue, which can have some negative impacts, including the rising frequency of catastrophic weather events, rising temperatures and sea levels, declining crop yields, and the disappearing of biodiversity. To address this environmental challenge, the United Nations Framework Convention on Climate Change (UNFCCC) formed the Paris Agreement. Two of the ambitious goals of the Paris Agreement are to maintain the efforts to prevent global warming increase to 1.5 degrees Celsius over pre-industrial levels by the end of this century and to keep the rise in the average global temperature well below 2 degrees Celsius (UNFCCC, 2016).

Maritime transport is vital to the global economy since approximately 80% of worldwide trade is carried out by sea, substantially impacting economic growth (European Community Shipowners' Associations, 2017). On the other hand, maritime activities account for up to 3% of global emissions. Climate change was caused by enormous amounts of greenhouse gas emissions, with the energy sector contributing about 34% of net global GHG emissions, making it the largest contributor in 2019 (Intergovernmental Panel on Climate Change, 2023). Moreover, 2.89% of all human emissions worldwide in 2018 came from shipping, which generated nearly a billion tons of greenhouse gas emissions (International Maritime Organization, 2021).

Given the high emissions created by maritime activities, the shipping industry must migrate from fossil fuel-powered transportation to renewable energy technology in order to facilitate the shift to clean energy (IRENA, 2021). Nonetheless, there is an economic barrier to the initial transition to renewable energy technology. On the other hand, the Connecting Europe Facility (CEF), the EU's funding instrument for boosting energy infrastructure, has set aside a budget of 8.7 billion euros to assist energy-related investments in EU infrastructure networks for the years 2021-2027 (European Commission, 2018). In the Netherlands, the Dutch government allocated 249 million euros for the Energy Investment Allowance in 2023, allowing businesses that make sustainable energy investments to pay less taxes (Netherlands Enterprise Agency, 2023). This significant budget allocation shows that the EU and the Netherlands are highly interested in fostering sustainable energy development.

In line with reducing emissions, studies by Harmsen (2021) and Gerritse and Harmsen (2023) highlighted the investigation of green methanol as a clean energy technology. Because it is widely available, can lower emissions, and has a relatively high energy density when compared to other alternatives, green methanol is considered one of the alternative energy carriers for maritime shipping in the short to medium term. However, not much is known about the feasibility of using green methanol in various shipping industries. This topic will be discussed further in the literature review chapter (see Section 2.5.), where the viability of green methanol, along with its opportunities and barriers, are discussed comprehensively.

Building on this approach, a study focuses on understanding the investment opportunities and attractiveness of clean energy technologies, namely the Clean Energy Technology Investment Attractiveness Scan (CETIAS). This tool provides an organised approach for assessing the investment attractiveness regarding policy, economic, social, technological, and environmental aspects (Donker et al., 2020). Compared to other frameworks, as discussed further in the literature review chapter (see Section 2.2.), CETIAS is chosen because it has more comprehensive criteria and systematic steps that can be used to evaluate the investment attractiveness of a specific clean energy technology. Additionally, a study by Hajonides (2023) proposes a list of uncertainties that related stakeholders will face in the maritime fuel transition. In this context, CETIAS and uncertainties list can support understanding the attractiveness level and investment decisions in the shipping industry for the green methanol transition. By using both frameworks, this study aims to provide a detailed evaluation of green methanol's viability that considers the political, economic, social, technological, and environmental aspects, as well as the specific uncertainties faced by the specific shipping stakeholders.

This study will focus on the socio-technical analysis of the transition to the utilisation of a specific clean energy technology, in this case, green methanol, in the shipping industry. The transition to a cleaner energy source is required to mitigate climate change and the increasing emissions from the shipping industry. However, little is known regarding the feasibility of the energy transition to green methanol related to its attractiveness level (Harmsen, 2021).

Therefore, the main objective of the research is to evaluate the viability of green methanol for the energy transition in the shipping industry. This objective also aims to discover the socio-technical opportunities and barriers affecting the viability of the methanol transition. Furthermore, this finding will assess the methanol's feasibility using Clean Energy Technology Investment Attractiveness Scan (CETIAS) criteria and assess the barriers to methanol. The CETIAS criteria consist of policy and political, economic and financial, social, technological, and environmental. These criteria aim to evaluate the attractiveness from various dimensions. This approach offers a comprehensive understanding of the potential role of green methanol in the transition to cleaner energy in the shipping industry.

1.2. Research Questions

The following research question was formulated.

To what extent is green methanol a viable option for the shipping industry?

Some sub-research questions are defined as follows.

- What are the potential socio-technical barriers affecting the viability of the transition to methanol?
- What does the value network of the shipping industry look like in terms of the financial flow for applying methanol?
- What are the potential socio-technical opportunities affecting the viability of the transition to methanol?

1.3. Management of Technology Relevance

This research topic aims to investigate the extent of the viability of green methanol, including the opportunities and the barriers, as well as the insights on investment decisions in methanol as a marine fuel in the entire supply chain. This topic aligns with the goal of the master thesis project of the Management of Technology (MoT) program.

The research focuses on assessing the barriers affecting potential investment in methanol as a cleaner energy technology. As this research will give valuable insights regarding the viability of methanol transition in the shipping industry based on the socio-technical analysis, it provides an understanding of how businesses can use methanol as a low-emission fuel in the shipping industry. Furthermore, this research incorporates the methodology and framework in which the knowledge has been gained during the study in the MoT program. It provides the analysis based on the MoT perspectives.

1.4. Thesis Structure

The structure of the thesis is as follows. The first chapter introduces the background of the research, including the formulated research questions and the relevancy to the Management of Technology program. The second chapter encompasses the results of the literature study that has become the basis of the research, which aims to provide an understanding of the framework used in the research and address the research gap. The third chapter consists of the methodology used in the research, including the population and sample, the research design, data collection methods, and the data analysis procedures of both qualitative and quantitative research design.

The fourth chapter discusses the findings of the study, which comprises the qualitative research obtained from the interview, and the quantitative research obtained from the survey. This chapter will explain how the related stakeholders view the methanol transition in the shipping industry. In the fifth chapter, the findings will be analysed further and connected to the previous studies and frameworks that can serve as a conceptual base for the research. Based on the interpreted findings, recommendations for practical improvement will be discussed. Lastly, the conclusion will be drawn based on the analyses of the findings by addressing the research questions.

2. Literature Review

This chapter discusses the literature study process, the findings from the literature study, and the research's conceptualisation. The literature study aims to analyse the steps to evaluate the viability of green methanol. Firstly, the literature study starts with defining shipping, the framework that will be the basis of the study, and the definition of viability. Furthermore, the study explores the literature regarding the viability of green methanol in the shipping industry and further investigates the barriers to the methanol transition. The literature study also defines the type of vessels to which the methanol is applicable. The literature review seeks to study the literature that can be the basis of the research in researching the extent to which green methanol is a viable option in the shipping industry, as well as the barriers and opportunities that are affecting the viability of methanol transition. In searching the literature, the PRISMA guidelines from Moher et al. (2009) were used. Some keywords were used to emerge all relevant literature from Google Scholar, such as "green methanol", "shipping", and "viability". Then, the literature was screened, and the relevant ones to the research were selected. Lastly, the conceptualisation and the research gap of the study were discussed.

2.1. Shipping Industry

Maritime transportation accommodates most commodities traded globally. According to the data from the United Nations Conference on Trade and Development, the volume of international maritime trade reached 12 million tons, with the majority of the delivered tonnage going to dry bulk carriers (31.4%), oil tankers (26.5%) and containerships (18.4%), in 2022 (UNCTAD, 2023). The growth of international trade has led to the large-scale movements of goods, which has driven the ongoing development of logistics networks to satisfy the demands of supply chains (Danyluk, 2019). This growth is mostly attributable to maritime logistics, which, compared to land and air transportation, can offer considerable benefits to the development of international trade and economic growth due to its cheaper transportation costs and higher cargo capacity (Park et al., 2019). As a result, the volume of cargo traffic increased, and the ports expanded.

Increased energy use and emissions from port operations and logistical activities have an impact on the environment, especially when it comes to the production of carbon dioxide (CO2), which is a greenhouse gas (GHG) that has far-reaching effects on the ecosystem (Zhang et al., 2023). Shipping accounted for about 3% of global CO2 emissions in 2018, and if mitigation measures are not implemented, emissions are expected to increase dramatically (Deng & Mi, 2023). In response to these challenges, the International Maritime Organization limited the sulphur cap to a maximum of 0.5% starting in 2020 and set an ambitious goal of having net zero GHG emissions from international shipping by 2050 (IMO, 2023). Table 1 shows the shipping terms defined by various sources, obtained from several literature studies.

Table 1. Shipping Definition

Shipping Definition	Source
Shipping is an affordable method for the transportation of goods. It ships goods internationally, facilitates trade, and contributes to the wealth of nations and people, enabling the most efficient and economical shipping of most items internationally.	International Maritime Organization (2023)

Shipping Definition	Source
Shipping is an essential element of the world economy, facilitating the handling of at least 80% of world goods and several tens of millions of passengers.	European Community Shipowners' Associations (2017)
Shipping is the backbone of global trade, facilitating the flow of commodities across international borders, impacting global supply chains, and emphasising the relationship between port operations, shipping, freight rates, and worldwide economic trends.	United Nations Conference on Trade and Development (2023)
Shipping is a part of the maritime industry designated as a critical sector that must reduce emissions by 45% by 2030 compared to 2010 levels, to bring the world fleet's fossil fuel usage down to around 6 EJ by 2030 and achieve net zero emissions by 2050.	Zero Carbon Shipping (2022)

Based on the definition defined by the literature, shipping can be defined as the operation and management of vessels used for the international transportation of goods, people, and commodities via waterways, which is a pivotal element to the global economy by facilitating over 80% of international trade and connecting markets, industries, and countries. Figure 1 shows the stakeholders in the shipping industry and their basic relationships, as defined by TNO (2024). The shipping stakeholders consist of the shipowners, shipyards, fuel producers and suppliers, fuel storage and transfer, original equipment manufacturers and suppliers, logistic service providers, classification societies, end customers, port authorities, financial institutions, knowledge institutions, regulatory bodies, trade associations, consultancy companies, national government, NGOs, and the societies.

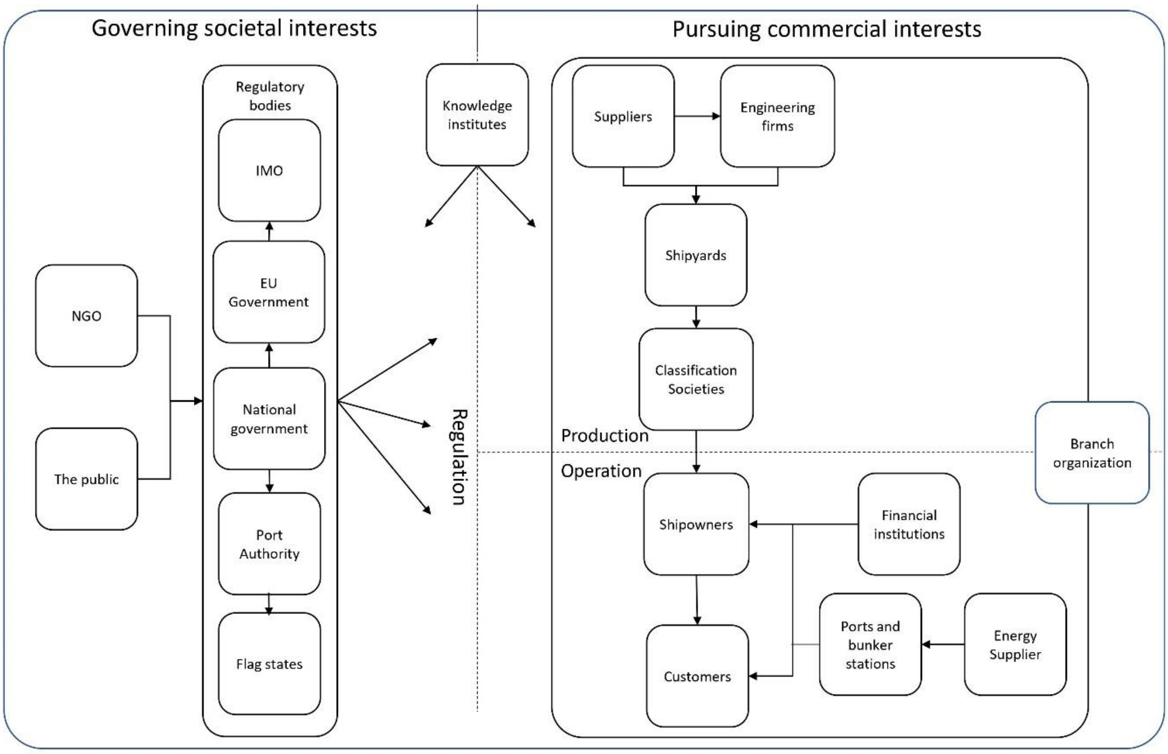

Figure 1. Shipping Stakeholders and Their Basic Relationships (TNO, 2024)

2.2. Evaluating Investment Attractiveness of a Clean Energy Technology

To address the increasing environmental concerns, systemic changes in energy and transportation are necessary, which are frequently referred to as socio-technical transitions. A socio-technical regime refers to the interaction between the social and technical factors which create the condition for successful system performance, in which a part of the interaction consists of cause-and-effect relationships (Walker et al., 2008). A study by Geels (2012) suggests a framework as a perspective for understanding low-carbon transitions in transport studies. The framework believes that transitions are the result of the interaction of three analytical levels of multidimensional development: technological niches, socio-technical regimes, and socio-technical landscape. With the numerous experiments and demonstration initiatives, several "green" niches have emerged. Innovations in certain niches can gain momentum if more actors and resources support them. For example, a niche can move towards the regime with the increasing investment decision towards a specific innovation.

In supporting the investment decision consideration of a clean energy technology, several tools are proposed by different researchers. The tools discussed in this section consist of the Clean Energy Technology Investment Attractiveness Scan (CETIAS) by Donker et al. (2020), the Green Energy Sustainable Investment Index (GESII) by Hussain et al. (2023), and the Renewable Energy Sustainability Index by Cirstea et al. (2018).

Research by Donker et al. (2020) presents a tool for evaluating the investment attractiveness of clean energy technologies, namely the Clean Energy Technology Investment Attractiveness Scan (CETIAS). Built upon the PESTE framework, CETIAS provides the investment attractiveness criteria, which consists of various aspects, including policy and political, economic and financial feasibility, social implications, technological feasibility, and environmental impact. Similarly, a study by Hussain et al. (2023) proposes the Green Energy Sustainable Investment Index (GESII) as a tool for guiding investment decisions for green energy. GESII provides sustainable investment criteria with regard to economic, environmental, social, and institutional dimensions. Another research conducted by Cirstea et al. (2018) suggests the Renewable Energy Sustainability Index that facilitates the evaluation of the advantages and disadvantages of a specific renewable energy. By highlighting the economic, social, institutional and environmental aspects of renewable energy investments, the index can provide a framework for assessing such decisions.

Compared to the two other tools, CETIAS can offer a wider scope since it incorporates non-technical characteristics adapted from PESTE to evaluate investment attractiveness. This makes it appropriate for analysing the socio-technical transition of that particular clean energy technology. Each aspect defined by CETIAS is assigned multiple criteria, each with at least an indicator, enabling a structured assessment. Furthermore, the CETIAS tool can be synthesised with a multi-level perspective framework to analyse the socio-technical transition of sustainable energy by assessing specific clean energy using its multidimensional assessment approach.

By using CETIAS, it is expected to understand the reasoning behind green methanol as a viable alternative fuel in the shipping industry and gather crucial information for determining whether further steps should be taken to integrate the fuel into the shipping industry's operations. Recognising the limitations of existing research related to the viability of green methanol transition, as stated by Harmsen (2021), CETIAS can offer new perspectives regarding the methanol's viability, including technological difficulties, investment attractiveness, market preparedness, environmental and societal acceptability of green methanol, which are vital for its adoption in green shipping.

Furthermore, the criteria provided by CETIAS to evaluate a clean energy technology are built upon thorough assessment through literature study and various readiness level frameworks, which consider different assessment dimensions in developing the steps to evaluate a technology with CETIAS. It can assess whether the current condition and the existing resources can support a clean energy technology transition. Moreover, the clean energy investment attractiveness from CETIAS enables the researchers to address the interaction of stakeholders affecting investment decisions to the potential investors. Therefore, the framework built by CETIAS is suitable for this research because it can guide in assessing how the interaction between stakeholders leads to deciding a technology investment. Both resources and actors' assessment will support the evaluation of whether a "green" niche can gain momentum and advance towards the regime. The framework proposed by Geels (2012) highlights the way how to see the systems. In this case, the methanol, as will be discussed in section 2.5., can be seen as a green niche that is being investigated, the extent and how this green niche can move towards the regime. However, evaluating the viability of making the methanol move towards the regime requires the investment attractiveness evaluation from CETIAS, which proposes the guidelines in supporting the investment decision considerations of the related stakeholders.

Built upon the CETIAS framework, TNO researchers developed a tool to weigh a score for every PESTE theme of clean energy technology (Halstead et al., 2021). In the form of Microsoft Excel, the tool provides the steps that can be taken to investigate to what extent a specific clean energy technology performs in every PESTE theme and as a whole assessment. Each criterion can be indicated by how the specific clean energy technology performs, from poor or not at all, to strong or very mature. The score will then be calculated automatically for each aspect. For the overall assessment results, weight can be given to each theme, based on assessing how important each theme is for the technology. The assessment can give an understanding of the extent of a specific clean energy technology's viability in every aspect.

2.3. Viability of a Clean Energy Transition

The Clean Energy Technology Investment Attractiveness Scan (CETIAS) framework defines that a clean energy technology can be stated as a viable option for the transition if clean energy is feasible based on the policy and political, economic and financial, social, technological, and environmental assessments (Donker et al., 2020). The term feasibility refers to the degree to which a clean energy technology can be successfully applied in the current circumstances under the given conditions. It is primarily related to whether a technology can be used within the existing constraints to achieve its intended purpose. The definition of the term viability is discussed in this section with reference to some literature. Several aspects need to be fulfilled in terms of feasibility evaluation to conclude the extent of the viability of a specific clean energy technology. In renewable energy, investment attractiveness can also be considered as viability. Based on the definition explained by Donker et al. (2020), each aspect's feasibility was defined in Table 2. Every aspect has a list of criteria that act as the parameters to assess whether a specific clean energy technology is feasible based on a certain aspect.

Table 2. Definition of each CETIAS Aspect (Donker et al., 2020)

Aspect	Definition	Criteria
Policy and Political	The influence of the political system connected to the investment decision, such as the political events that can affect the investments value.	• Technology Alignment with National Government Targets • Policy Design, Instruments and Uncertainty • Market Design, Regulation and Legislation
Economic and Financial	The aspect that impacts the business case for the typical use of technology under consideration, in relation to the economic aspect of the investment.	• Profitability • Payback Period • Operation & Maintenance • Market Uncertainty • Investment Size • Strategic Opportunity • Ability to Obtain Financing • Investor Risk Appetite • Exit Strategy
Social	The characteristics within the community that can affect the investment attractiveness, such as the attitudes, opinions, and interests of the community.	• Societal Acceptance • Job Impact • Social Impact
Technological	The development of the technology's functionality and its surrounding standards directly impact the economic results.	• Technology Maturity • Construction Risk • Operational Risk • Technical Know-how • Technical Excellence • Critical Infrastructure
Environmental	The characteristics that have shown a positive impact on an economy's capacity to mitigate climate change and adaptation.	• EU Taxonomy Status[1] • Water Use • Material Use • Land Use • Environmental Incidents

1 – Taxonomy is a tool to assist in organising and documenting the transition to an economy that is in line with the environmental goals of the EU (EC, 2020).

Furthermore, studies by Geels (2007) define the socio-technical transition pathways based on the timing of interactions. The studies proposed some proxies as credible indicators for stabilising commercially successful specialised inventions that are prepared to become more generally accepted. The proxies consist of (a) learning procedures in a dominant design have stabilised; (b) strong actors have joined the network of support; (c) there have been gains in pricing and performance, and there are high expectations for more advancements; and (d) the innovation is applied to market niches with a combined market share of greater than 5%. If the following indicators are fulfilled, the innovations can be considered viable for stabilisation.

Moreover, Bergsma and van Son (2022) define viability as the ability to overcome barriers that restrict the new technologies driving the energy transition from being implemented and scaled up, when implementing zero-emission solutions into practice for different types of transportation. Viability is defined from multiple lenses, focusing on economics, knowledge, standards and regulations, interaction between stakeholders, directionality, technology, and infrastructure. Based on the studies, clean technology can be considered viable depending on the transition barriers that need to be overcome.

Based on the studies from various literature, it can be concluded that a clean energy technology can be considered viable if it is feasible based on the assessments from different aspects, including political, economic, social, technological, and environmental; it is supported by powerful actors and has a favourable performance for advancements; and it is deemed feasible based on the barriers assessed.

2.4. Defining Uncertainties vs. Barriers and Drivers in Relation to Investment Decisions

In making an investment decision to transition towards clean maritime fuel, shipping stakeholders often face certain uncertainties. A study conducted by Hajonides (2023) proposed a list of uncertainties usually found in a maritime fuel transition, along with the stakeholders that faced the uncertainties. In Hajonides's (2023) framework, each uncertainty with the related actor is differentiated according to whether the actor can reduce the uncertainty themselves or whether they need other actors to help. For instance, international and national shipping companies face uncertainty regarding ship or engine technology availability in the maritime fuel transition, and they need other actors to help reduce the uncertainty. It can be seen that for the same uncertainty, shipyards and engine manufacturers can reduce this uncertainty themselves, thus will be able to support the other actors that face the same uncertainty but need others to help reduce it.

The definition of the terms used in this study is as follows. The researcher defines the terms with references from Geels (2012) and Hajonides (2023). Uncertainty is a stakeholder-specific situation that affects an investment decision towards implementation positively or negatively. It involves unknown outcomes and probability, making it difficult to predict. Uncertain events may have a large or small impact, or their effects may even be known. While its probability, is difficult or impossible to be determined. For example, the availability of fuel is an uncertainty that impacts the shipping stakeholders' decision to invest in a specific fuel. If the fuel availability is limited, then it might impact the investment decision negatively. However, if the fuel availability might be increased in the future, the stakeholders might consider investing in the specific fuel.

Conversely, a barrier is a structural challenge in the regime, hindering the transition. Barriers are always negative and obstruct progress, such as the limited infrastructure for new fuel types that obstruct the transition to the specific fuel because the infrastructure is not supporting it. Lastly, a driver is a factor that can support a niche to move towards the transition to a regime with the increasing investment decision in a specific innovation. While uncertainty can be either a barrier or a driver, a barrier or a driver cannot be an uncertainty.

These terms are used in this study to identify the barriers that limit the investment decision to a cleaner energy transition and the drivers that support the transition. The barriers identified will then be linked to uncertainties to investigate whether a specific challenge can be supported by other stakeholders who perceive uncertainties differently, thus positively affecting the investment decision of a specific stakeholder. For example, a shipping stakeholder, the shipowners, are experiencing the barrier of fuel availability. This barrier might negatively affect the shipowners' decision to invest in a fuel transition. Equal to the fuel availability barrier, the barrier is then linked to the uncertainty of fuel availability. The limited fuel availability, which is a barrier, is linked to the uncertainty of fuel availability because limited fuel makes the availability of fuel uncertain. The other stakeholder that faces the same uncertainty and has a relationship with the shipowners is then identified. In this case, the fuel suppliers also face uncertainty regarding methanol availability. However, the importance of perceived uncertainty between the shipowners and the fuel suppliers differs. While the uncertainty of fuel availability for the shipowners is highly important, it is not true for fuel suppliers. Fuel suppliers can help reduce the uncertainty of fuel availability for shipowners by developing an agreement to supply several amounts of fuel at a specified time. Therefore, the uncertainty of fuel availability for both the shipowners and fuel suppliers can be reduced, which positively affects the investment decision to a cleaner fuel transition.

Everything can be an uncertainty, but the likelihood of the uncertainty cannot be quantified. The knowledge regarding the probabilities of uncertainty can be considered problematic because its occurrence is unknown (Stirling, 2010). The uncertainties discussed by Hajonides (2023) consist of 16 uncertainties in the maritime fuel transition, including the availability of feedstock for fuel production; availability of the fuel; purchase fuel price; infrastructure development; availability of ship or engine technology; price of ship and engine technology; fuel production technology; governmental stimulation; regulations on fuel production and distribution; regulations on the emission of fuels; ship and engine certification; certification of alternative marine energy carriers; knowledge or capacity of regulators and inspectors; market demand for low-emission maritime services; overall pace and direction of the maritime energy transition; and lack of qualified personnel. For a specific technology investment, it can be seen whether the uncertainty is stopping investment decisions. If the uncertainty is stopping or hampering the investment decisions to cleaner energy technology, then it can be called the barriers that need to be overcome.

Mitigation strategies will be required for the uncertainties that hamper the investment decisions. To make these uncertainties into acceptable level for the stakeholders in considering investment decisions, one of the steps that can be done is to create a value network map, which can illustrate the interactions of the stakeholders, the value that they exchange, the uncertainties between them, and how it can be reduced through the stakeholders’ engagement (Hajonides, 2023). Therefore, the value network map is a framework that can be created as the recommendation in facing the uncertainties of a clean energy technology transition.

Incorporating Hajonides’ list of uncertainties tool can support understanding the willingness of the specific stakeholders to invest in a specific energy transition. Further studies by Hellemans and Hajonides (2023) explore the uncertainties of Dutch hydrogen infrastructure and incorporate the CETIAS tool to assess investment attractiveness through the PESTE lens. Incorporating the CETIAS tool, complemented by the list of uncertainties, can map out a value network to see the stakeholder interactions and interdependencies. Therefore, in addition to the CETIAS tool, this list of uncertainties can be incorporated into the research as a starting point to better understand the potential aspects affecting the investment decision consideration for a clean energy transition. Measuring the willingness of various stakeholders to invest in an energy transition and assessing the implications of PESTE aspects will consequently give an understanding of the extent to which a transition to a specific clean energy is viable in the shipping industry.

2.5. Methanol

In an effort to address decarbonisation in the maritime industry, many alternative marine fuels that are less harmful to the environment compared to traditional heavy fuel oil are being introduced. Research indicates that the shipping industry can potentially reduce its carbon footprint by utilising renewable marine fuels. Some of the greener alternative maritime energy sources include liquefied natural gas (LNG), methanol, liquefied biogas (LBG), hydrogen, ammonia, ethanol, hydrotreated vegetable oil (HVO), nuclear power, wind, solar, and electric power (Harahap et al., 2023; Sheng et al., 2024).

Among these alternatives, studies, such as those by Harmsen (2021), have demonstrated that using methanol from a green source, either bio or synthetic, can be a practical and effective means of reducing emissions from the shipping industry. Its availability and compatibility with existing shipping infrastructure make this fuel a favourable choice for energy deployment. Furthermore, even though the density of methanol is substantially lower than that of diesel when on board storage is considered, it is higher than other fuels such as LNG, hydrogen, and ammonia. This comparison gives methanol a favourable energy density, giving many shipping companies a more accessible option. Additionally, employing green methanol is compliant with the policy on using alternative marine fuels for sustainability. However, the transition to green methanol faces some challenges, such as the initial expenses associated with the shift, the adjustment of supply infrastructure for methanol, and the acceptance in the widespread industries.

There are three different types of methanol, as defined by Harmsen (2021): biomethanol, synthetic methanol, and grey methanol. Biomethanol is made from biomass feedstock, which includes agricultural and forestry products. This biomass can then be fermented to produce biogas or gasified to produce syngas in the anaerobic digestion process. Synthetic methanol can be made from hydrogen and green electricity. Hydrogen is produced by hydrolysis, and carbon dioxide can be captured from industrial exhaust gases, biomass, or direct air capture. The combination of hydrogen and carbon dioxide can produce syngas or react to form methanol. Lastly, grey methanol is produced from fossil fuels by gasifying coal or reforming natural gas, to produce synthetic gas. Sustainable methanol consists of bio and synthetic. However, since synthetic methanol is not readily available in the market, this research focuses predominantly on biomethanol.

The literature study aims to analyse the steps to evaluate the investment attractiveness of green methanol by applying the criteria defined in section 2.3. (see Table 2), being evaluated from different aspects, such as political, economic, social, technological, and environmental. Moreover, the study analyses the viability of methanol based on its opportunities and barriers and maps the barriers mentioned in the literature. In addition, the barriers are also overlayed with the list of uncertainties in the maritime fuel transition from Hajonides (2023) as a basis for further analysis towards investment decisions in the value network (refer to section 2.4.).

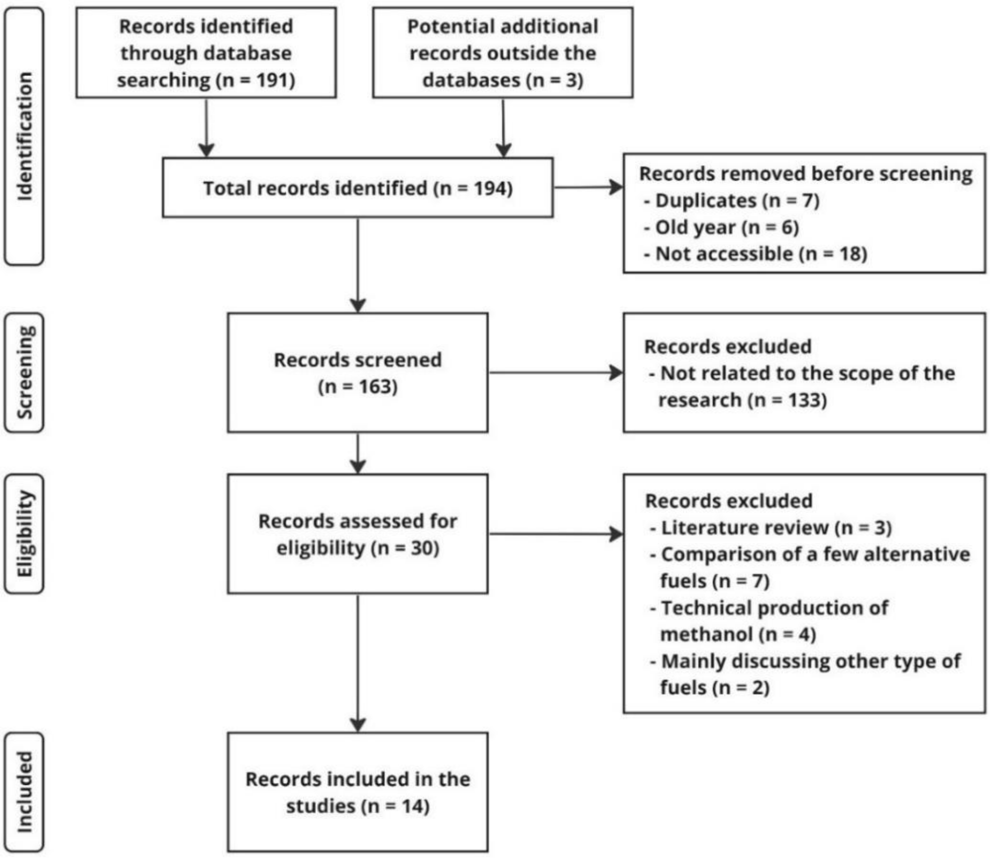

Figure 2. Literature Study Process Flowchart

Using the PRISMA guidelines, the literature study process was conducted (Moher et al., 2009). The study starts by searching the relevant literature on Google Scholar using the keywords "green methanol", "shipping", and "viability". In the identification stage, 191 pieces of literature were identified from the keywords search, and 3 potential pieces of literature were added outside the databases. Before the screening, several records were then removed due to the duplicates, old records that were more than five years old, and not accessible records because they had been retracted, access was not available anymore, or the records had to be purchased. The records removal resulted in 163 works of literature that will be screened. The records were screened by reading the title, abstract, keywords, and conclusion of the literature, resulting in 30 pieces left to be assessed for eligibility. Despite the literature discussing methanol, 16 records were excluded for various reasons, such as a literature review record, the technical production side of methanol, mainly discussing other types of fuels instead of methanol, and a comparison of a few alternative fuels from the technical production side. In summary, 14 records were included in the studies. Figure 2 shows the flowchart of the literature study process.

The following tables show the results of the literature study. The list of literature studied, the information received regarding what the literature discusses and which type of literature it is can be seen in Appendix A (Table 17). The classification of the studies in Table 3 shows the distinction of the type of methanol discussed in the literature, whether it is about biomethanol, e-methanol, or both; the viability discusses, including the barriers and opportunities; and which aspects of investment attractiveness that are discussed, consisting of (P) political, (Ec) economic, (S) social, (T) technological, and (En) environmental.

From Table 3, insights can be obtained regarding which literature discusses biomethanol, the barriers to green methanol transition, and the aspects affecting investment attractiveness. Out of 14 works of literature, 10 discuss the barriers. The barriers affecting the green methanol transition discussed in the literature were identified further, as shown in Appendix A (Table 18). Most of the literature covers barriers, therefore the aspects that are analysed in this literature study are the barriers towards methanol transition, not the drivers and the uncertainties. The translation towards uncertainties occurs in further analysis of the value chain network if relevant or based upon additional sources. It can be concluded that technology is the aspect that every literature discussed regarding the investment attractiveness of green methanol. While economic and environmental aspects are also discussed in most of the literature studied, the social aspect is the least aspect that is discussed, only 1 literature source (Shi et al., 2023) discusses a bit about it, therefore indicating that the social aspect might not be applicable in affecting the investment attractiveness of green methanol.

Furthermore, the barriers identified were mapped into the 16 uncertainties in the maritime fuel transition by Hajonides (2023), shown in Table 4. The uncertainties correspond to (1) availability of feedstock for green methanol production; (2) availability of green methanol as a marine fuel; (3) the purchase price of green methanol; (4) development of methanol infrastructure; (5) availability of ship and power train technology; (6) price of ship and engine technology; (7) green methanol production technology; (8) (lack of) government subsidies and/or other incentives; (9) rules and regulations on fuel production and distribution; (10) rules and regulations on (reduction of) maritime emissions of greenhouse gases and pollutants; (11) certification of ships and engines; (12) certification of alternative marine energy carriers (such as methanol); (13) knowledge or capacity of regulators and inspectors; (14) market demand for low-emission shipping, fuels and services; (15) overall pace and direction of the maritime energy transition; and (16) lack of qualified personnel. Table 6 shows that almost all of the uncertainties in the maritime fuel transition provided by Hajonides can be confirmed as relevant. This confirmation is because the barriers to methanol transition found in the literature affect the uncertainties towards investment decisions in the value network. What represents a barrier for one stakeholder can be a driver for other stakeholders. However, the list of uncertainties must be overcome as a consideration for the investment decision. Of the 16 uncertainties, only the lack of qualified personnel barrier was not identified in the literature studies. The most identified barrier was the knowledge or capacity of regulators and inspectors barrier, with 6 out of 10 literature discussed about it. The second most discussed barrier was the overall pace and direction of the maritime energy transition, with 5 out of 10 literature discussing the barrier. Lastly, the third most discussed barriers, with 4 out of 10 literature discussed, were the barriers of the availability of feedstock for green methanol production, the purchase price of green methanol, and the price of ship and engine technology.

Table 3. Identification of Methanol Types, Viability, and Investment Attractiveness

Author(s)	**Green Methanol**			**Viability**			**Investment Attractiveness**				
	Bio-methanol	E-methanol	Unspecified	Barriers	Opportunities	Unspecified	P	Ec	S	T	En
Anika et al. (2022)			x	x	x		x			x	x
Antwerpen et al. (2023)		x				x	x	x		x	x
Bertagna et al. (2023)			x		x			x		x	
De Fournas and Wei (2022)	x	x		x				x		x	x
Harmsen et al. (2020)	x	x		x	x		x	x		x	x
Harmsen (2021)	x	x		x	x		x	x		x	x
Harris et al. (2021)	x	x		x	x		x	x		x	x
Morrison et al. (2024)			x			x		x		x	x
Reddy et al. (2023)	x	x		x	x		x	x		x	x
Shi et al. (2023)	x	x		x	x		x	x	x	x	x
Svanberg et al. (2018)	x			x	x		x	x		x	x
Tabibian and Sharifzadeh (2023)	x	x		x	x		x	x		x	x
Sheng et al. (2024)	x					x	x	x		x	x
Zero Carbon Shipping (2022)	x	x		x	x		x	x		x	x

P = Political; Ec = Economical; S = Social; T = Technological; En = Environmental

Table 4. Barriers of Methanol Transition Mapped into Hajonides' (2023) List of Uncertainties

Author(s)	Uncertainties in Maritime Fuel Transition															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Anika et al. (2022)					x	x									x	
De Fournas and Wei (2022)			x			x			x							
Harmsen et al. (2020)						x		x			x		x			
Harmsen (2021)		x									x		x		x	
Harris et al. (2021)	x		x													
Reddy et al. (2023)	x			x		x	x						x			
Shi et al. (2023)													x		x	
Svanberg et al. (2018)	x	x	x	x						x	x			x		
Tabibian and Sharifzadeh (2023)			x									x	x		x	
Zero Carbon Shipping (2022)	x	x		x						x		x	x		x	

1 = Availability of feedstock for green methanol production; 2 = Availability of green methanol as a marine fuel; 3 = Purchase price of green methanol; 4 = Development of methanol infrastructure; 5 = Availability of ship and power train technology; 6 = Price of ship and engine technology; 7 = Green methanol production technology; 8 = (Lack of) Government subsidies and/or other incentives; 9 = Rules and regulations on fuel production and distribution; 10 = Rules and regulations on (reduction of) maritime emissions of greenhouse gases and pollutants; 11 = Certification of ships and engines; 12 = Certification of alternative marine energy carriers (such as methanol); 13 = Knowledge or capacity of regulators and inspectors; 14 = Market demand for low-emission shipping, fuels and services; 15 = Overall pace and direction of the maritime energy transition; and 16 = Lack of qualified personnel.

2.6. Applicable Vessels

A previous study by Van Lieshout et al. (2020) shows that the majority of the midrange shipping markets appear to be applicable to sailing on methanol, based on data analysis of Rotterdam and Amsterdam ports' vessel arrival data. Methanol also appears to be a promising option for inland shipping, while larger tanks are being constructed for ultra-large container ships.

Developing the methanol-powered vessels involves choosing between the options of newbuild or retrofit. Most newbuild vessels are interested in methanol because major marine engine manufacturers provide methanol-powered engines, enabling shipyards to build ships powered by methanol and market the newly built methanol vessels. The newly built vessels consist of tankers, container ships, work vessels, pilot boats and ferries (Gerritse and Harmsen, 2023).

On the other hand, retrofitting is another option for developing methanol-powered ships. Retrofit is converting existing engines to run on methanol, which involves modifying the ship engine, fuel supply lines, pumps and storage tanks. If an engine conversion kit is available for the ship's engine, it is possible to retrofit existing ships (Gerritse and Harmsen, 2023). However, it is often not economically feasible for existing vessels. Because green methanol is quite expensive compared to the conventional fuel of marine gasoil, there is currently little demand for retrofit packages for methanol engines. Furthermore, conversions to methanol are not always possible because methanol requires larger fuel tanks, and the installation of methanol infrastructure for the ship's conversion might put more strain on a ship's hull (Harmsen, 2021).

Over the last five years, the Green Maritime Methanol project has attracted interest from many engine manufacturers. It is a significant step for most of them to begin producing larger quantities of methanol engines or retrofit packages towards methanol engines (Harmsen, 2021). To get insights regarding which type of vessels, both newbuilds and retrofits, are applicable to methanol, three pieces of literature were studied.

Table 5 shows which type of vessel methanol looks applicable for the transition. The table shows the current situation of the methanol applicability for each type of vessel discussed, the points of attention, and whether the methanol is applicable for that type of vessel. From the table, most of the vessels are applicable to methanol; some of them are already designed to apply methanol, and some look promising but need further analyses related to applicability. Based on the study, safety, engine, and space appear to be the most important points of attention for the methanol applicability in assessing whether the vessels are applicable to the methanol.

Table 5. Analysis of Vessels Applicable to Methanol

Type of Vessels	Newbuild or Retrofit	Current Situation	Point of Attention	Applicable to Methanol?	Author (s)	Literature
Short Sea Shipping Container Vessel	Retrofit	The design complies with methanol.	Further analyses on safety items, regulations, operational aspects and environmental footprint are needed.	Yes	Harmsen (2021)	Green Maritime Methanol 1.0 Report
Dredging Vessel	Retrofit	Bunker capacity in relation to sufficient autonomy is a big challenge.	An increase in cost will further affect the decision.	No		
Cable Laying Vessel	Retrofit	Methanol combined with MGO is a suitable option.	Concept design needs to be made.	Yes		
Hydrographic Survey Vessel	Retrofit	Methanol is a suitable option.	Overall cost price is slightly higher than a regular diesel system.	Yes		
Port Patrol Vessel	Retrofit	Not feasible yet.	The existing vessel has little room for extra bunker capacity.	No		
Inland Patrol Vessel	Retrofit	Methanol engines are still in the experimental stage.	Further discussion with stakeholders is needed.	No		

Type of Vessels	Newbuild or Retrofit	Current Situation	Point of Attention	Applicable to Methanol?	Author (s)	Literature
Container Ships	Newbuild	Maersk prefers to use renewable methanol due to its speed, optionality, and cost.	The ship has dual-fuel engines.	Yes	Gerritse and Harmsen (2023)	Green Maritime Methanol 3.0 Report
Jack-up Vessel	Newbuild	Van Oord views renewable methanol as the most promising way of reducing GHG emissions.	The ship is powered by methanol.	Yes		
Methanol-fuelled Tankers	Newbuild	Methanol is easy to manage and inexpensive to handle and transport.	Methanol runs well in existing engine technology.	Yes		
Construction Service Operating Vessels	Newbuild	The ships have dual-fuel engines capable of running on methanol and diesel blends.	The supply of renewable methanol for Acta's vessels still has to be arranged and is currently not available in the market.	Yes		
Crew Tender	Newbuild	Methanol (and gaseous hydrogen) are seen as the most promising alternative energy carriers.	A standardised engine is not yet available for methanol. However, pilot vessels are already sailing around.	No	Nusselder (2024)	Applicability of energy carriers for different ship types
Offshore Service Vessel	Newbuild	Methanol seems to be the best option for long periods at sea.	Space utilisation.	Yes		
Port-based Tugs and Work Boats	Newbuild	Battery electric is the preferred option.	A standardised engine is not yet available for methanol. However, pilot vessels are already sailing around.	No		
Dredgers Maintenance Coast & Harbour	Newbuild	Methanol (and LNG) are seen as the most promising applications.	Space utilisation.	Yes		

Type of Vessels	Newbuild or Retrofit	Current Situation	Point of Attention	Applicable to Methanol?	Author (s)	Literature
Big Dredgers & Seagoing	Newbuild	Methanol (and LNG) are seen as the most promising applications.	Space utilisation.	Yes		
Coastal Shipping	Newbuild	Methanol (and LNG) are seen as the most promising applications.	Space utilisation.	Yes		
General Global Cargo	Newbuild	Methanol (and LNG) are seen as the most promising applications.	Space taken is at the expense of cargo space/operational profile.	Yes		
Superyacht	Newbuild	Methanol is seen as the most promising application.	Point of attention: space utilisation and inaccessible hazardous areas.	Yes		

2.7. Research Gap

The need to shift to a more sustainable practice has arisen due to concerns about climate change, especially in the maritime transportation sector, which considerably contributes to global emissions and is essential to the support of the global economy. Methanol has been acknowledged as an alternative fuel for reducing emissions in the shipping industry. However, the challenges lie in understanding the shipping industry's willingness to invest in and adopt methanol as a cleaner energy source.

Based on the literature, CETIAS is chosen because it offers criteria that will be applied to a specific energy technology, making it a suitable method for determining investment attractiveness (Donker et al., 2020). Furthermore, comparable studies such as GESII and RES index offer some tools to assess the investment criteria of sustainable energies. Additionally, the list of uncertainties can be incorporated with CETIAS to support the investment decisions of a specific maritime fuel transition (Hajonides, 2023). It is also argued that methanol is suggested to be a workable and efficient way to lower emissions from the shipping industry (Harmsen, 2021). Despite the crucial need for the shipping industry to make a shift to sustainable energy resources to combat climate change and policy compliance, a gap remains in understanding how the different CETIAS criteria impact the feasibility evaluation of the methanol transition in the shipping sector, as well as the importance of the perceived uncertainties in methanol transition for the shipping stakeholders. CETIAS tool can bring a more thorough and organised criteria assessment compared to other tools. Furthermore, Hajonides' list of uncertainties can guide in understanding the uncertainties in the methanol transition and prioritise which uncertainties have the most impact when considering the investment in methanol per stakeholder. By incorporating the CETIAS and Hajonides' list of uncertainties framework in the methanol transition context, this research seeks to bridge the knowledge gap between the CETIAS and Hajonides' list of uncertainties tool application to support investment decisions and methanol utilisation. The analyses from both frameworks will enable the study to assess how uncertainties affect the main criteria for the viability of methanol in shipping and how to reduce the uncertainties to enable faster methanol transition.

2.8. Conceptualisation

The increase in global maritime trade raises emissions and energy usage, escalating fossil fuel-based maritime transport and contributing to climate change. In response, because of its favourable energy density and fewer emissions while adhering to environmental standards, methanol can be considered an alternative clean energy source. The CETIAS tool will be utilised to assess the attractiveness of investments from multiple aspects. Based on CETIAS criteria, the industry is more likely to invest in methanol if it is seen to be economically and technologically feasible, has adequate regulatory support, and reduces environmental impacts. With the support of the list of uncertainties from Hajonides (2023), the uncertainties affecting the investment decision to methanol can be identified and prioritised.

This research will analyse the socio-technical methanol transition in sustainable shipping by applying the CETIAS criteria and Hajonides' list of uncertainties in supporting the energy transition. This study examines five aspects to determine the attractiveness of methanol and defines the uncertainties, as shown in the figure below, to identify how it might influence the transition. By evaluating whether methanol will remain relevant in the shipping sector over the long run, the attractiveness and uncertainties evaluation of methanol can provide insights into the viability of methanol as a transitional solution. Furthermore, the engagement between the shipping stakeholders can help each other reduce the uncertainties faced in considering the methanol transition. Therefore, the stakeholders' support contributes to the viability assessment of methanol. Additionally, the transition supports can drive the methanol transition, including the methanol opportunities, superiority compared to other types of fuels, stakeholders' activities related to methanol transition, and the viability approximation time. The expected results will be in the form of assessing green methanol's viability and potential technological development, a value network map regarding shipping stakeholder relationships, and the prioritisation of the uncertainties affecting methanol investment decisions.

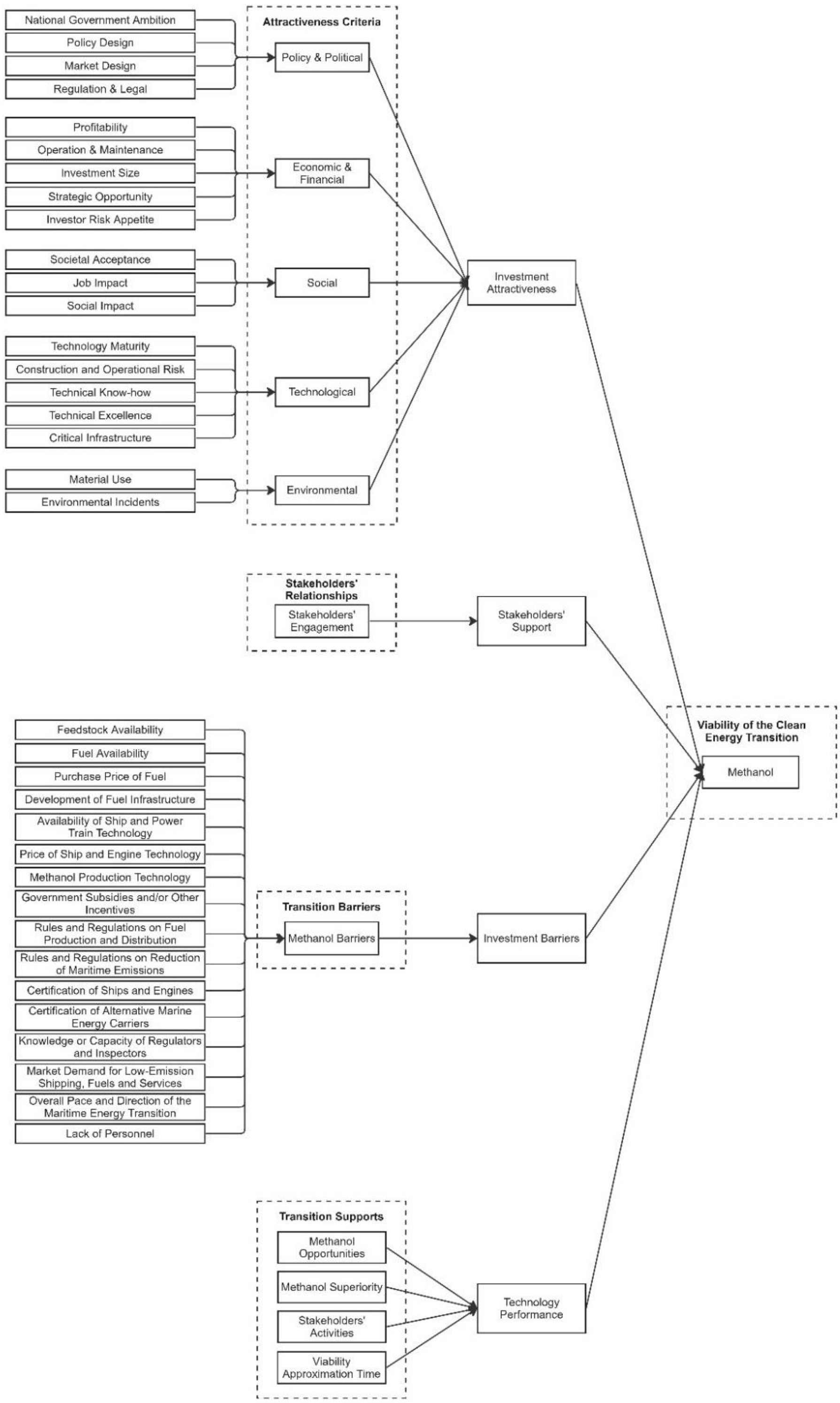

Figure 3. Conceptual Framework of the Study

3. Methodology

The study incorporates both qualitative and quantitative research design through semi-structured interviews and a survey. The third chapter discusses the methodology used in this study, including the methods, data collection flow, and data analysis steps.

3.1. Research Methods and Research Flow

An exploratory study is used to answer the main research question of “To what extent is green methanol a viable option for the shipping industry?”. The choice of exploratory study is because the topic of evaluating the viability of green methanol has not been thoroughly examined before. Therefore, it is used to seek new insights regarding what is currently happening in the industry.

In this study, a combination of qualitative and quantitative research designs were incorporated. Qualitative research enables the researcher to study the attractiveness of methanol in their natural settings. These are relevant when analysing the Clean Energy Technology Investment Attractiveness Scan (CETIAS) criteria, which evaluates criteria that assess non-measurable variables, including policy implications, economic and social feasibility, technological feasibility, and environmental benefits. The data for the qualitative study were collected through semi-structured interviews with several stakeholders from the shipping industry, to gain their perspectives on the actual situation and experiences.

Quantitative research enables the researcher to observe the situations based on numerical data analysis in a larger sample size. These are relevant to understanding the importance of perceived uncertainties related to the methanol transition for the stakeholders in the shipping industry. For the quantitative study, the data were collected through a survey distributed within the Green Maritime Methanol Consortium, to discover insights regarding the uncertainties affecting methanol's viability.

The flow of answering the sub-research questions is explained below.

- What are the potential socio-technical barriers affecting the viability of the transition to methanol?
  It has been observed that the maritime fuel transition will face some barriers that may impact its viability. This sub-question aims to understand the barriers faced by the methanol transition and how important the perceived barriers are for the relevant stakeholders. The study will identify and thoroughly assess the barriers associated with methanol transition. Many barriers might be faced in the methanol transition and hinder the process speed, including the price of methanol, availability of feedstock and fuel, knowledge of regulators and inspectors, and the training challenge. Furthermore, the research will investigate how different stakeholders perceive these barriers. By exploring the barriers, the study seeks to provide valuable insights into which barriers are the most important for each type of stakeholder.
- What does the value network of the shipping industry look like in terms of the financial flow of methanol?
  In their activities in the shipping industry, some shipping stakeholders closely relate to other stakeholders. The interactions between stakeholders might support the investment decisions for the transition to a clean energy technology. Therefore, this sub-question aims to develop a value network map that shows the relationships between shipping stakeholders in terms of the financial flow of methanol. The goal is to establish a shared understanding among stakeholders regarding the values that can

be exchanged and the appropriate investment decisions that can be made. Therefore, the solutions that might be the most urgent to address for specific stakeholders can be assessed, in reducing the uncertainties to methanol transition.

- What are the potential socio-technical opportunities affecting the viability of the transition to methanol?
  In assessing the viability, it is important to discover the opportunities that drive the transition to green methanol. This sub-question aims to understand the advantages of methanol and why methanol is preferred compared to the other alternatives.

3.2. Data Collection

3.2.1. Population

This study's primary unit of analysis was the individual companies in the shipping industry, which involves entities making decisions for the transition to methanol. The research aims to explore the extent of the green methanol viability in the shipping industry. Therefore, the population comprises all companies in the shipping industry in the Netherlands that are potentially considering utilising methanol. The stakeholders in the shipping industry can be divided into the commercial part and the supporting part. The commercial part consists of shipowners and charterers or users of methanol as a marine fuel, shipyards, original equipment manufacturers and suppliers, fuel producers, fuel suppliers or bunker parties, fuel storage and transfer, shippers or cargo owners or logistic service providers, end customers, port authorities, financiers or investment companies, trade associations, and consultancy companies. The supporting stakeholders are the Dutch government, certification and classification, research and development, and NGOs.

3.2.2. Sample

The sampling frame was derived from the databases of shipping companies in the Netherlands, which can be retrieved from the database of the 3rd TNO Green Maritime Methanol consortium. For both qualitative and quantitative research, a judgment sampling approach was applied as the sampling strategy to ensure detailed knowledge from experts. The data was collected from the shipping industry stakeholders, mainly shipowners, shipyards, energy carrier providers, and original equipment manufacturers and suppliers. This selection is based on the experience relevancy and the stakeholders that have an important influence on the methanol. Each company has assigned specialists who were asked to be the interviewees and respondents. The sample of companies was selected based on the researcher's judgment regarding who are thought to be most useful for this study. This strategy was chosen to obtain an in-depth understanding of specific information from experts in the shipping industry.

After the sampling approach had been conducted, eleven participants agreed to participate as the interviewees in sharing their experiences and insights regarding the methanol transition. The interviewees were classified according to their type of stakeholders. The number of interviewees was considered sufficient when no new relevant data to the research topic would be obtained if further interviews were conducted.

Table 6 shows the interviewee list categorised according to their type of stakeholder. The interviewees consisted of shipowner, shipyard, fuel supplier, original equipment manufacturer and supplier, and classification society. These stakeholders were chosen because they are the main shipping stakeholders in close relation to the methanol transition. Therefore, it is believed that these stakeholders will have insights and knowledge regarding methanol transition. The shipowner is the organisation that owns ships to assist in their activities. The shipyard is the organisation that designs and builds the ships (Organisation for Economic Co-operation and Development, 2022). The fuel supplier is the organisation that provides and distributes fuel for shipping. The original equipment manufacturer and supplier is the organisation that manufactures the equipment for the ships, including the engines (Okumus et al., 2023). The classification society is the organisation that reviews the ship designs and ensures that the designs are safe for the people on board and the environment in supporting the ships' designs to meet the standard technical rules (Anyanova, 2008). The government entity is the governmental organisation that is doing research and pilot projects related to sustainable shipping and its green fuel options, to support the policy development, implementation, and inspection in the maritime sector (Brooks et al., 2022). Lastly, the Non-Governmental Organisation (NGO) is an organisation that plays a role in environmental conservation and management, ensuring that shipping activities are paying attention to a sustainable environment (Calado et al., 2012).

Table 6. Interviewee List

Interviewee Code	Type of Stakeholder
A1	Shipowner
A2	Shipowner
A3	Shipowner
B1	Shipyard
B2	Shipyard
C1	Fuel supplier
D1	Original equipment manufacturer and supplier
E1	Classification society
E2	Classification society
F1	Government entity
G1	Non-Governmental Organisation (NGO)

Furthermore, thirty-nine respondents participated in sharing their views regarding their investment consideration and the importance of uncertainties in affecting the investment attractiveness to methanol. The number of respondents was considered satisfied if it reached the amount determined at the beginning of the study as a sufficient amount that can provide reliable results.

3.2.3. Research Design

The first method used to gather qualitative data was interviewing stakeholders of the shipping industry to obtain their insights. It is necessary to check the extent of the viability of methanol transition from different aspects and perspectives. Therefore, the interviews aimed at identifying the opportunities and barriers associated with methanol usage and the feasibility of methanol to be implemented in the current shipping industry were discussed from various aspects, including political, economic, social, technological, and environmental factors. This approach is vital for understanding which barriers most significantly impact the viability of methanol transition. In addition to the literature study, the implications for the industry's shift towards methanol can be assessed by understanding different stakeholders' specific challenges and opportunities. These insights were gathered through semi-structured interviews, which were used to enable flexibility and adaptability with the questions in accordance with the expertise and topic being discussed with the interviewees. The interview questions were divided into two parts. The first part consists of the main questions that were asked to the interviewees regarding the activities related to methanol within their organisation, along with the opportunities and barriers for methanol transition. The interview uses the terms barriers and opportunities because the interview aims to seek which aspects either hinder or promote the methanol transition. With these insights regarding the barriers and opportunities, it can be assessed the extent of the methanol's viability. Additionally, the interview questioned the most important partners for the interviewees, regarding methanol application. The second part consists of specific questions regarding the economic viability, policy implications, technological feasibility, social factors, and environmental impact of methanol adoption, which were developed according to each CETIAS criteria to align with the framework. Multiple questions from the second part were asked, depending on the topics discussed with the interviewees. The interview output was essential in highlighting the potential socio-technical barriers and opportunities affecting the viability of the methanol transition. Moreover, the output was important in understanding the viability of applying methanol discusses from several aspects, such as political, economic, technological, social, and environmental feasibility.

Furthermore, the quantitative data was collected through a structured survey that was created to collect numerical data from the shipping industry stakeholders and was distributed electronically. The survey consists of two main parts. The first is the "investment" part, which contains questions about the stakeholder's willingness to invest in green methanol as a marine fuel. The second part is the "uncertainties" part, which questions the uncertainties related to the development of green methanol and how important these uncertainties are to the respondents as stakeholders in the shipping industry. Additionally, similar to the interview, the survey also questioned regarding the stakeholders who are in the most direct contact with the respondents. The survey used the term uncertainties, not barriers, because what represents as a barrier for one stakeholder can be a driver for another, as clarified in section 2.4. The uncertainties can potentially influence the stakeholder decision-making regarding the uptake of green methanol positively or negatively. Therefore, the survey aimed to investigate how important the uncertainties are perceived by the shipping stakeholders, to prioritise the uncertainties that have the most impact when considering an investment in the use or production of sustainable methanol, and to see whether the uncertainties can be reduced with the support from the stakeholders' relationships.

Table 7 shows the uncertainties to methanol transition, which importance was being asked in the survey. These uncertainties were formulated from the incorporation of the list of uncertainties in the maritime fuel transition by Hajonides (2023) and the CETIAS framework by Donker et al. (2020). Based on the incorporation of the tools, the list of uncertainties that were believed to be the relevant ones for the methanol transition in the current shipping industry were selected and determined. Additionally, the uncertainties were refined through an iterative process based on the stakeholders' feedback from the survey testing and the condition of the methanol transition, to ensure that the uncertainties were relevant to the stakeholders involved in the shipping industry. Based on that, the second part of the survey questioned 20 uncertainties related to the uptake of green methanol, which was designed to capture stakeholder perceptions across four categories: Science and Technology, Policy and Regulation, Social and Environmental, Economic and Financial. These categories were classified according to the five aspects in the CETIAS framework, which evaluates the investment attractiveness through the PESTE perspectives, including political, economic, social, technological, and environmental. However, in the survey, the social and environmental aspects are combined because social acceptance is often influenced by the environmental benefits offered by cleaner technologies. By combining both aspects, the survey addressed the interconnectedness of these aspects, demonstrating environmental sustainability initiatives often receive positive support from the society if they offer a positive impact on the community and its surrounding environment.

The respondents were then asked to indicate how important the perceived uncertainties were for them or their organisation. Since some of the uncertainties only affect a few stakeholders and the other uncertainties are highly relevant for some, but not all stakeholders, the survey is essential for understanding the relationship between perceived uncertainties and the viability of methanol, highlighting that certain uncertainties may significantly impact specific stakeholders in affecting their potential investment in methanol and the relationship between stakeholders. Moreover, the survey revealed the importance of the perceived uncertainties, distinguishing between those generally acknowledged as uncertainties and others thought to be less critical. The goal is to prioritise which uncertainties have the most impact when considering sustainable methanol utilisation. Therefore, the survey questions the respondents about the stakeholders with whom they are most directly in contact and scales the importance of the perceived uncertainties. The table below shows the uncertainties affecting the methanol investment decision, which importance level is being asked in the survey.

Table 7. Uncertainties to Methanol Transition Formulated for the Survey

Category	Uncertainty
Science and Technology	Technical readiness to the use of required technology in your intended operational environment (TRL) (e.g., ships for shipping companies and/or production facilities for energy producers)
	Chance that other energy carriers (e.g., ammonia, biodiesel) will prove to be a better investment
	Availability of feedstock for production of low-emission methanol
	Availability of sufficient amounts of sustainable methanol for maritime use, when considering sustainable methanol demand from other sectors
	Level of infrastructure (distribution, storage) readiness at ports for your intended use of methanol
Policy and Regulation	Compliance of methanol with national, EU, and global climate goals (e.g. IMO greenhouse gas reduction targets)
	Long-term stability of the regulation and government policy support concerning sustainable fuels
	Availability and/or applicability of clear safety regulation for production and storage of methanol
	Availability and/or applicability of clear safety regulation for bunkering and use of methanol as a marine fuel
	Rate and/or clarity of technology certification for the use of technologies related to methanol (e.g., type approval engine)
	Capacity and ability to enforce emission and methanol-related regulation
	Level playing field between the EU and the rest of the world
Social and Environmental	Social acceptance of methanol as an alternative energy carrier by the wider public
	Ability to attract and/or train qualified staff necessary for the

Category	Uncertainty
	production or use of methanol
	Uncertainty of actual emission reduction from the use of methanol as a marine fuel
Economic and Financial	Uncertainty or lack of return on investment
	Impact of capital intensity in comparison to alternatives (both fossil and non-fossil)
	Impact of operational expenses in comparison to alternative energy carriers (both fossil and non-fossil)
	Availability and quantity of subsidies towards sustainability applicable to methanol
	Lack of, or uncertain, customer willingness to pay more for sustainable transport using "sustainable" methanol

From the findings regarding the uncertainties to methanol transition, discovering the stakeholders' relationships are important to see how their engagements can help each other to reduce the uncertainties. Both the interview and survey questions about which stakeholders are in most direct contact with the participants, to confirm whether the findings from both sources are relevant. In response to the findings, the value network map was created, which shows how the uncertainties can be reduced through the stakeholders' relationship. The value network map was important to give recommendations regarding the actions that can be taken for certain stakeholders, to reduce the uncertainties and support their investment decisions to methanol.

This research incorporates both interviews and a survey to provide a comprehensive understanding of the viability of methanol transition in the shipping industry. The interviews aim to gain in-depth insights into stakeholders' experiences and perspectives regarding the methanol transition. The interviews will provide a rich understanding of the methanol's feasibility from various perspectives with detailed qualitative data on the stakeholders' experiences. In complementary to the interviews, a survey aims to gather numerical data on stakeholders' opinions to gain a detailed understanding of methanol investment considerations. The survey will provide quantitative data that reveals the trends in stakeholders' opinions and the statistical assessment of the uncertainties influencing methanol transition. Both data collection methods aim for a robust evaluation by incorporating the strengths of both qualitative and quantitative research designs. With this approach, stronger conclusions regarding methanol's viability can be concluded, and an enhanced understanding can be gained regarding the stakeholders' willingness to invest in methanol. As a result, a comprehensive value network map that illustrates the stakeholders' relationships and how their engagement can reduce the uncertainties to foster the methanol transition can be created. These mixed methods ensure that both interviews and a survey complement each other, providing a holistic view of the methanol transition in the shipping industry.

Additionally, aside from the combination of qualitative and quantitative data analysis, there are existing studies that TNO has conducted that can be used for the data analysis. Some of the studies that TNO has conducted were being incorporated as a framework in this study, consisting of the Clean Energy Technology Investment Attractiveness Scan by Donker et al. (2020), a list of uncertainties of the maritime fuel transition by Hajonides (2023), and green methanol overview by Harmsen (2021).

There are two types of sustainable methanol: biomethanol and synthetic methanol. Biomethanol and synthetic methanol have some differences in their feedstock, production process, and costs. However, synthetic methanol is currently not readily available in the shipping market, while biomethanol is already available. Furthermore, biomethanol is a more affordable sustainable methanol option. Therefore, the discussion in this study considered biomethanol. A few group sessions with experts to review this consideration were conducted to clarify the research findings.

3.2.4. Data Collection Flow

The data collection steps are explained systematically in this section, to enable further validation and replication of the research. The interview and survey questions were formulated separately, each with their own goals for the expected outcomes. The data collection flow consists of three phases. The first phase is to review the problem by assessing the barriers to methanol transition. The second phase is to structure the problem by assessing the uncertainties to methanol transition. Lastly, the third phase is to solve the problem by recommending mitigation actions.

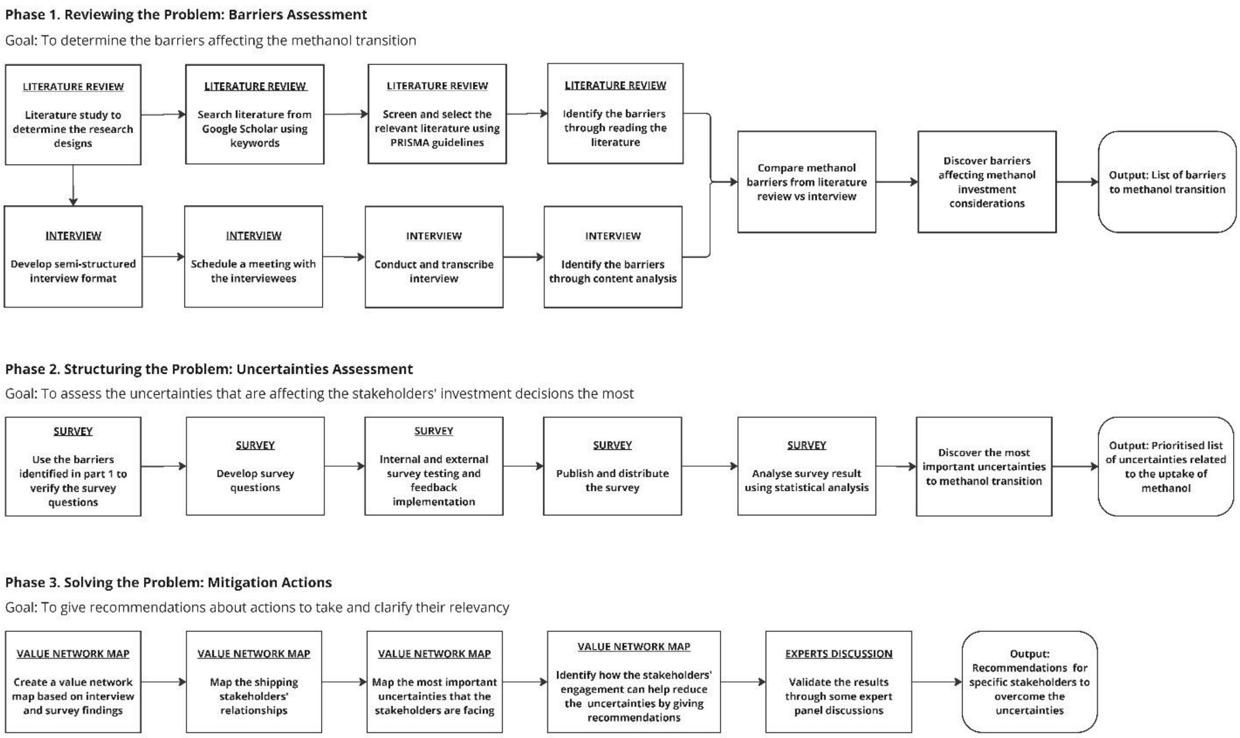

Figure 4. Data Collection Flow

The lists below are the data collection steps in this study.

- Prepare the documents required for the Human Resource Ethics Committee (HREC) application, including the HREC Checklist Form, Informed Consent Form, and Data Management Plan.
- The steps in the first phase are as follows.
    - o The required information for the research designs was determined and gathered through the literature review, which will be the basis for developing the interview and survey questions.
    - o The literature review process continues as follows.
        - ▪ The list of literatures were searched from Google Scholar, using the keywords of “green methanol”, “shipping”, and “viability”.

        - Using PRISMA guidelines, the literature were screened. The relevant literature were selected.
        - The barriers to methanol transition from the literature review were identified.
    - The literature review was used as a basis to formulate the interviews. The interview steps are as follows.
        - The interview questions were developed with reference from the literature review output regarding assessing a specific clean energy technology using the PESTE aspects, the identification of barriers to methanol, and the feasibility assessments.
        - After the HREC application was approved, the invitations were sent to the candidates of interviewees.
        - If the candidates agreed, the interview was scheduled. Before the interview started, the consent form and the list of interview questions were sent to the interviewees.
        - The interview was conducted by asking the interviewees the prepared questions, including the barriers to methanol transition.
        - The original transcription was gathered.
        - The interview results were analysed using Atlas.ti and Microsoft Excel software to connect the interviewees' related responses.
        - The barriers to methanol transition were identified from the interviews.
        - Furthermore, the interview output is in the form of a PESTE feasibility assessment, the barriers and drivers for methanol transition, the methanol transition requirements, the viability approximation time, and the shipping stakeholders' relationships.
    - The findings regarding the barriers from both literature review and interviews were compared to analyse its similarities and differences.
    - The barriers affecting methanol investment considerations were discovered.
    - The output is the list of barriers to methanol transition.
- The steps in the second phase are as follows.
    - The survey questions were developed, with reference from the literature review output regarding the identification of methanol barriers, incorporation of uncertainties to maritime fuel transition to evaluate the importance of uncertainties for certain stakeholders, and the viability assessments. The results from the first phase regarding the barriers to methanol transition, verified the formulation of the survey questions.
    - The initial findings of the interview were used to verify the survey questions, and whether the questions were relevant to answer the research questions.
    - The survey draft was sent to three internal researchers at TNO. The feedback was collected and implemented in the survey draft.
    - The updated survey draft was sent to four external stakeholders within the Green Maritime Methanol Consortium. A meeting was conducted with the external parties to collect the feedback. The feedback was implemented, and the second updated survey draft was produced.
    - After the HREC application was approved, the survey was published and sent to the candidates of respondents.
    - The survey responses were gathered.

    - The survey results were analysed using RStudio software to gather insights regarding the relationships between the uncertainties and the stakeholders related to the methanol transition in the shipping industry.
    - The survey output is in the form of the rank of the methanol uncertainties' importance for specific stakeholders, the stakeholders' relationships regarding which stakeholders are in most direct contact in relation with methanol, the investment status of the shipping stakeholders, and the difference in the importance uncertainties between the shipping stakeholders.
    - Moreover, the most important uncertainties to methanol transition was discovered.
    - The output from the second phase is the prioritised list of uncertainties related to the uptake of methanol.
- The steps in third phase are as follows.
    - The value network map was developed, which maps the relationships between the shipping stakeholders, and the uncertainties between them in regard to methanol.
    - The stakeholders' relationships were first mapped, then the most important uncertainties for certain stakeholders were drawn.
    - From the relationships and the uncertainties drawn in the value network map, the control measures can be identified to be recommended for the stakeholders to reduce the uncertainties with the help of others. These control measures act as the mitigation actions to reduce the uncertainties from the stakeholders.
    - The recommendations were validated through some expert panel discussions with a shipowner, a shipyard, and a fuel supplier.
    - The output from the third phase is the recommendations for specific stakeholders to overcome the uncertainties to methanol transition.
- Lastly, the conclusion was drawn from both the interview and survey analysis results.

3.3. Data Analysis

The data collected was analysed using several data analysis techniques. For the qualitative data, content analysis determines the key insights from the variables of the attractiveness of methanol. Content analysis was conducted with the help of the computer software Atlas.ti and Microsoft Excel. Atlas.ti was used to help analyse the transcripts, provide the codes, and assign similar themes between one transcription and the others. Microsoft Excel was used to support the analysis concluded from the Atlas.ti, ensuring that the code generated was reliable to the original transcription. This technique aligns with the research objectives in examining to what extent and when green methanol is a viable option as a clean energy technology for the sustainable transition in the shipping industry by incorporating the CETIAS criteria to the interview questions, to obtain key insights related to the reasoning of methanol's viability.

The content analysis process in this study used the stages defined by Braun and Clarke (2006) as a reference to the sequence of steps needed to analyse the data. First, the verbal data were collected by conducted interviews and then transcribed into written form to familiarise with the data. The transcripts were checked against the original recordings and sent to the interviewees for accuracy. Next, the initial codes from the data were produced by labelling the texts in which the topics were discussed by the interviewees. The codes were analysed at the broader level of themes by sorting and gathering the relevant coded data into the potential themes and aggregate dimensions. After gathering a set of potential themes and aggregate dimensions, they were reviewed and refined. Lastly, the themes and aggregate dimensions were defined, and the reports were produced based on the analysis obtained.

For the quantitative data, statistical analysis provides an overview regarding the interpretation of the variable measurements. First, descriptive and correlation statistics provide an understanding of how the various variables' measurements turned out, including whether the respondents fully used the offered response scale, the variables' distribution, and the relationship between the variables. Then, the chi-square test checks if the observed uncertainties regarding methanol transition in the shipping stakeholders match the hypotheses.

3.4. Validity and Reliability

Validity is an instrument for ascertaining whether a research method has accurately quantified what it is intended to measure. Reliability is an instrument that measures the stability and consistency of a research concept to indicate consistent measurement throughout time and demonstrate the degree of error-freeness (Sekaran and Bougie, 2016). In this research, two criteria will be used to ensure validity.

First, construct validity was used to determine how the measure's outcomes align with the theories underpinning its creation. Construct validity was tested by triangulating research data with industry reports and expert validation, where three experts from the shipping industries reviewed the research design to ensure precise measurement of the constructs. The second test was internal validity, which was used as an attempt to determine a cause-and-effect relationship between the factors influencing the viability of green methanol in the shipping industry. The internal validity was tested by matching the patterns from the findings of the data collected with the hypotheses established.

To ensure reliability, all information gathered from the study, including literature review, interview and survey responses, and data analysis findings, were secured in a database. This database facilitates cross-referencing information to ensure data integrity. Additionally, limitations were mitigated through several measures that were conducted during the research, such as experts' reviews of the research findings, and survey pilot testing that was performed to refine the survey instruments and ensure that the survey questions are relevant to achieve the main goals.

4. Findings

The following chapter presents the findings from the interviews and the survey. From the interview, the findings consist of the current situation for the methanol transition, the methanol transition opportunities and barriers, the viability approximation time, and the feasibility evaluation discusses from political, economic, social, technological, and environmental aspects. In addition, the survey findings consist of the current methanol investment stage of the shipping stakeholders, the importance of perceived barriers to methanol transition, and the hypotheses testing regarding the significant difference between two different aspects.

4.1. Interview Findings

This section discusses the findings from eleven interviews as qualitative data. The full codes can be found in **Appendix D**.

4.1.1. Methanol Transition

During the interview, the conditions for the methanol transition were discussed, including the current methanol situation, the activities related to the methanol that the shipping stakeholders are doing, and the requirements to support the transition.

Current Methanol Situation

The methanol application is experiencing a transitional phase in the shipping industry, marked by the emergence of early adopters that have been significantly scaling up their production. As shipowners, shipyards and fuel producers are the key players in sustainable energy for shipping solutions, the scale-up indicates a good start for the shift to methanol, driven by the increased decision to use methanol as a low-emission fuel. The increase in methanol utilisation leads to an increase in the number of potential markets that can be opened, but it might also lead to industry competition. For example, there might be a possibility that aviation would compete for the same feedstock as the maritime industry.

Stakeholders' Activities Regarding Methanol

From the interview, it was discovered that all interviewees are doing activities to support the methanol transition. While several stakeholders, such as the original equipment manufacturers, the government entities, and the NGOs, are doing research and development for the introduction of new technologies, classification societies and fuel producers are setting up the methanol value chain to facilitate the methanol transition. Most interviewees from the shipowners and shipyards are currently adapting the ships to methanol, including making the concept design, converting the vessels to be applicable with methanol, developing the fuel systems, and building new vessels that can support methanol. Furthermore, A1 and A3 mentioned that their organisation is investigating the technical feasibility of a methanol engine for constructing their vessel, which is prepared to be applicable to methanol. Moreover, the government entities are doing the pilot project for implementing subsidy schemes that can support the shipping stakeholders to switch to low-emission fuel, including methanol. Additionally, the NGOs are communicating from their perspectives, the steps to uptake sustainable fuels, including green methanol.

Methanol Transition Requirements

The stakeholders have different requirements for supporting the current condition of the methanol transition. The shipowners' equipment, including the engines for the vessels, needs to be developed to adapt to methanol. The availability of methanol as the marine fuel itself is also required to enable the vessels to sail with the fuel. For the shipyards, a broader engine range is needed to enable the applicability of methanol. Furthermore, more training opportunities are needed from the classification societies' perspective to increase the skills in putting the new systems on board. Lastly, the willingness to invest more from the related shipping stakeholders is required to increase the number of methanol utilisation.

4.1.2. Transition Drivers

The drivers for methanol transition can be divided into the methanol opportunities discussed with the interviewees, and the methanol superiority compared to other alternatives. Methanol has a large decarbonisation potential for reducing emissions and a sustainable feedstock source, making the decision to adopt methanol increase more compelling for the shipping industries. In the future trajectory, methanol will have a clear fuel pathway and will be a good choice for retrofits. Furthermore, the positive social perception, including showing that methanol is a safe fuel and the social perception regarding the ships that will exhaust better if using green methanol, can be the opportunity for methanol transition. Moreover, strict regulations are mentioned the most by the interviewees, as the opportunities that can drive the methanol transition. If the government aims to lower emissions and the carbon emissions could be regulated more strictly, it will speed up the transition. Additionally, awarding the front runners that want to do the investment now, for example, by giving subsidies, can drive the stakeholders to consider methanol investment.

Compared to other fuel alternatives, such as ammonia, LNG, and hydrogen, methanol preferences are being discovered. Methanol is less toxic and requires less space, making methanol easier to adopt, handle, integrate, and store than the other alternatives. Moreover, D1 discovered that methanol would be the lowest cost of ownership option, especially for deep-sea shipping. Overall, out of 11 interviewees, 6 of them stated explicitly that methanol is preferred in their organisation, compared to the other alternatives.

> *"I think methanol can be an alternative. There are various alternatives, but this is one of the most promising. Technically, I think it's possible. We are now building a vessel prepared for methanol, but not all the parts that you need are there already. So, engine builders and other components that you need on a vessel still need to be developed further, but that will be ready in 2030."* -A1.

4.1.3. Transition Constraints

Shipping stakeholders face various barriers in implementing the transition to methanol. Some of the barriers discovered are the price of methanol, which tends to be more expensive than diesel, a business case that has not been yet completed, bunkering challenge, the availability of methanol and its feedstock, the needs for ship adaptation for methanol, the know-how, emissions and fuel production regulations, fulfilling the market demand, and the lack of skills in handling the methanol.

From the barriers identified, their occurrences are counted to receive an understanding regarding which barriers the stakeholders face the most in the shipping industry related to methanol transition. The findings were compared to those from the literature study (Table 4) to see the links between the literature study and the actual situation. Table 8 compares the occurrences of methanol barriers between the literature study and the qualitative analysis from the interview. The occurrences in the literature study are based on how much a specific barrier is discussed on the list of literature being studied for this research. In contrast, the occurrences in the qualitative analysis are based on how many stakeholders interviewed are experiencing specific barriers. From the table, it can be concluded that fuel pricing is one of the major barriers to the current methanol transition in the shipping industry. The second-most major barriers are the overall pace and direction of the maritime energy transition. The overall direction consists of the required business case, fuel scalability, and the mindset that reflects the concerns that methanol still contains carbon. The third barrier is the availability of sustainable methanol. Finally, the fourth major barrier is the training challenge: the lack of personnel on board, which relates to the ability to attract sufficient workers with skills in handling, storing, and transporting the methanol.

> *"Availability and scalability of green methanol is a challenge because there needs to be a consumer and there needs to be supply, and of course, that needs to grow stepwise and that's not instantly done. And, of course, bio-methanol will have its limitations in terms of scalability because not all bio is sustainable. So, we need to have a clear distinction between what bio is sustainable and what bio is not. And from the sustainable bio, you need to decide what I'm going to do with it and which industry I am going to supply it."* -B1.

Table 8. Methanol Barriers Comparison Between Literature Study and Interview Results

Literature Study		**Interview**		
Barriers	Occurrences	Barriers	Occurrences	Interviewees
Knowledge of regulators and inspectors	6 out of 10	Price of methanol	8 out of 11	A1, A2, A3, B1, C1, D1, F1, G1
Overall pace and direction of the maritime energy transition	5 out of 10	Overall pace and direction of the maritime energy transition	7 out of 11	A1, A3, B1, B2, D1, E2, G1
Availability of feedstock	4 out of 10	Methanol availability	6 out of 11	A1, A2, B1, D1, E2, F1
Price of methanol		Training challenge	4 out of 11	A2, A3, D1, E1
Price of ship and engine technology				

Table 8 also shows the differences in the findings, one of which is the barrier regarding the availability. In the literature study, the barrier was the availability of feedstock. Four literature mentioned that the barrier to methanol transition is the availability of the feedstock to produce sustainable methanol. This finding indicates that from the academic study, it is found that the feedstock availability to produce sustainable methanol is currently still limited. However, from the interview, the barriers currently are more towards the availability of methanol as a marine fuel. On the same level, four out of ten literature discussed the barriers of methanol price that is higher than the conventional fuels, and the ship and engine price that requires additional costs to be applicable with methanol. These findings indicate that these barriers are some of the major aspects that hinder the methanol transition. The findings from the literature study were used to compare their differences with the interview findings further.

The other difference between the literature and interview findings is the knowledge challenge. The most occurring barrier from the literature study is the knowledge or capacity of regulators and inspectors, which means that academic theoretical knowledge regarding methanol is still one of the major concerns. However, from the interview, it can be seen that the barriers occur more in the training challenge, which means that the concerns are related to the skills in handling, storage, and transportation of methanol by the crew members on board. None of the literature mentions the barrier of the training challenge, which indicates that the academic concern is more towards the theoretical knowledge of the methanol transition, e.g., whether the methanol is feasible for the current shipping industry. In contrast, the technical concern in the real field is more about technical knowledge in methanol handling, including storing and transporting the methanol.

4.1.4. Feasibility Evaluation

The concepts of feasibility evaluation were derived with reference to the Clean Energy Technology Attractiveness Scan (CETIAS) criteria. It was described that to assess the viability of clean energy technology, one of the things that needs to be fulfilled is to be assessed as feasible in light of evaluations from different aspects. Therefore, this section's feasibility evaluation of the methanol transition consists of political, economic, social, technological, and environmental themes. Each aspect acquired from the interviewees will then be mapped into the feasibility evaluation, whether it contributes positively or negatively towards a specific feasibility.

4.1.4.1. Policy and Political

Policy and political feasibility evaluate the political system's influence on the investment decision, including the political developments that might impact the investment's value. First, it is discovered that the transition to methanol is a way to support the ambition of achieving net zero emissions in 2050, which is aligned with the government's ambition, as discussed by seven out of eleven interviewees. Moreover, it is discussed by E1 that the methanol lifecycle policy fits with the national government's goals in its well-to-wake situation, which means that the entire methanol process, including production, distribution, and utilisation, aligns with the government's energy and climate change goals.

Regarding the market design and regulation, it is argued by A2 and B1 that, to a certain extent, the conditions for the methanol transition are predictable. Still, although the goal related to energy and climate is clear, the actual enforcement remains very limited in predictability. A3 stated that it is also difficult to get investors in methanol because, currently, many risks are involved, one of which is determining a suitable methanol production plan. This risk is caused by the uncertainty of feedstocks that will be used to produce methanol, which will be available again next year or the year after, to continue producing the methanol.

Furthermore, it has been discovered that there are already some existing policy instruments to support the methanol transition, such as the regulation for emissions reduction, the European Trading System, which limits the number of emissions produced, the government subsidies for stakeholders that are using methanol, and the government subsidies to produce methanol. F1 discussed that their organisation is currently exploring further subsidy schemes for sustainable fuel. However, a different view also mentions that more external funding is still needed to support the methanol transition, as argued by some of the interviewees from the shipowners and classification societies. Additionally, it is argued by A1 and A2 that the administrative risks from the regulation are low, which would not lead to delays and cost overruns in the methanol transition. On the other hand, A3 argued that getting licenses to bunker methanol is difficult because the rules for bunkering and safety are not ready yet. Thus, it might be easier if there exists a type of approval for different practices, to enable easier access to green fuels. Moreover, E2 argued that there is a delay in obtaining sufficient methanol quantity to supply the vessels, leading to a delay in the supply chain. In addition, F1 argued that there is an administration risk regarding the waiting time, which is not undetermined, how long it will take to have a new Dutch administration in place.

Overall, the transition to low-emission methanol aligns with the government's ambition in energy and climate change, with the alignment that encompasses the overall fuel process. Although it is still difficult to get investors, and the actual enforcement remains very limited in predictability, the methanol transition is predictable based on emissions reduction goals to a certain extent. Various policy instruments exist, including government subsidies and regulations to limit emissions, even though a few argue that more funding is needed. Lastly, there exist administrative risks, such as the difficult license for bunkering, the possibility of delay in the supply chain due to the delay in getting enough fuel, and the undetermined administrative waiting time. However, it is also argued that the administrative risks are low. In conclusion, based on the current political situation, methanol is feasible based on the assessment of policy and political aspects.

4.1.4.2. Economic and Financial

Economic and financial feasibility evaluates the aspect that affects the business case for the methanol transition under consideration in connection with the investment's financial component. There is not much information obtained regarding the financial side of the methanol transition because the interviewees are from the technical side of the organisation and, therefore, do not have much understanding regarding the financial aspect. Furthermore, there is limited knowledge regarding the profitability of methanol. B1 and B2 argued that the expectation regarding the return on investment might take up to 10 years. A1 argued that the methanol transition even has no return on investment.

Currently, the use of methanol is mainly for better emissions. However, it might be profitable in a few years. A3 discussed that in the long-term business case of the ship's lifecycle, the general approximation estimated that, in the end, methanol would be cheaper in the lifecycle. But for the rest, it will not be profitable because it aims more to reduce emissions. However, if strict regulations exist, such as higher CO2 taxes for those using diesel or high-emission fuel, it would be more profitable to use cleaner fuel. Moreover, A3 argued that methanol might become profitable in the future, when the right regulation and administration are in place in the upcoming years. Additionally, B1 discussed that the current shipping industry faces uncertainty in cost projection because the future costs needed for methanol are still unpredictable. On the other hand, the methanol transition can open a potential market, including the sustainable shipping market, start-up companies, vessel suppliers, and the wind industry. However, the potential market in the chemical and aviation industry might potentially become the competitors that are also looking forward to methanol, thereby increasing the methanol demand and fuel prices.

There are different perspectives regarding the interviewees' willingness to invest in methanol. Although B2 argued that the investment in methanol is not financially beneficial, the investment risks are still acceptable. The investment that is currently not financially beneficial is caused by the fact that most investments are driven by the willingness to comply with the emissions reduction regulation, and methanol is the most promising alternative for low-emission fuel compared to other alternatives. Moreover, C1 argued that their willingness to invest depends on the customer base and the demand-supply dynamics. Whereas for B1, their investment is on the research and development side in supporting the sustainable maritime industry. Additionally, A2 discussed that there are more investment decisions for methanol. Still, it must be ensured that the other companies that have not invested in methanol will also be confident that they can make the necessary investments to prepare this fuel for the market. This confidence must be ensured because using methanol is a big investment, and most companies will likely have to ensure whether they can benefit from the investment.

In overall, the understanding regarding the financial aspect of methanol transition is still lacking. There is uncertain cost projection and a long return on investment. This is due to the fact that methanol is used mainly for better emissions. However, in the long term, it might be more profitable than using diesel, based on the lifecycle calculation of methanol. Furthermore, there are various potential markets that can be opened from the methanol transition. Lastly, even though the investment is not financially beneficial currently, the investment risks are still acceptable. The current investment that organisations are making is in the research and development of cleaner energy transition, and it depends on their customer base and demand-supply dynamics. Therefore, if there is a considerable willingness to invest and potential markets for its transition, methanol is partially feasible economically and financially.

4.1.4.3. Social

Social feasibility evaluates the characteristics within society that can influence investment attractiveness. Most interviewees, eight out of eleven interviewees, mentioned that the reaction from society will be positive towards methanol since methanol can reduce emissions. If people are educated properly, it is discussed that the acceptance of methanol will be quite high and easier than that of other fuels, such as hydrogen or ammonia, because methanol is less toxic and significantly reduces emissions. Moreover, methanol will have positive social impacts because it can offer emission reduction benefits and increase air quality with its application.

The methanol transition can impact job opportunities in the shipping industry. It is found that job opportunities will increase with the methanol transition because it is a new fuel that needs to be taken care of, and new engines have to be made, as discussed by C1, F1, and G1. On the other hand, it is argued by A1 and B2 that the job opportunity would roughly be the same because the usage on board is not very different from the existing usage. Additionally, E2 discussed that there might be a possibility that the necessity is more to the training on board, rather than new job opportunities. The crew members need to understand the new system and the hazards that are different when using methanol. Therefore, the changes need additional training for the people on board.

Overall, societal acceptance is positive towards methanol transition if the people are educated correctly, the social impact is positive in creating an environment with better air quality, and there might be a possibility of increasing job opportunities because of the methanol transition. Based on the conditions stated by the interviewees, the methanol transition is feasible socially.

4.1.4.4. Technological

The technological aspect evaluates the development of the technology’s capabilities and surrounding standards, directly affecting financial outcomes. Methanol has the competitive advantage of a broad feedstock range, as discussed by C1, can use the existing shipping infrastructure as stated by E2, and can be utilised in certain power generation systems, as discussed by B1. Moreover, E1 discussed that methanol has the possibility for retrofit, which is one of the ways to develop methanol-powered vessels through modifying the existing ship engines, fuel supply lines, pump and storage tanks, to be applicable to run on methanol.

Nowadays, the adoption of methanol is increasing, supported by the fact that it already has on board implementation and safety procedures, as discussed by E1. Currently, the vessels are under development to be applicable to methanol, as discussed by A2, offering the technology maturity of methanol. Moreover, some parties act as the front runners that are willing to pay premium prices for methanol. However, B2 argued that the engines to use methanol are not yet ready for small ships. A3 also argued that the guidelines from the regulatory bodies, such as IMO, need to be simpler for methanol, to support easier ship design processes for the hazard certification. Additionally, F1 argued that there is no standardisation between the bunkering and ports yet, making the methanol production cost expensive.

Regarding the infrastructure for methanol transition, some stakeholders in the current shipping industry, such as C1 and E1, already have sufficient infrastructure to support methanol, while others, such as A2, are still developing their infrastructure. A1, B2, and E2 also mention that most current infrastructure can be used for methanol. Therefore, the infrastructure is still pretty much the same, allowing a quicker transition for methanol than some other fuels. Moreover, it is found that more theoretical knowledge of methanol applicability has been developed. However, it is argued that the current shipping industry does not yet have much experience in applying methanol. To bridge the knowledge gap regarding methanol transition, knowledge sharing between stakeholders is very crucial to get better knowledge.

During the methanol transition's construction and operational phases, there are some technical risks that usually occur. The most occurring risks experienced by most interviewees are the risks in equipment availability and reliability and the risks regarding the larger space required to implement methanol compared to diesel. The other risks consist of the clearance of regulations, the efficiency in energy substitution, investment in limited-use technologies, the suitability of vessel design, the low flashpoint fuel, the dynamic behaviour of methanol, the regulatory compliance, the safety measures, the training gap for the crew members on board in handling methanol, and the vessel design suitability for methanol. On the other hand, E2 argued that the technical risks in methanol transition are relatively low compared to other fuels, because the existing infrastructure can be used for methanol.

Overall, adaptability can make methanol an appealing choice for a low-emission fuel option, as it enables the possibility to use existing shipping infrastructure and convert existing vessel engines to run on methanol with certain modifications. Not much change is needed for the methanol infrastructure because the infrastructure is similar, and existing infrastructure can be used. Therefore, the existing on board implementation and safety procedures can be used for methanol. However, the guidelines still need to be simplified, and the engines for small ships are not yet ready. Moreover, while more knowledge has been gained, there is not much experience yet regarding the methanol application. Additionally, although various risks might occur during the construction and operational phases of the methanol transition, it is also argued that if the other fuels are being considered, the technical risks are comparatively low. In conclusion, based on the current technical conditions, methanol is feasible technologically.

4.1.4.5. Environmental

The environmental aspect evaluates the characteristics that influence an economy’s ability to alleviate the effects of climate change and energy transition. From this aspect, it is discovered that the material used to produce methanol comes from sustainable feedstock, as stated by B2 and G1. Moreover, A1 discussed that the fabrication of the fuel is an important aspect to be looked into to ensure the most efficient way of making the fuel in regards to its feedstock. As for the environmental impacts, while the methanol application can significantly reduce emissions, as discussed by A3, B1, F1 and G1, there are also the risks of transporting methanol, as argued by E1, and the biodegradation of leaks, as argued by B2 and C1.

Overall, the material used to produce methanol comes from sustainable feedstock, yet attention must be paid to fuel fabrication to produce fuel from the efficient feedstock option. With methanol, the emissions can be significantly decreased. Although some environmental risks are associated with methanol application, such as the risks of methanol transportation and leaks, methanol is less toxic and flammable than other alternatives. Therefore, the current requirement is more towards the training for the personnel on board to handle the fuel. Based on the environmental aspect, methanol transition is feasible.

4.1.5. Viability Approximation Time

The estimation of when methanol is a viable option is difficult to estimate, because the future is unpredictable and full of uncertainties. Different stakeholders mentioned different approximation times of the methanol viability. An interviewee, A1, mentioned that methanol's engine adoption had already started in 2023. If this is the case, in 2030, the shipping industry is predicted to switch to green methanol. Furthermore, F1 argued that the regulatory impact that limits the use of fossil fuels to bridge the price gap between fossil and sustainable fuels is expected to take place in 2030. Another interviewee, C1, predicted that the shipping industry would switch to green methanol in 2028. Moreover, E2 argued that more availability of methanol is expected in the next five years because, in 2030, the shipping industry needs to meet the target of reducing emissions, and most of the existing infrastructure can be applicable to methanol. In addition, A3 discussed that methanol is already quite ready for commercial deployment because there are already ships sailing on methanol. However, it would take some time to make the methanol application efficient. Therefore, hopefully, methanol will be ready for full implementation in two or three years.

> "*I think around 2028 because there will be way more supply of green methanol which will also drive the price a bit down. But if you would say 2030, I would also believe you. To be honest, there's not really one-time data I can state it will happen.*" -C1.

Furthermore, three interviewees, B1, B2 and E1, mentioned that methanol is currently technically viable in the shipping industry because there are already a considerable number of ships sailing with methanol. Therefore, from the ship's side, methanol is already doable for most stakeholders. As soon as the scaling up of methanol and the availability of the fuel is sufficient, it will become more viable in the shipping industry.

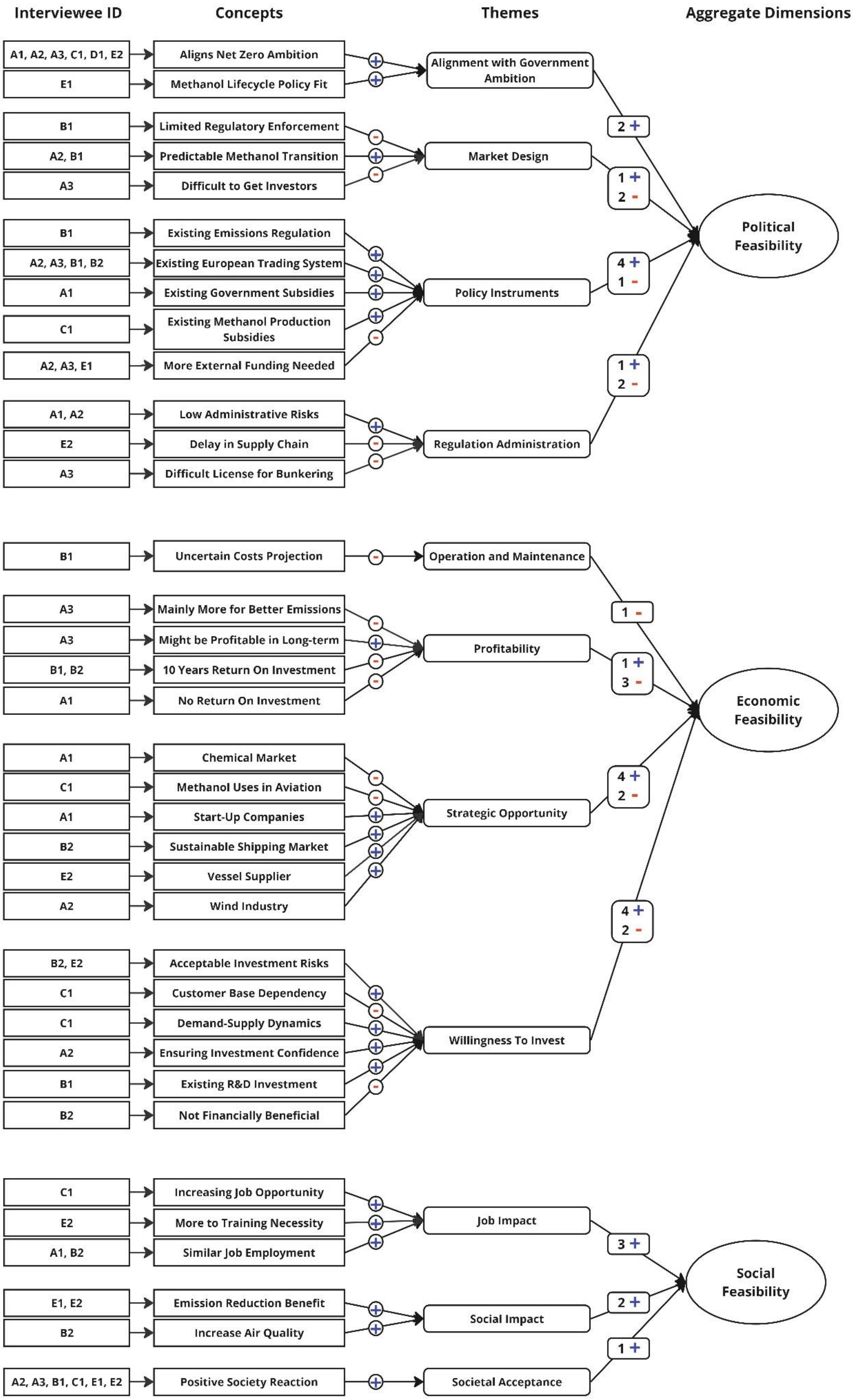

Figure 5. Feasibility Evaluation (Political, Economic, and Social)

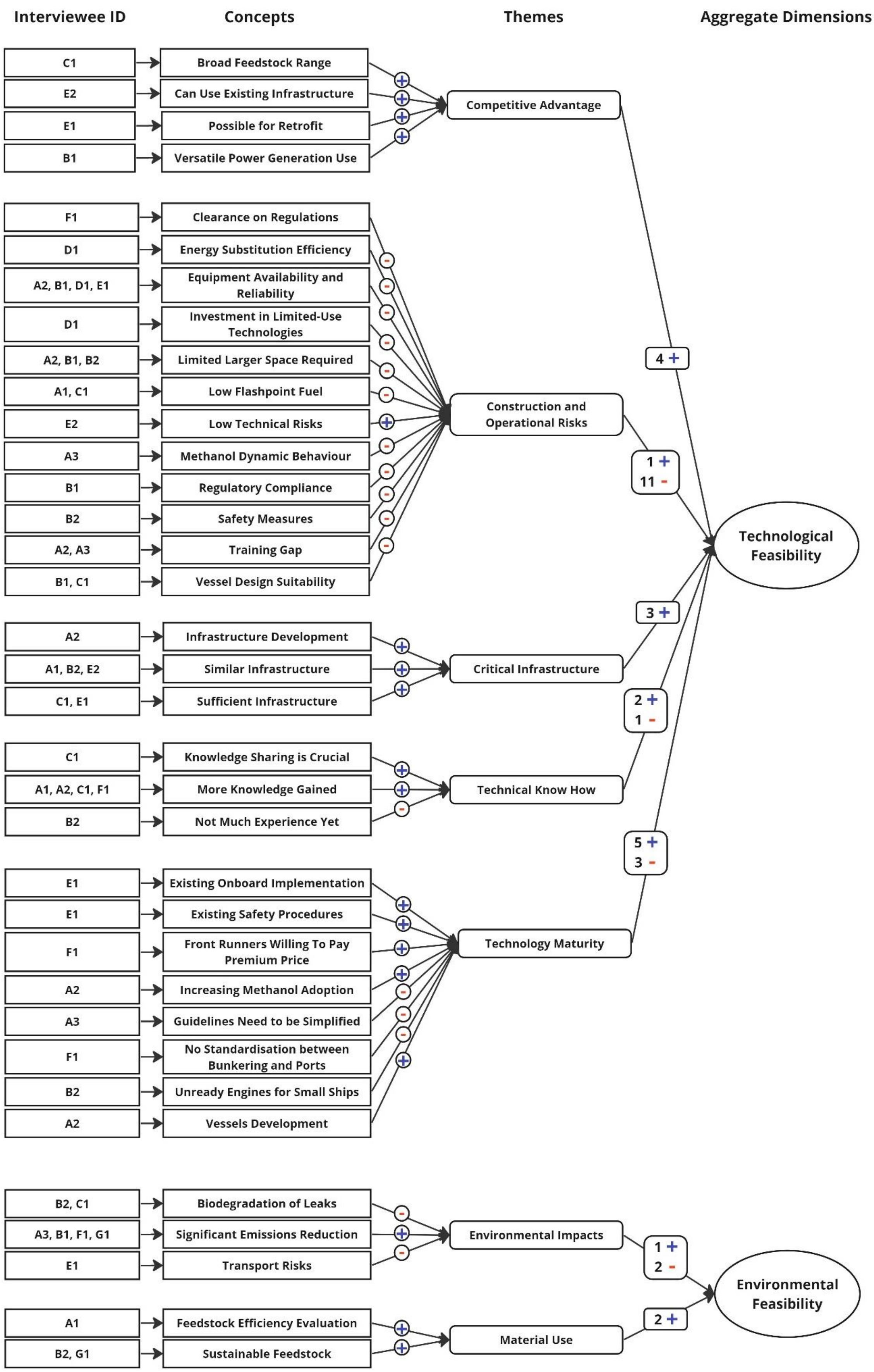

Figure 6. Feasibility Evaluation (Technological and Environmental)

4.1.6. Summary of the Interview Findings

The interviewees have indicated a preference for using methanol as a low-emission fuel in the shipping industry, with 6 out of 11 explicitly mentioned that they prefer methanol compared to the other alternatives. Methanol is preferred because it is less toxic and is easier to adopt, handle, integrate, and store compared to other fuels, such as ammonia, LNG, and hydrogen. This superiority promotes the viability of methanol transition. Furthermore, the shipping stakeholders are currently taking on some activities for the methanol transition, including fuel monitoring, research and development, setting up the methanol value chain, ship adaptation, subsidies pilot project, and technical feasibility study. These stakeholders' activities towards methanol support the viability of the methanol transition.

There are opportunities that can promote the methanol transition. Methanol can reduce significant emissions, has a high technological readiness level, has a good future trajectory, and has a sustainable feedstock source. Furthermore, methanol has become a popular choice for retrofits due to the similar infrastructure requirements compared to the existing one. Moreover, strict regulations and awards for front-runners investing in methanol can speed up the transition process by strictly regulating carbon emissions. Additionally, the positive social perception regarding ships sailing with methanol will result in better emissions can drive the transition from societal perspectives. However, many barriers influence the shipping stakeholders' decision to transition to methanol. The most frequent barriers are the fuel price, the availability of methanol, the overall pace and direction of the maritime energy transition, and the training challenge for the personnel on board. Despite the barriers, all interviewees stated that they think methanol can be a viable option in the shipping industry and relates to the current shipping industry needs, especially in contributing to emissions reduction.

To obtain an understanding of the extent of methanol's viability, the methanol transition was evaluated from different aspects. Based on the current conditions discussed with the interviewees, methanol transition is feasible from the political, social, technological, and environmental aspects. Moreover, methanol is partially feasible from an economic perspective. From the assessment, it is found that several requirements are needed for methanol transition, which consists of the methanol availability that needs to be increased, engine range that needs to be broadened to be applicable with methanol, the equipment development, more training opportunities for the crew members on board, and the willingness to invest more to methanol from the shipping stakeholders.

In conclusion, the interview findings reveal that methanol is considered feasible based on the PESTE (political, economic, social, technological, and environmental) assessments. Politically, methanol is feasible because it aligns with the international regulatory ambition of net zero emissions in 2050, is supported by various existing policy instruments, and to a certain extent, the transition is predictable based on emissions reduction goals. Economically, methanol is partially feasible, because it has uncertain cost projection, long return on investment, and the possibility of not being financially beneficial in the current situation. However, methanol might be profitable if there exists a policy that limits the usage of diesel fuel. Furthermore, more investment decisions are taken for methanol and the investment risks are still acceptable for certain stakeholders. Socially, methanol is feasible because it has positive social acceptance, might increase job opportunities, and creates a healthier environment. Technologically, methanol is viable since methanol offers the possibility to use existing infrastructure and vessel engines with certain modifications. Although various risks might occur during the methanol transition, the technical risks of methanol are low compared to other types of fuels. Environmentally, methanol is viable because the emissions can be significantly reduced, and it is made from sustainable feedstock.

The interview findings discover the feasibility of methanol from the PESTE perspectives and the technology performance advancements. The survey was developed to explore further the feasibility of methanol from the assessments of whether it is supported by powerful shipping stakeholders and is deemed feasible based on the evaluated barriers. The initial interview findings were used to validate the relevancy of the survey questions. Both interview and survey questions about the stakeholders in most direct contact with the respondents, to get an overview regarding the stakeholders' relationship in relation to methanol, and to see how the engagement might speed up the transition process. With the feasibility assessments from both the interview and survey findings, the extent to of methanol is a viable option in the shipping industry can be concluded.

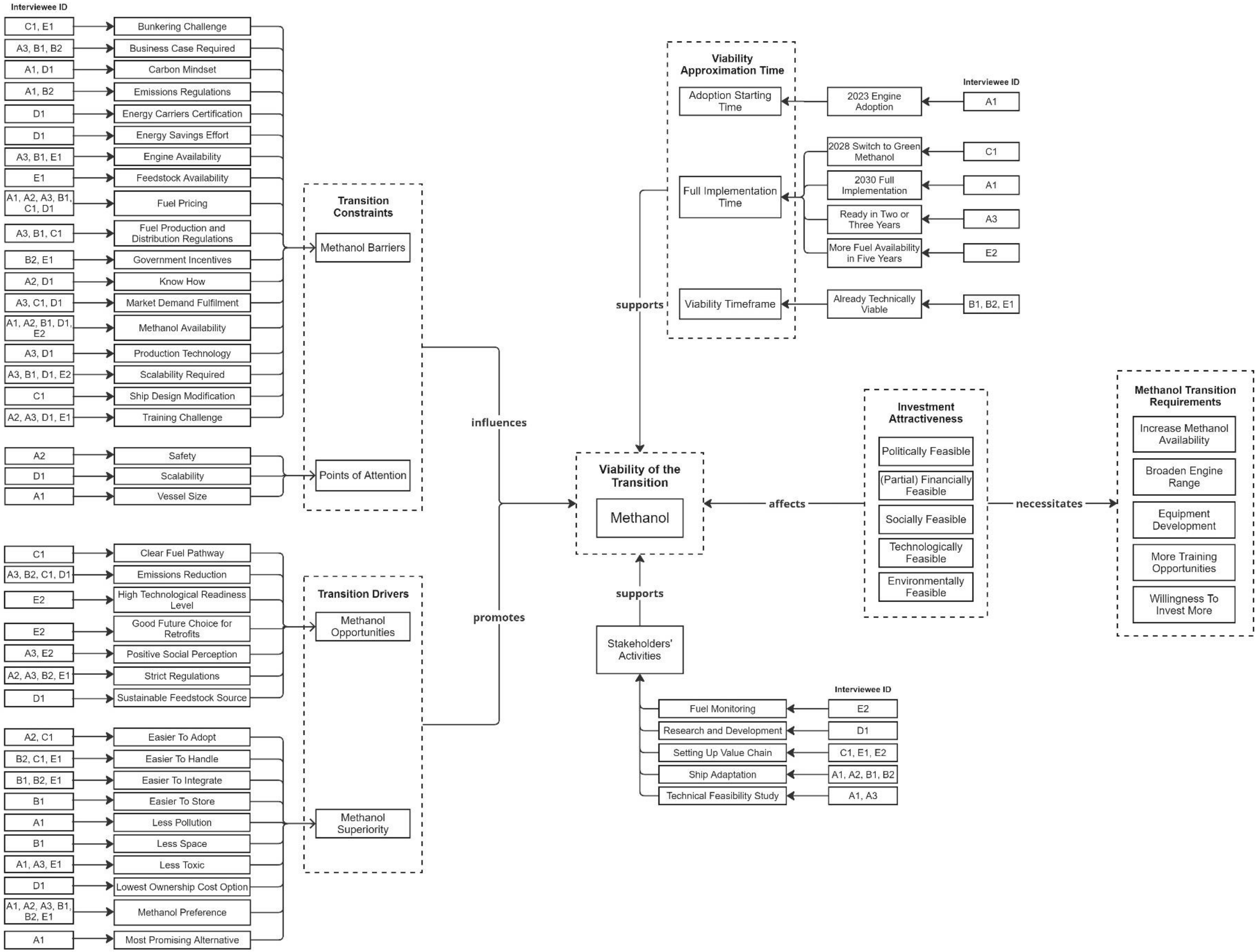

Figure 7. Viability of Methanol Transition and the Transition Requirements

4.2. Survey Findings

This section discusses the survey findings from thirty-nine respondents as quantitative data. The distribution of the stakeholders' type is as follows. There are fifteen respondent shipowners, seven shipyards, four fuel suppliers or bunker parties, four original equipment manufacturers and suppliers, three consultancy companies, three trade associations, two port authorities, and one classification society.

4.2.1. Methanol Investment Consideration

The first part of the survey aims to obtain an understanding of the willingness of the shipping stakeholders to invest in sustainable methanol as a marine fuel. The first part questions the importance of sustainable shipping investment, the reasons for considering sustainable methanol investment, what main investments are being considered in the short term up to five years, and at what stage are the investments for methanol as a marine fuel in shipping.

The Importance of Sustainable Shipping Investment

From the survey, the findings regarding the importance of sustainable shipping investment for the shipping stakeholders are as follows. Out of 39 respondents, 17 of them chose sustainable shipping investment as one of their main concerns, and 18 others think that the investment is of major importance for their organisation. Various reasons are given to justify why the investment is important in their organisation, including the regulations compliance regarding emissions reduction, to contribute to the sustainable future of the shipping industry, client's requirements fulfilment, to support the industry in moving towards a future with less carbon, and to adapt with the changing demand of the clients. Furthermore, only four respondents think that the investment is of minor importance for them, because their organisation is not directly in contact with the need to use sustainable shipping sources.

> *"Transport is our core business. We have to reduce our emissions over the years."*
> -a shipowner, which chose sustainable shipping investment of major importance for their organisation
>
> "*Many of our customers, suppliers and shipyards are faced with various global challenges such as economic decline, climate change, and energy transition. These global challenges, including realising sustainable development goals, will have a major impact on the maritime industry. We wish to contribute to a sustainable future. Our company is determined to play a leading role in making the maritime industry more efficient and sustainable.*"
> -a shipyard, which chose sustainable shipping investment as one of their main concerns.

The Reasons for Sustainable Methanol Investment

There are three options that the respondents can select multiple in stating their reasons for methanol investment consideration: customer demand, desire for sustainability, and regulatory compliance. Table 9 shows the distribution of the answers. It is found that the most chosen reasons are the desire for sustainability, followed by customer demand. These reasons are driven by the fact that many shipping organisations are making efforts to reduce emissions while continuing maritime activities and fulfilling customer demand. Furthermore, it can be seen that the occurrence of reason regarding the desire for sustainability exceeds the reason of customer demand for methanol investment consideration, which indicates a proactive attitude of the companies towards sustainable maritime activities, regardless of the external pressures. A compelling narrative explains that it is a moral obligation for the organisation to make shipping more sustainable, which underscores that sustainability is a fundamental duty rather than just a strategic choice. Moreover, the data indicates that many respondents consider sustainability essential to their business plan to reach long-term climate-neutral goals in 2050. Lastly, regulatory compliance is the least reason to consider sustainable methanol investment. The reason for regulatory compliance to consider methanol investment is that regulations are required for the shipping stakeholders. The regulations influence customer needs, which consequently affects the operational decisions of the other stakeholders that manufacture, develop, and supply the supporting equipment.

Table 9. Reasons for Methanol Investment Consideration

Reasons for Methanol Investment Consideration	Occurrences
Only Customer Demand	4
Only Desire for Sustainability	12
Only Regulatory Compliance	1
Customer Demand and Desire for Sustainability	11
Customer Demand and Regulatory Compliance	2
Desire for Sustainability and Regulatory Compliance	3
All Three Reasons	5
None	1

Main Investments Considered by the Shipping Stakeholders

There are various main investments that the shipping stakeholders are considering in the short term up to 5 years, including the operational measures, the use of sustainable fuels, the sustainable sourcing of transport services, the investment in alternative power trains, the offering of sustainable fuels, and the offering of sustainable fuel infrastructure. The occurrences for each type of investment are shown in the table below.

Table 10. Main Investments Considered by the Shipping Stakeholders

Stakeholders	Investments Type	Occurrences	Total
Original equipment manufacturer and supplier	Sustainable sourcing of transport services	1	3
Shipowner		2	
Fuel supplier	Operational measures	1	14
Original equipment manufacturer and supplier		1	
Port authority		1	
Shipowner		8	
Shipyard		2	
Trade association		1	
Consultancy	Use of sustainable fuels	1	23
Fuel supplier		2	
Original equipment manufacturer and supplier		1	
Port authority		2	
Shipowner		12	
Shipyard		4	

Stakeholders	Investments Type		Occurrences	Total
Trade association			1	
Fuel supplier	Investment in alternative power trains		1	19
Original equipment manufacturer and supplier			2	
Shipowner			10	
Shipyard			5	
Trade association			1	
Fuel supplier	Offering sustainable fuels		3	3
Fuel supplier	Offering sustainable fuel infrastructure		3	5
Port authority			2	
Original equipment manufacturer and supplier	Other investments	Engine technology to burn methanol	1	1
Consultancy		Knowledge or know-how regarding the fuels, ship designs, and implementation	2	2
Original equipment manufacturer and supplier		Methanol Engine Development Program	1	1
Consultancy		Rule development	1	1
Trade association		Projects initiation for innovation towards carbon-neutral	1	1
Shipyard		Review, selection, and implementation of renewable energy storage or future fuels	1	1

From the table, it can be seen that the investment that is being considered the most by the shipping stakeholders is the use of sustainable fuels, mostly considered by the shipowners, to support sustainability and optimise their sailing profile. The second and third place of the most considered sustainable investments is consecutively the investment in alternative power trains and operational measures, dominantly considered by the shipowners. Since many organisations are investing in the use of several renewable fuels on board, but the fuels are more expensive, the new power trains and operational measurements need to be researched further to reduce energy consumption.

The shipyards, similar to the shipowners, are mostly considering the investments for alternative power trains and the use of sustainable fuels. The fuel suppliers are mostly considering investments in offering sustainable fuels and their infrastructure. For the original equipment manufacturers and suppliers, their investment consideration is spread evenly in all types of investments.

Methanol Investment Stage

In the survey, there are five investment stages that the respondents can select that describe their involvement in investments for applying methanol as a fuel for shipping. The selection is as follows. Stage 1 is for the organisations that are not involved in the investment at all. Stage 2 is for the organisations currently in the explorative stage, which consists of developing the business case and researching the market. Stage 3 is for the organisations in the feasibility assessment phase, which involves researching the feasibility of methanol transition for investment consideration. Stage 4 is for the organisations finalising the methanol investment consideration and moving towards their Final Investment Decision (FID). Lastly, stage 5 is for the organisations that already have positive Final Investment Decision and have finalised that they will be investing in applying methanol in the shipping industry. The table below shows the occurrences of the responses regarding the methanol investment stage as well as the type of stakeholders that are in certain stages.

Table 11. Distribution of Methanol Investment Stage

Stakeholders Type	Investment Stage	Occurrences	Total
Classification society	Stage 1: Not involved at all	1	5
Consultancy		1	
Trade association		3	
Consultancy	Stage 2: Explorative	2	7
Fuel supplier or bunker party		1	
Original equipment manufacturer and supplier		1	
Shipowner		1	
Shipyard		2	
Original equipment manufacturer and supplier	Stage 3: Feasibility assessment and Stage 4: Moving towards Final Investment Decision (FID)	3	15
Port authority		1	
Shipowner		8	
Shipyard		3	
Fuel supplier or bunker party	Stage 5: Already positive Final Investment Decision (FID)	3	12
Port authority		1	
Shipowner		6	
Shipyard		2	

The table shows that most organisations are currently in stage 3, which is the feasibility assessment stage for methanol investment decisions. Those stakeholders are in the third stage because of various reasons. For shipowners, they are currently investigating the potential of building newbuild vessels for methanol. For shipyards, they are assessing the technical and economic feasibility of new fuel developments. There is an original equipment manufacturer and supplier and a shipowner that actually chose that their investment stage is in stage 4, in which their investment consideration is moving towards the Final Investment Decision (FID). However, in Table 11, the stage 3 and 4 are combined, with the consideration that the time related to the feasibility study (stage 3) and already positive FID (stage 5) requires a long time, but it needs a very short time when moving towards FID (stage 4).

Slightly different from the first place, the second-most methanol investment stage is stage 5, which is the stage where the organisations are already in positive Final Investment Decision. For fuel suppliers in the fifth stage, they already have sustainable methanol ready and are able to deliver the fuel at any time. For port authorities, they already put their own investments in methanol in human resources and infrastructure development. For shipowners, they are working on several projects to build newbuild vessels applicable with methanol. Lastly, for shipyards, they are doing investment in methanol in certain topics and periods.

4.2.2. The Importance of Perceived Uncertainties and Their Correlations

The methanol investment stage, the importance of perceived uncertainties, and the correlations among the variables are analysed to see which perceived uncertainties are the most and least important, how are the distributions of the responses, and the correlations between the variables. In this section, the responses are analysed from each type of stakeholders, which survey has a minimum response of 5, and the overall data from all stakeholders that responded to the survey. The results differentiation by the stakeholders' minimum responses of 5 is based on the consideration that the responses below 5 are a number that can be considered too low to be analysed separately, which might result in the outcome inaccuracy. If the responses are too low, there might be a possibility of the same level of importance for certain uncertainties from all responses, which results in a standard deviation of zero and inapplicable relationships between variables.

Descriptive and Correlations among Shipowners

The methanol investment stage of shipowners results in a mean score of 3.80, suggesting a moderate level of investment stage in methanol. The spread is high, with a standard deviation of 1.08, indicating a wide range of views regarding the methanol investment stage. Regarding the ratio of the standard deviation of a variable, none of them has a standard deviation larger than the mean, indicating that no variables have a skewed distribution. All variables have a standard deviation lower than the mean, which indicates that the variables have a relatively normal spread. Furthermore, the perceived uncertainties of methanol availability result in the highest mean of 4.73, which indicates that the availability of methanol as a marine fuel is the most important perceived uncertainty for shipowners. The second most important uncertainty is the regulation stability, with a mean of 4.60. On the other hand, subsidy availability has the lowest mean of 3.20, which indicates that the availability and quantity of subsidies towards sustainability applicable to methanol is the least important perceived uncertainty for shipowners.

Regarding the variables' correlations, the value with an asterisk symbol (*) indicates that the result is statistically significant with a p-value less than 0.05. Two asterisks (**) mean the higher significance level, with a p-value less than 0.01. For the shipowners, a strong positive correlation exists between the regulation stability and feedstock availability (.65**), indicating that the increase of importance regarding the long-term stability of the regulation and government policy support concerning sustainable fuels will increase the importance of the availability of feedstock for the production of low-emission methanol. Furthermore, there exists a strong positive correlation between the technology certification and the infrastructural readiness (.67**), and the technology certification and the bunkering regulation (.64**). These correlations indicate that the increase of importance regarding the rate of technology certification for the use of technologies related to methanol will increase the importance of the level of infrastructure readiness at ports for the intended use of methanol and the importance of the availability of clear safety regulation for bunkering and use of methanol.

Moreover, there exists a strong positive correlation between the bunkering regulation and the production regulation (.70**), which indicates that the increase of importance regarding availability of clear safety regulation for production and storage of methanol will increase the importance regarding the availability of clear safety regulation for bunkering and use of methanol as a marine fuel. There is also a strong positive correlation between the operational expenses and the social acceptance (.65**), indicating that the increase of importance regarding the impact of operational expenses in comparison to alternative energy carriers is associated with the increase of importance regarding the social acceptance of methanol as an alternative energy carrier by the wider public. Additionally, there exists a strong positive correlation between the capital intensity and the return on investment, which indicates that the increased importance of the capital intensity impact in comparison to other alternatives will increase the importance regarding the uncertainty of return on investment. On the other hand, the findings indicate a strong negative correlation between capital intensity and production regulation (-.73**), indicating that the increased importance regarding the impact of capital intensity compared to other alternatives will lower the importance of clear safety regulation availability for the production and storage of methanol.

Descriptive and Correlations among Shipyards

The methanol investment stage of shipyards has a mean of 3.29, suggesting a moderate level of methanol investment stage. The standard deviation of 1.25 indicates the high spread of the responses, signifying the variability of the shipyards' methanol investment stage. Regarding the ratio of the standard deviation of the variables, all variables in shipyards also have a standard deviation lower than the mean, indicating that the variables have a relatively normal spread as the variables of shipowners. Moreover, the variables with the highest mean of 4.71 are the technical readiness and the technology certification, which indicates that the uncertainty regarding the technical readiness to the use of required technology in the shipyards' intended operational environment and the uncertainty regarding the rate of technology certification for the use of technologies related to methanol is the most important consideration for the shipyards. On the other hand, the subsidy availability has the lowest mean of 3.00, indicating the availability of subsidies towards sustainability applicable to methanol is the least important uncertainty for shipyards.

Regarding the correlations between variables, there exists a strong positive correlation between feedstock availability and technical readiness (.92**), indicating that the increased importance of the uncertainty regarding the availability of feedstock for low-emission methanol production will increase the importance of uncertainty regarding the technical readiness to the use of required technology in their intended operational environment. Another strong positive correlation exists between infrastructural readiness and feedstock availability (.91**). This strong correlation indicates that the increased importance of perceived uncertainty regarding the level of infrastructure readiness at ports for the shipyards' intended use of methanol will increase the importance of uncertainty regarding the feedstock availability for the production of low-emission methanol. Furthermore, a strong positive correlation exists between the bunkering regulation and technical readiness (1.00**) and between the bunkering regulation and feedstock availability (.92**). These correlations indicate the increased importance of the uncertainty regarding the availability of clear safety regulations for bunkering and the use of methanol as a marine fuel will increase the importance of the uncertainty regarding technical readiness to the use of required technology for sustainable methanol, and will also increase the importance of the uncertainty regarding the feedstock availability to produce sustainable methanol.

On the other hand, there is a strong negative correlation between the operational expenses and the alternative fuel investment (-.88**), which indicates that the increased importance of uncertainty regarding the impact of operational expenses in comparison to alternative energy carriers will affect in decreasing the importance of uncertainty regarding the chance that other energy carriers, such as ammonia and biodiesel, will prove to be a better investment.

Descriptive and Correlations among Fuel Suppliers

Four responses were obtained for the fuel suppliers category, which is relatively low. Thus, the statistical correlations cannot be analysed because of the zero standard deviation for some aspects. The insights that can be gained are the methanol investment stage, the most important uncertainty related to the sustainable methanol transition, and the least important uncertainty for the fuel suppliers.

The methanol investment stage of fuel suppliers has a mean of 4.25, indicating a high level of methanol investment, which is almost one stage further compared to other stakeholders such as shipowners and shipyards. The standard deviation of 1.50 signifies widespread responses from the stakeholders. The most important uncertainties are the technical readiness and the willingness to pay, with a mean of 5.00. Social acceptance is the least important uncertainty, with a mean of 2.75, indicating a low priority in addressing the public perceptions regarding the investment decisions of the fuel suppliers. Additionally, an interesting finding is discovered, that the subsidy availability is also highly important for the fuel suppliers, with a mean of 4.75. This importance is contradictory with the shipowners and the shipyards, which put the subsidy availability as the least important uncertainty.

Descriptive and Correlations among Original Equipment Manufacturers and Suppliers

Four responses were also received for the original equipment manufacturers and suppliers category. Therefore, for this type of stakeholder, a limited analysis is also explained. The methanol investment stage of original equipment manufacturers and suppliers has a mean of 3.00, indicating a moderate level of methanol investment, with a moderate spread of responses (standard deviation of 0.82).

The regulation stability and the technology certification have the highest mean of 4.75, indicating that these two uncertainties are the most important for the original equipment manufacturers and suppliers. Similar to the fuel suppliers, social acceptance is the least important also for the original equipment manufacturers and suppliers, with a mean of 3.00. The subsidy availability is the third-least important, with a mean of 3.50, indicating that the uncertainty regarding the availability of subsidies towards methanol transition is not a priority either for the original equipment manufacturers and suppliers.

Descriptive and Correlations among Shipping Stakeholders in Overall

Based on the shipping stakeholders' survey responses overall, the methanol investment stage has a mean of 3.23, indicating a moderate level of methanol investment. The standard deviation of 1.40 notifies the high spread of responses, indicating the various investment stages of the stakeholders. The regulation stability has the highest mean of 4.49, indicating that the long-term stability of the regulation and government policy support concerning sustainable fuels is the most important uncertainty related to the uptake of sustainable methanol. Furthermore, the second highest mean is technology certification, with a mean of 4.36. On the other hand, the lowest mean of 3.23 is achieved by the qualified staff, which indicates that the uncertainty regarding the ability to attract and train qualified staff necessary for the production or use of methanol is the least important for the shipping stakeholders.

From the correlations, it is found that there is a strong positive correlation between the feedstock availability and the methanol investment stage. A positive strong correlation also occurs between the methanol availability and the methanol investment stage. These correlations indicate that the increased importance of the uncertainty regarding the availability of feedstock to produce methanol, and the availability of sufficient sustainable methanol amounts for maritime use, will increase the stage in which the stakeholders' methanol investment is progressing. Furthermore, 34 strong positive correlations and no strong negative correlation exist between the importance of two uncertainties. The strong positive correlations indicate that the increased importance of a specific uncertainty will increase the importance of the other uncertainty that correlates with each other. The correlations can be seen in the table below.

Table 12. The Correlations between Two Variables of the Shipping Stakeholders

Correlations Between Two Variables	Correlation Coefficient
Feedstock Availability and Methanol Investment Stage	.51**
Methanol Availability and Methanol Investment Stage	.48**
Feedstock Availability and Technical Readiness	.42**
Methanol Availability and Technical Readiness	.47**
Infrastructural Readiness and Technical Readiness	.52**
Production Regulation and Technical Readiness	.42**
Bunkering Regulation and Technical Readiness	.49**
Emission Reduction and Technical Readiness	.59**
Feedstock Availability and Alternative Investment Potential	.50**
Methanol Availability and Alternative Investment Potential	.49**
Production Regulation and Alternative Investment Potential	.45**
Emission Reduction and Alternative Investment Potential	.46**
Methanol Availability and Feedstock Availability	.89**
Infrastructural Readiness and Feedstock Availability	.56**
Bunkering Regulation and Feedstock Availability	.46**
Infrastructural Readiness and Methanol Availability	.61**
Bunkering Regulation and Methanol Availability	.44**
Production Regulation and Infrastructural Readiness	.47**
Bunkering Regulation and Infrastructural Readiness	.59**
Qualified Staff and Infrastructural Readiness	.50**
Emission Reduction and Infrastructural Readiness	.44**
Bunkering Regulation and Production Regulation	.62**
Enforce Capacity and Production Regulation	.45**
Emission Reduction and Production Regulation	.42**
Qualified Staff and Bunkering Regulation	.42**
Emission Reduction and Enforce Capacity	.45**
Operational Expenses and Qualified Staff	.42**
Capital Intensity and Return On Investment	.80**
Operational Expenses and Return On Investment	.62**
Subsidy Availability and Return On Investment	.49**
Willingness To Pay and Return On Investment	.62**
Operational Expenses and Capital Intensity	.80**
Subsidy Availability and Capital Intensity	.47**
Willingness To Pay and Capital Intensity	.50**
Willingness To Pay and Operational Expenses	.49**
Willingness To Pay and Subsidy Availability	.55**

Table 13. Descriptives and Correlations among Variables (Shipowners)[1]

Variable	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Methanol investment stage…..	3.80	1.08	-																				
2. Technical readiness………….	4.47	0.83	-.44	-																			
3. Alternative fuel investment….	4.00	1.00	.13	.34	-																		
4. Feedstock availability……….	4.40	0.74	.47	.02	.48	-																	
5. Methanol availability………..	4.73	0.46	.17	.35	.31	.55*	-																
6. Infrastructural readiness……..	4.53	0.64	-.45	-.10	-.33	-.03	.03	-															
7. Goals alignment……………..	4.20	0.86	.05	.36	.25	.20	.14	.05	-														
8. Regulation stability………….	4.60	0.51	-.03	.30	.28	.65**	.43	.26	.20	-													
9. Production regulation………..	4.13	0.52	-.20	.34	.55*	.23	.46	-.01	-.22	.22	-												
10. Bunkering regulation………	4.40	0.63	-.19	.43	.56*	.40	.39	.32	.24	.53*	.70**	-											
11. Technology certification…...	4.40	0.63	-.40	.16	.11	.09	-.10	.67**	-.03	.31	.26	.64**	-										
12. Enforce capacity…………...	4.00	0.85	-.16	-.20	.08	.11	.18	.00	-.20	.00	.33	-.13	-.27	-									
13. Level playing field…...…….	4.27	1.16	-.07	-.36	.31	.03	-.26	-.30	-.27	-.17	.17	-.16	-.25	.58*	-								
14. Social acceptance…………..	3.47	0.74	.30	-.03	.10	.29	.18	.34	.51	.15	.01	.49	.49	-.45	-.48	-							
15. Qualified staff……………...	3.60	1.18	-.12	-.30	-.06	-.05	-.21	.21	-.06	-.17	-.02	.23	.42	-.07	.24	.31	-						
16. Emission reduction………...	4.13	0.99	-.11	.09	.50	.22	-.07	-.01	.22	.11	.24	.36	.02	.26	.53*	-.19	.11	-					
17. Return on investment………	3.93	1.10	-.25	-.12	-.26	.12	-.04	.36	.17	.08	-.36	-.27	.04	.46	.29	-.13	.20	.21	-				
18. Capital intensity……………	4.07	0.59	.02	-.07	-.36	.10	-.19	.28	.25	.09	-.73**	-.27	.11	-.28	-.13	.09	.24	.11	.66**	-			
19. Operational expenses………	4.20	0.68	.35	-.43	-.21	.26	.18	.40	.05	.04	-.29	-.03	.30	-.25	-.25	.65**	.29	-.47	.21	.32	-		
20. Subsidy availability………..	3.20	0.94	.32	-.04	.08	.29	.30	-.07	.48	-.03	-.50	-.26	-.38	-.09	.01	.06	-.05	.20	.43	.61*	.27	-	
21. Willingness to pay………….	3.87	1.19	-.08	-.00	-.18	.23	.19	.19	-.18	.14	-.32	-.40	-.02	.14	-.02	-.25	-.29	-.29	.54*	.42	.39	.35	-

[1] $n = 15$ $^{**}p < .01$; $^{*}p < .05$.

Table 14. Descriptives and Correlations among Variables (Shipyards)[1]

Variable	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Methanol investment stage…..	3.29	1.25	-																				
2. Technical readiness………….	4.71	0.49	-.12	-																			
3. Alternative fuel investment….	3.71	1.11	-.77*	.13	-																		
4. Feedstock availability……….	3.29	0.95	-.08	.92**	.25	-																	
5. Methanol availability………..	3.29	1.11	-.31	.79*	.62	.85*	-																
6. Infrastructural readiness……..	3.86	1.21	-.08	.76*	.21	.91**	.77*	-															
7. Goals alignment……………..	4.43	0.53	.78*	-.09	-.60	.05	-.24	.11	-														
8. Regulation stability………….	4.43	0.53	.28	-.09	-.32	-.28	-.24	-.40	.42	-													
9. Production regulation………..	4.14	0.90	-.34	.49	.55	.33	.62	.02	-.50	.20	-												
10. Bunkering regulation………	4.43	0.98	-.12	1.00**	.13	.92**	.79*	.76*	-.09	-.09	.49	-											
11. Technology certification…...	4.71	0.49	.43	.30	-.18	.21	.18	-.08	-.09	-.09	.49	.30	-										
12. Enforce capacity…………...	4.14	0.69	.52	.14	-.37	-.07	-.06	-.37	.26	.71	.50	.14	.64	-									
13. Level playing field…...…….	4.00	1.15	.81*	.30	-.65	.15	.00	.00	.54	.54	.16	.30	.59	.84*	-								
14. Social acceptance………….	3.43	0.79	.19	.37	.35	.48	.60	.25	.28	.28	.61	.37	.37	.48	.37	-							
15. Qualified staff……………...	3.57	1.40	.18	.77*	-.41	.61	.31	.55	.29	.29	.06	.77*	.03	.25	.52	.04	-						
16. Emission reduction………...	4.29	0.52	.39	-.30	-.13	-.21	-.18	-.20	.73	.73	-.11	-.30	-.30	.35	.30	.50	-.03	-					
17. Return on investment………	3.86	0.90	.34	-.11	-.21	-.33	-.12	-.48	.15	.84*	.44	-.11	.27	.84*	.64	.34	.08	.49	-				
18. Capital intensity……………	3.86	0.90	.63	-.11	-.55	-.33	-.29	-.48	.15	.50	.24	-.11	.65	.84*	.80*	.10	.08	.11	.79*	-			
19. Operational expenses………	4.29	0.76	.78*	-.19	-.88**	-.36	-.51	-.31	.47	.47	-.32	-.19	.26	.55	.76*	-.24	.29	.19	.56	.81*	-		
20. Subsidy availability………..	3.00	1.53	.52	.22	-.49	.00	.00	-.09	.41	.82*	.24	.22	.22	.79*	.85*	.28	.55	.45	.85*	.73	.72	-	
21. Willingness to pay………….	3.57	1.27	.51	.04	-.57	-.16	-.13	-.05	.32	.56	-.08	.04	.04	.46	.68	-.12	.44	.23	.67	.67	.84*	.86*	-

[1] *n* = 7 $^{**}p < .01$; $^{*}p < .05$.

Table 15. Descriptive and Correlations among Variables (All Data)[1]

Variable	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Methanol investment stage…..	3.23	1.40	-																				
2. Technical readiness………….	4.33	1.08	.26	-																			
3. Alternative fuel investment….	3.72	0.97	.07	.37*	-																		
4. Feedstock availability……….	3.85	1.04	.51**	.42**	.50**	-																	
5. Methanol availability………..	3.95	1.07	.48**	.47**	.49**	.89**	-																
6. Infrastructural readiness……..	4.00	1.12	.28	.52**	.24	.56**	.61**	-															
7. Goals alignment……………..	4.13	1.03	.07	.31	.22	.07	.03	.32*	-														
8. Regulation stability………….	4.49	0.64	.40*	.40*	.31	.39*	.30	.40*	.26	-													
9. Production regulation………..	4.05	0.94	.07	.42**	.45**	.25	.31	.47**	.07	.39*	-												
10. Bunkering regulation………	4.28	0.92	.28	.49**	.33*	.46**	.44**	.59**	.13	.34*	.62**	-											
11. Technology certification…...	4.36	0.71	-.03	.15	.15	.11	.09	.17	-.06	.13	.37*	.37*	-										
12. Enforce capacity…………...	3.97	0.87	.16	.12	.21	.20	.19	.19	.24	.35*	.45**	.11	.10	-									
13. Level playing field…...…….	3.92	1.29	.04	-.06	.09	.01	-.04	.05	-.07	.17	.22	-.05	.15	.23	-								
14. Social acceptance………….	3.33	0.90	.17	.21	.32*	.39*	.35*	.29	.32*	.17	.20	.30	.18	.25	.00	-							
15. Qualified staff……………...	3.23	1.18	.11	.27	.04	.18	.18	.50**	.28	.16	.23	.42**	.28	.03	.27	.05	-						
16. Emission reduction………...	3.92	1.06	.33*	.59**	.46**	.39*	.34*	.44**	.35*	.40*	.42**	.35*	.14	.45**	.27	.28	.27	-					
17. Return on investment………	3.87	1.03	.08	.16	-.01	.18	.14	.23	.11	.37*	-.07	-.10	.03	.17	.29	-.07	.24	.18	-				
18. Capital intensity……………	3.90	0.94	.24	.24	-.09	.14	.12	.20	.04	.35*	-.14	-.09	.14	-.10	.21	-.11	.31	.12	.80**	-			
19. Operational expenses………	4.00	0.95	.38*	.28	-.06	.24	.21	.40*	.13	.35*	-.03	.03	.16	-.06	.15	.03	.42**	.10	.62**	.80**	-		
20. Subsidy availability………..	3.49	1.12	.14	-.05	-.11	.09	.02	-.15	.08	.25	-.20	-.06	-.19	.01	.03	-.01	.01	-.14	.49**	.47**	.30	-	
21. Willingness to pay………….	3.87	1.08	.26	.10	-.14	.24	.20	.20	.02	.36*	-.12	-.07	-.08	.05	.07	-.23	.02	-.10	.62**	.50**	.49**	.55**	-

[1] $n = 39$ $^{**}p < .01$; $^{*}p < .05$.

4.2.3. Significant Differences in the Importance of the Uncertainties

To test whether there is a significant difference in the importance of perceived uncertainties between two groups of stakeholders, the chi-square test is used in this study. Two types of stakeholders are chosen to test the difference in their perception regarding the uncertainty affecting the methanol investment decision. The type of stakeholders used in this study is the stakeholders whose survey responses reach at least five respondents. Therefore, shipowners and shipyards are the only stakeholders whose important differences are tested. These significant differences analysis will help provide insights into the extent to which each group perceives a specific uncertainty as a critical factor, potentially influencing industry strategies and policy development.

Differences in the Importance of a Specific Perceived Uncertainty

The difference in the importance of a specific perceived uncertainty is tested, to see whether there is any difference between the importance of a specific uncertainty between two stakeholders. The first set of hypotheses is formulated as follows.

Null Hypothesis*: There is no significant difference in the importance of methanol availability between shipowners and shipyards.*
Alternate Hypothesis*: There is a significant difference in the importance of methanol availability between shipowners and shipyards.*

The uncertainty regarding methanol availability is chosen in this hypothesis testing because there might be a difference in the importance of methanol availability between shipowners and shipyards. While shipowners need to consider the availability of the fuel itself before deciding to invest in a certain fuel, the shipyards are more focused on designing the ships to comply with a certain type of fuel. The first hypothesis result is as follows.

```
##         Pearson's Chi-squared test
##
## data:  contingency_table4
## X-squared = 10.909, df = 3, p-value = 0.00877
```

According to the output above, as the p-value is 0.00877, which is lower than 0.05 and close to zero, the null hypothesis can be rejected and accept the hypothesis that there is a significant difference in the importance of methanol availability between shipowners and shipyards. The outcome proves the significant perception disparities between the two stakeholders. The methanol availability is highly important for the shipowners. Whereas for the shipyards, methanol availability is one of the least important uncertainties affecting their methanol investment decision. This discrepancy highlights the different priorities and challenges each group of stakeholders face when considering the methanol investment.

The second set of hypotheses is formulated as follows.

Null Hypothesis*: There is no significant difference in the importance of the feedstock availability between shipowners and shipyards.*
Alternate Hypothesis*: There is a significant difference in the importance of the feedstock availability between shipowners and shipyards.*

Furthermore, the uncertainty regarding the availability of feedstock for the production of low-emission methanol is chosen, because there is a difference in the most occurring barriers between the literature study and interview results. While in the literature study, one of the most occurring barriers is the feedstock availability, the availability of methanol is one of the most occurring barriers from the interview. Furthermore, shipowners focus on whether there is sufficient feedstock for a specific fuel to ensure enough fuel that is suitable for their vessels. In contrast, shipyards focus on designing and building the vessels according to their customers' needs. Therefore, there might also be a different in the importance of the uncertainty regarding the feedstock availability between these two stakeholders. The second hypothesis result is as follows.

```
##        Pearson's Chi-squared test
##
## data:  contingency_table4
## X-squared = 8, df = 3, p-value = 0.03381
```

According to the output above, as the p-value is 0.03381, which is lower than 0.05 and close to zero, the null hypothesis can be rejected and accept the hypothesis that there is a significant difference in the importance of feedstock availability between shipowners and shipyards. The uncertainty of feedstock availability is moderately important for the shipowners, because the feedstock is important to produce the fuel, therefore will affect the uncertainty of the methanol availability as well. On the other hand, the uncertainty of feedstock availability is neutrally important for the shipyards, because it is not of major importance for them, who are focusing on building and designing the vessels.

Differences in the Ranking of the Uncertainties' Importance

The importance of the perceived uncertainties is ranked for the shipowners and shipyards, to see whether there is any significant difference in the importance ranking between the shipping stakeholders. The comparison is shown in the table below.

Table 16. Comparison in the Uncertainties Importance Between the Shipping Stakeholders

Rank	Shipowners (n = 15)	Shipyards (n = 7)
1	Methanol availability (4.73)	Technical readiness (4.71)
2	Regulation stability (4.60)	Technology certification (4.71)
3	Infrastructural readiness (4.53)	Goals alignment (4.43)
4	Technical readiness (4.47)	Regulation stability (4.43)
5	Feedstock availability (4.40)	Bunkering regulation (4.43)
6	Bunkering regulation (4.40)	Emission reduction (4.29)
7	Technology certification (4.40)	Operational expenses (4.29)
8	Level playing field (4.27)	Production regulation (4.14)
9	Operational expenses (4.20)	Enforce capacity (4.14)
10	Goals alignment (4.20)	Level playing field (4.00)
11	Production regulation (4.13)	Infrastructural readiness (3.86)
12	Emission reduction (4.13)	Return on investment (3.86)
13	Capital intensity (4.07)	Capital intensity (3.86)
14	Alternative fuel investment (4.00)	Alternative fuel investment (3.71)
15	Enforce capacity (4.00)	Qualified staff (3.57)
16	Return on investment (3.93)	Willingness to pay (3.57)
17	Willingness to pay (3.87)	Social acceptance (3.43)
18	Qualified staff (3.60)	Feedstock availability (3.29)
19	Social acceptance (3.47)	Methanol availability (3.29)
20	Subsidy availability (3.20)	Subsidy availability (3.00)

The third set of hypotheses is formulated as follows.

***Null Hypothesis**: There is no significant difference in the ranking of the uncertainties' importance between shipowners and shipyards.*
***Alternate Hypothesis**: There is a significant difference in the ranking of the uncertainties' importance between shipowners and shipyards.*

The importance ranking of the uncertainties between shipowners and shipyards is tested to see whether there is any significant difference between the priorities of the uncertainties between the stakeholders. As different type of stakeholders have their own roles, insights, and experiences regarding the uptake of a sustainable fuel, there might be a difference in the uncertainties that are becoming the most and the least important for their methanol investment decision. The third hypothesis result is as follows.

```
##          Pearson's Chi-squared test
##
## data:  contingency_table4
## X-squared = 240, df = 210, p-value = 0.2358
```

According to the output above, as the p-value is 0.2358, which is higher than 0.05, the alternate hypothesis can be rejected and accept the null hypothesis that there is no significant difference in the ranking of the uncertainties' importance between shipowners and shipyards. Although there is a significant difference in the importance of the methanol availability and feedstock availability uncertainties between the shipowners and the shipyards, as the methanol and feedstock availability is highly important for the shipowners, but one of the least important for the shipyards, the other perceived uncertainties rank similarly. Therefore, the ranking of the uncertainties' importance between these two stakeholders has no significant difference.

4.2.4. Summary of the Survey Findings

The survey revealed the shipping stakeholders' interest in investing in methanol as a marine fuel and the importance of perceived uncertainties related to the sustainable methanol transition. Of the 39 respondents, 35 view sustainable investment as either a primary concern or of great importance for their organisations. The primary motivations are the desire for sustainability and customer demand fulfilment, with less significance on regulatory compliance. This finding enlightens that the shipping industry is giving efforts for sustainability as both a business strategy and a moral obligation, rather than solely regulatory compliance. Investments in the use of sustainable fuels are discovered as the main investments that are being considered the most. Since these sustainable fuels are more expensive, more investments are being considered in alternative power trains and operational measures to lower energy use.

The survey categorises the methanol investment into five stages. It is discovered that the mean of the methanol investment stage is 3.23, indicating a moderate level of methanol investment. Most stakeholders are in the third stage of feasibility assessment, which signifies active involvement in researching the methanol viability for investment consideration. A significant portion of stakeholders have already finalised their methanol investment decision, indicating their readiness for methanol transition.

In conclusion, the shipping industry shows a strong inclination towards sustainable methanol, supported by the fact of a moderate level of investment, with most stakeholders assessing the feasibility of methanol transition and some of them are already positive with their methanol investment decision, which is mostly driven by the desire for sustainability and fulfilling customer demand, indicating a move towards sustainable shipping driven mostly because of the business target for continuous improvement and a moral obligation to contribute to sustainability. The differences in stakeholders' priorities in facing the uncertainties related to the uptake of sustainable methanol underscore the diverse challenges in deciding the methanol investment for the sustainable methanol transition. The shipowners are looking for possibilities to make their vessels applicable with methanol, either newbuild an entire vessel or retrofit by changing parts of the vessel's engines. Therefore, their most important uncertainty is the availability of methanol. For the shipyards, they are designing and building the ships as requested by the shipowners. Therefore, their most important uncertainty is the technical readiness of the technology utilisation in their intended environment. For the fuel suppliers, they are looking for the possibilities to get green methanol as a sustainable fuel option to supply. However, the sustainable methanol price that is higher than the fossil fuels make the uncertainty regarding the willingness to pay from the customers, are the most important for the fuel suppliers. For the original equipment manufacturers and suppliers, they are having the technology development projects, to develop more high-tech engines. However, it is uncertain whether their innovated products would be bought by their customers. Therefore, the uncertainties regarding the technology certification and the long-term regulation stability are the most important for them. Finally, both shipowners and shipyards perceived the subsidy availability as the least important, and also one of the least important for the original equipment manufacturers and suppliers. However, it is highly important for fuel suppliers. The different perception is because the main investment needed for methanol transition is on its production, enabling the existing subsidies for the operational costs of fuel, which makes them highly important for fuel suppliers, but not relevant for others.

4.3. Value Network Map

The study's findings resulted in a value network map that shows the relationships between shipping stakeholders related to methanol transition. The value network map is based upon the outcomes of the survey, supported by the literature review and the interviews, that shows the stakeholders in which most direct contact with a specific stakeholder and the most important uncertainties for them. The relationships that are depicted in this value network map are the relationships between the main shipping industry stakeholders from the commercial side, and the flow depicted is the financial flow. This map aims to enhance the understanding regarding the relationships and alignment of the most important uncertainties between the shipping stakeholders, to enable the support between stakeholders in response to contribute to the more efficient methanol transition. Therefore, the map creates a sectoral focus on the most important uncertainties affecting the pace of the methanol transition. The other uncertainties are deliberately not depicted here because this map focuses on reducing the uncertainties that are the most crucial for each main stakeholder, which hinders the stakeholders' consideration to invest in methanol. Thus, with the more certain conditions, it is expected that the willingness to invest of the main shipping stakeholders will increase, and, therefore, foster the transition process within the value network.

The green methanol value network map is divided into two figures. Figure 8 shows the main shipping stakeholders, the relationships, and the main issues that they face during the methanol transition. Figure 9 expands the previous figure into mapping the uncertainties between stakeholders, the recommendation for its control measures, and what the intended effect would be on the uncertainties.

The green methanol value network map shows the relationships between the shipping stakeholders of shipowners, shipyards, fuel suppliers, original equipment manufacturers and suppliers, classification societies, shippers, end customers, fuel producers, feedstock producers, and port authorities. These main shipping stakeholders and their relationships were based on the findings obtained from the interview and survey regarding the stakeholders in most direct contact with the participants. The green arrow marks the financial exchange between the two stakeholders, the purple arrow signs the services flow, the yellow arrow marks the product flows, and the light blue arrow marks the information flow.

The shipping stakeholders' relationships in Figure 8 are as follows. The shipowners pay a certain amount of money to the shipyards for designing and building the ship. The shipyards then distribute the money to the original equipment manufacturers and suppliers to buy specialised goods, such as the engines and equipment for the ship, and also distribute money to the classification societies as the ship's certification and inspection fee. The shipowners receive the design and the construction of their ships from the shipyards. The shipowners pay money to the fuel suppliers to purchase fuel, in which the fuel suppliers purchase the fuel from the fuel producers, and the fuel producers purchase feedstock from the feedstock producers. Additionally, fuel suppliers also pay a certain amount of money for the license fee to the port authorities, as they require a license to operate in the port. Furthermore, the shipowners give the shipping services to the shippers and receive money from them as the service fee, and the shippers also provide shipping services to the end customers. This model is a simplification of reality as many roles of the stakeholders are integrated into one company, and more detailing is also possible. This set up is chosen for this study because the stakeholders depicted in the simplified value network map are based on the available data from the survey respondents within the Green Maritime Methanol consortium. The simplified map is also to gain general recommendations for the main shipping stakeholders that act as the early adopters, which recommendations can be in more detailed in future research if more different types of stakeholders are involved in the methanol transition process.

Figure 8 maps the ideal relationships in regards to the methanol utilisation. However, suppose one or more of the stakeholders are not considering investing in methanol. In that case, the whole value network will be disrupted because the interaction between the stakeholders is important in the supply, production, and distribution of the methanol, along with its supporting vessels, to enable the shipping services to the end customers. The uncertainties faced related to the uptake of sustainable methanol affect the investment considerations of the stakeholders. If the stakeholders face uncertainties that will be really hindering their activities, they will reconsider the methanol transition feasibility, and thus, might not be willing to invest in a specific sustainable fuel. Therefore, it is highly important to ensure that every stakeholder within the value network is considering investing in a specific sustainable fuel, in this case, methanol. Since the level of uncertainties faced by each stakeholder is different, the related stakeholders that are more certain in a specific aspect can help the other stakeholders that are facing a high uncertainty in the related aspect, therefore reducing the high level of a specific uncertainty of the related stakeholder. With the interaction that can help reduce each others' uncertainties, it is expected that the consideration to invest in methanol will tend to be more positive with the reduced uncertainties, compared to the high uncertainties level.

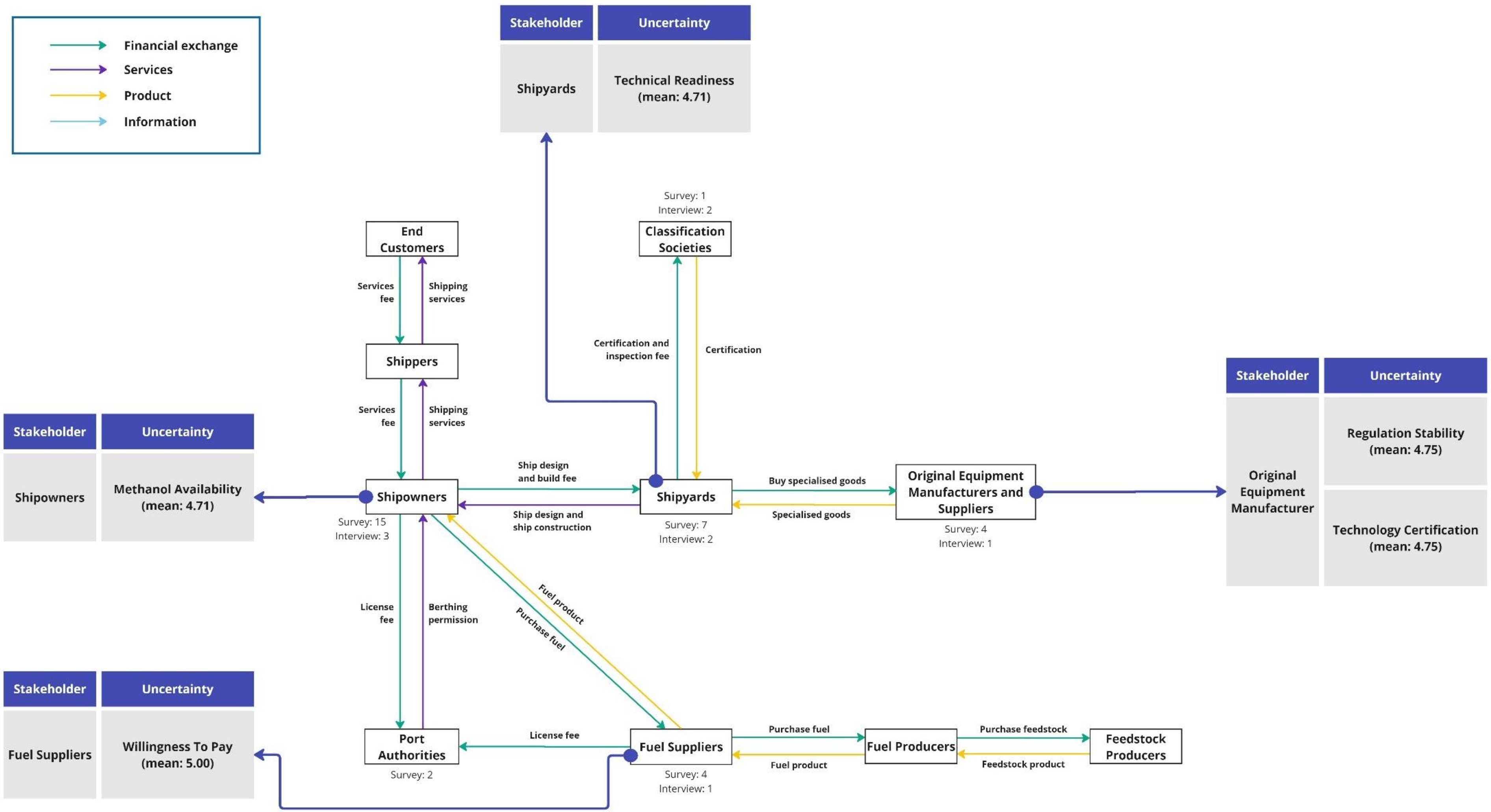

Figure 8. Green Methanol Value Network Map (Part 1)

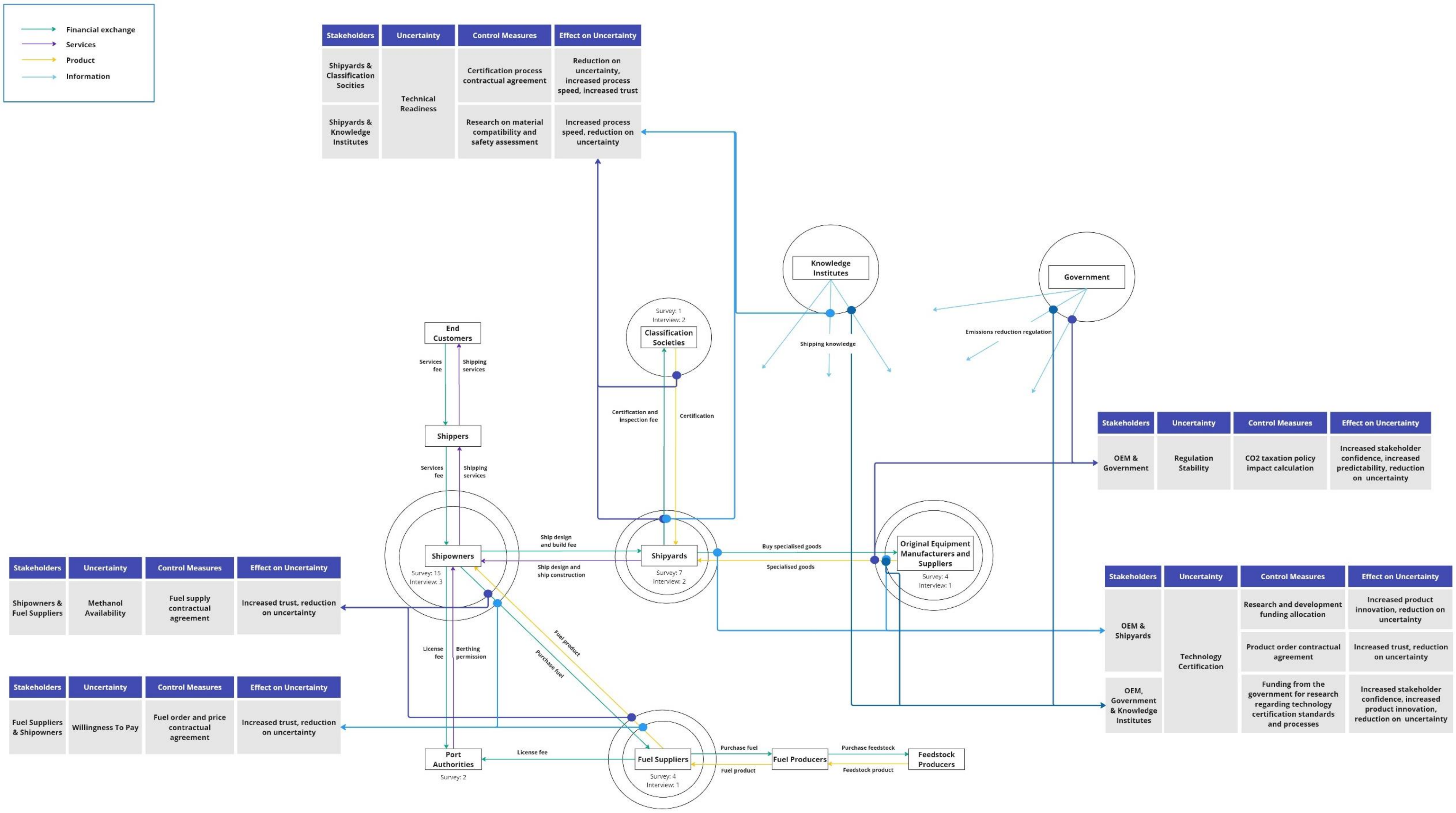

Figure 9. Green Methanol Value Network Map (Part 2)

The main uncertainties faced for the methanol transition from the survey are shown in Figure 8. The uncertainties are shown for certain types of stakeholders, including shipowners, shipyards, fuel suppliers, and original equipment manufacturers and suppliers. These four stakeholders are chosen to show their most important perceived uncertainties related to the uptake of methanol, because a considerable amount of survey responses are received for these four stakeholders. For shipowners, their most important uncertainty is the methanol availability. For shipyards, the most important one is the technical readiness for the use of methanol. For fuel suppliers, their most important uncertainty is the customer's willingness to pay more for sustainable transport using sustainable methanol. Lastly, regulation stability and technology certification are the most important uncertainties for the original equipment manufacturers and suppliers.

These main uncertainties are considered essential to mitigate, as the availability of methanol is a ‘chicken and egg’ issue, and the regulatory impact of the certification is also causing delays. As stated by one of the fuel suppliers and shipowners, the fuel suppliers are willing to investigate and invest money in getting methanol ready. However, they cannot supply the energy without demand, whereas the shipowners cannot handle the risks of the fuels that are too expensive and volatile. Therefore, the shipowners mitigate the risks by purchasing dual-fuel engines, making them utilise other types of fuels more, because the fuel is not limited solely to methanol, whose price tends to be higher at the moment than the other conventional fuels. However, the demand for mid and high-speed engines is too low due to the earlier mentioned chicken and egg issue, and thus, the technology availability lags behind and the green methanol is really limited at the moment. Many other issues also occur; however, based on the literature review, interviews, and extensive questionnaire, the example above can be concluded.

Figure 9 maps the uncertainties mentioned in Figure 8 into the connection flow between the related stakeholders. For the methanol availability uncertainty of the shipowners, through their engagement with the fuel suppliers, this uncertainty can be reduced by making a contractual agreement between shipowners and fuel suppliers regarding a certain amount of fuel that needs to be supplied by the fuel suppliers to the shipowners, for every certain amount of time. Methanol availability is the most important uncertainty because it is highly important for shipowners to ensure that there are sufficient amounts of fuel to sail their vessels. With this agreement, it is expected that the uncertainty will be reduced and the trust between both stakeholders will increase.

A similar case also applies to the fuel suppliers. The uncertainty faced by the fuel suppliers is the customer's willingness to pay more for sustainable fuel. The reason is that renewable fuels are more expensive compared to fossil fuels. The price disparity can make customers hesitant to switch to renewable fuels. Without a guarantee that the customers that willing to pay premium prices, the fuel suppliers will face risks in considering the technology and infrastructure investment that is applicable to sustainable fuels. Therefore, even though the price is expected to be more expensive, the fuel suppliers think that front runners should have benefits for their proactive efforts. A contractual agreement between the fuel suppliers and shipowners regarding a certain amount of fuel that the shipowners will order along with the agreed price will make the fuel suppliers get a more guaranteed income that will be received routinely.

The contractual agreement between the shipowners and the fuel suppliers can be in the form of an indexed price agreement with flexibility clauses that adjust prices according to the specific fuel purchased. The contract connects a green methanol index to the price of green methanol to ensure that the base price remains competitive in the market. The agreement involves a minimum volume of fuel that is required at every specific time to ensure that the fuel suppliers have a stable demand. This recommendation has been brought up in an expert panel validation by discussing it with the related companies, including a fuel supplier.

The most important uncertainty related to the uptake of green methanol for shipyards is technical readiness. This uncertainty is related to the classification societies, in which they do the pilot process for the certification and inspection of the ship design and construction. Usually, the certification process requires several years to complete, making the uncertain condition for technical readiness to the use of required technology in the shipyards' intended operational environment, because the shipyards cannot implement technologies which are not at a sufficient level of technology readiness. Collaborating using the contractual agreement regarding the certification process between the shipyards and classification societies can speed up the certification process. The agreement involves a clear timeline for each stage of the certification process, with a dedicated joint team consisting of representatives from the shipyards and the classification societies to manage the entire certification process, ensuring alignment between the two parties. Thus, the technical readiness uncertainty can be reduced, the process speed can be sped up, and the trust between both stakeholders will increase. Furthermore, the knowledge institutions also can help in reducing this uncertainty, by researching the material compatibility and safety assessment to foster the readiness of the required technology for methanol utilisation.

There are two most important uncertainties for the original equipment manufacturers and suppliers in relation to the uptake of green methanol. The first uncertainty is the long-term regulation stability of the regulation and government policy support concerning sustainable fuels, which requires engagement with the government to reduce the uncertainty. The changing regulations regarding emissions reduction create uncertain regulation stability for the original equipment manufacturers and suppliers. An impact calculation for the CO2 taxation policy is given as the recommendation. The CO2 taxation policy is the policy that requires the stakeholders that still producing a lot of CO2 emissions, to pay a certain amount of taxes. If the calculation has been done for a certain policy plan, then the policy can be made, and thus the regulation will be stable in the long term.

The second uncertainty for the original equipment manufacturers and suppliers is the rate of technology certification for the use of technologies related to methanol. To use the equipment produced, the original equipment manufacturers and suppliers need a technology certification to check whether their product works. However, to check whether their product makes sense, it requires a certain amount of investment. The uncertainty regarding whether people will buy the product makes it risky to invest. To reduce this uncertainty, three actions are recommended to be taken. The first one is to allocate a certain amount of funding for research and development to increase product innovation and reduce uncertainty. The second recommendation is to make a contractual agreement between the shipyards and the original equipment manufacturers and suppliers regarding a certain amount of product that will be purchased every certain amount of time. The agreement consists of the guaranteed minimum quantity purchases of the certified technology over a set period and the collaborative efforts in achieving technology certification. The collaborative efforts can consist of product testing, data collection, and idea generation. Therefore, the original equipment manufacturers and suppliers will get a more certain condition for doing the research and development for innovative products and the trust between both stakeholders will increase. Lastly, the knowledge institutions can also help reduce this uncertainty by researching the technology certification standards and processes, with the help of funding from the government. The support from both knowledge institutions and the government can increase the process of product innovation from the original equipment manufacturers and suppliers, and thus reduce the technology certification uncertainty.

With these recommendations of actions for the shipping stakeholders, it is expected that the stakeholders' engagement can help reduce the uncertainties faced by the others related to the uptake of green methanol. In conclusion, based on the value network map analysis, the outcome of the prioritised uncertainties most heavily affecting the viability of methanol and on which main relation the issue occurs, is visualised. This analysis provides a basis for practitioners to increase their impact, as it provides a focal point for mitigatory actions. Additionally, based upon expert panel discussions, a subset of seven actions have been recommended, which are suggested to be continued in further research, including the quantitative analysis for its impact, to foster the methanol transition process.

5. Discussion

The result of this study aims to provide an understanding regarding the viability of methanol transition assessed from various aspects and the importance of barriers affecting methanol's investment decision between the shipping stakeholders. This chapter explores the integration of the research findings with the theoretical literature and the supporting evidence. The findings are examined to answer the research questions while comparing them to the previous theory. The recommendations for future research are also discussed in this chapter.

5.1. Discussion about Methods Used in This Study

The study analyses the socio-technical system of green methanol in the shipping industry. Referring to Geels's (2012) model of multi-level perspective on low-carbon transition, a niche can move towards the regime if it is supported by sufficient actors and resources, with the increasing investment decision towards a specific innovation as an example. It is important to highlight that all eleven interviewees stated that they are currently developing the necessary infrastructure for methanol, and they have confirmed that methanol relates to the current shipping industry needs. This highlights the increasing investment decision towards methanol, and therefore, methanol can move towards a higher level of regime in multidimensional development, signifying the process of methanol transition as a low-carbon innovation in the transportation sector. The shift to a higher level is facilitated by the increasing investment decisions and strategic actions by the stakeholders' engagement who recognise methanol's potential to meet environmental and regulatory requirements. The dynamic interaction between the niche, regime, and landscape levels highlights how multidimensional development can drive the transitions from diesel fuel to sustainable methanol, signifying a shipping industry's move towards sustainability.

In evaluating the investment attractiveness of methanol, the Clean Energy Technology Investment Attractiveness Scan (CETIAS) by Donker et al. (2020) was used. This framework helps in guiding the investment attractiveness evaluation by providing the criteria for each aspect, which consists of political, economic, social, technological, and environmental. In this research, the criteria were useful in formulating the interview questions regarding the feasibility of methanol transition from different aspects, and formulating the survey questions regarding the importance of perceived uncertainties affecting investment attractiveness that are adjusted from both CETIAS and Hajonides' List of Uncertainties. The findings revealed that methanol is seen as a feasible green alternative fuel, especially favoured for its social, technological, and environmental feasibility. However, the findings also highlighted some challenges, particularly in economic and political aspects. Because CETIAS guides in assessing the investment attractiveness for each aspect, it enables easy question formulation for data collection and in drawing conclusions about each aspect's feasibility. However, the criteria in this framework for each aspect have been determined absolutely. They thus are rigid, which makes it inflexible if any other factors also affect the specific energy technology in certain aspects. The limitation highlights the need for continuous updates to CETIAS, ensuring that the framework remains relevant in evaluating the quickly changing industry. Therefore, it is recommended to add flexibility in criteria application by adding an optional additional criterion that can be added manually based on the needs. Moreover, it is also recommended to develop a more-detailed tool based on the CETIAS, that is specifically made for evaluating the investment attractiveness of sustainable fuel.

Furthermore, this study used the List of Uncertainties by Hajonides (2023) in evaluating the uncertainties of methanol transition as a marine fuel. This framework helps in identifying the barriers to methanol transition and investigating the stakeholders' relationships to reduce the barriers. In this research, the list of uncertainties was useful in formulating the survey questions regarding methanol's uncertainties affecting investment attractiveness, in which the respondents will reflect on how important the perceived uncertainties are for their organisation. Because the Hajonides' List of Uncertainties provides a list regarding the uncertainties for maritime fuel transition, it guides clear methanol transition assessment in checking whether the barriers to maritime fuel transition are also faced in the methanol transition. However, it is hard to define the term 'uncertainties' and differentiate it from the 'barriers', which makes the data analysis more complex.

The following steps are taken to make a clearer definition. Firstly, the definition between the uncertainties and the barriers are defined (refer to section 2.4.). Uncertainty is a situation faced by a stakeholder which can affect their investment decision to cleaner energy either positively or negatively, where the possible outcomes and the probability of occurrence are unknown. In contrast, a barrier is a challenge that hampers a transition to proceed. Then, the differences and how to interpret the information are clarified. Uncertainty can be a barrier or a driver, but it does not apply if the statement is reversed. Lastly, the reasons why a specific term is used in a specific section are justified. The barrier term is used to analyse the interview findings because the research seeks to discover what aspects can hinder the investment decision to methanol transition. On the other hand, the uncertainty term is used in the survey to evaluate the most important situation in which the probability of occurrence and impact is unknown. By discovering the most important uncertainties, it can be analysed further regarding how to reduce the uncertainties through the stakeholders' engagement, thus fostering the investment decision process. A recommendation of providing a guideline is suggested to improve this tool. The guideline will be helpful to effectively distinguish and apply the terms in different contexts, which consists of case studies and examples that illustrate the differences between the uncertainties and the barriers in real-world cases.

The combination of both qualitative and quantitative research design complements the research findings in certain aspects. First, a strong conclusion can be concluded regarding the extent of methanol's viability, because it was assessed from multiple aspects that complement the conclusion: the feasibility assessment from PESTE aspects obtained from the experiences of the stakeholders in their natural settings, and the barriers assessment obtained from the opinions of the stakeholders which patterns can be analysed. Second, the broader knowledge regarding the willingness to invest from the stakeholders can be obtained by the qualitative descriptions of activities related to methanol transition in the organisations, the type of investments that are considered, and the reasons for investment consideration, complemented by the qualitative assessment of the investment stage of methanol application. Lastly, the mixed methods can provide multiple data sources, which leads to less subjectivity in the research outcomes.

Both the interviews and a survey asked about the stakeholders in most direct contact with the participants to validate the outcomes, although each method engaged slightly different stakeholder types. Both the interviews and a survey collected data from the main shipping stakeholders, including shipowners, shipyards, fuel suppliers, original equipment manufacturers and suppliers, and classification societies. However, the survey also received responses from the broader stakeholders, including the port authorities, the consultancy companies and the trade associations. The survey responses were from the stakeholders within the Green Maritime Methanol consortium that has been biased towards methanol. On the other hand, the study also interviewed two stakeholders, one from a governmental organisation and the other one from an NGO, which is outside the consortium, to verify the intermediate findings of the study from the perspectives of the stakeholders looking forward to sustainable fuels but unbiased towards methanol. These two interviewees were researching the use of sustainable fuels, including methanol, but they have no preferences towards a specific type of fuel. Combined together, this study involves various perspectives from different stakeholders, mostly inside the methanol consortium but also some from outside the consortium, providing a thorough view of the shipping stakeholders towards green methanol.

Combining qualitative and quantitative research designs provided added value to the study by ensuring comprehensive and robust evaluations. The interviews offered deep, personalised insights from the stakeholders, allowing an understanding of their experiences, perspectives, and specific issues related to methanol transition. A survey provided quantitative data across a larger group of shipping stakeholders, allowing for the validation of trends observed in the interviews. While the qualitative data from the interviews enriched the understanding of stakeholders' investment considerations and perceived barriers, the quantitative data from a survey quantified these insights, providing a clearer picture of investment stages and priorities. Finally, the use of both methods, complemented by a literature review, enabled data triangulation, thereby enhancing the reliability and validity of the findings.

Overall, the researcher concluded that doing both interviews and a survey in this study is worthwhile. Both methods complement each other in obtaining a thorough evaluation regarding methanol's viability and creating recommendations to foster its transition. A value network map was created as a result, in which the insights obtained from the combination of both methods strengthened the confidence that the recommendations suggested from the map are relevant for the current conditions. This approach ensured that the value network map and suggested control measures are highly relevant and actionable, that can effectively support the methanol transition process.

5.2. Analysis of the Findings

The study investigated the viability of methanol transition in the shipping industry. From the interview, it was found that methanol is feasible based on the political, social, technological and environmental aspects; and is partially economically feasible. The economic aspect is partially feasible because currently, it is not financially beneficial to use methanol. However, the methanol investment risks are still acceptable and there might be a possibility that using methanol will be profitable if a certain policy is applied for those who still use high-emission fuels. Moreover, compared to other fuels such as ammonia, LNG, and hydrogen, methanol is favoured by many shipping stakeholders because it has favourable advantages, including being less toxic, easier to handle and integrate with the existing infrastructure. Many shipping stakeholders are currently conducting activities to support the methanol transition, which supports its viability. From the survey, it was found that the shipping stakeholders are currently at a moderate level of methanol investment (mean of 3.33), with most stakeholders in the third stage of feasibility assessment for methanol investment consideration and the fifth stage of already positive final methanol investment decision. Out of 39 responses, 35 of them consider sustainable investment to be either their top priority or a great important investment, which is mostly driven by the desire for sustainability and customer demand fulfilment. It can be concluded that methanol investment is highly supported by the shipping stakeholders that give priority to sustainable investment, and some of them already decided to invest in methanol. Therefore, methanol is deemed feasible based on its performance in technology advancements and the supporting actors. Furthermore, although there are various barriers to methanol transition, the barriers can be reduced through the existing stakeholder relationships that are dedicated to adapting to cleaner fuel and prefer to use methanol. Therefore, methanol is deemed feasible based on the barriers assessed. In conclusion, based on the study's assessments of both the interview and survey findings, methanol is a viable option in the shipping industry. Compared to the literature review, these findings regarding methanol's viability are expected since most of the literature discussed that methanol is a potentially sustainable fuel option, and the barriers to methanol transition are low, compared to the other type of fuel options, including ammonia, hydrogen, and LNG. Additionally, a weighted score is automatically generated through a CETIAS excel sheet developed by Halstead et al. (2021) by selecting an option that best matches the current situation regarding the use of methanol. The assessment confirmed the qualitative PESTE feasibility assessment, that methanol is feasible politically, socially, technologically, environmentally, and is partially economically feasible.

From the interview, an interesting finding was discovered regarding a favourability aspect of methanol. Harmsen (2021) and Gerritse and Harmsen (2023) emphasised the consideration to use methanol as a low-emission fuel in the shipping industry, one of which is the fact that methanol is available globally. However, this study found a slightly different outcome because the interview findings showed that many shipping stakeholders are still dealing with the availability of methanol as a low-emission fuel, which supply needs to be increased. This finding is also slightly different from the literature study, which found that one of the barriers that mostly occurs is the availability of feedstock to produce methanol.

An interesting finding was also discovered from the survey. The subsidy availability is the least important uncertainty to methanol transition for the shipowners and the shipyards, and is one of the least important for the original equipment manufacturers and suppliers. However, it is highly important for the fuel suppliers. These different outcomes signify that there might be a different perception regarding the importance of subsidy availability from other stakeholders, that view the uncertainty of subsidy availability as highly important. Furthermore, from the interview, three interviewees, consisting of two shipowners and a classification society, mentioned that more external funding is needed to support the transition to sustainable fuel in the overall system. Compared to the literature review, the study found that the price of methanol is one of the most occurring barriers to methanol transition, although the lack of government incentives is one of the least discussed barriers. This disparity shows that although some stakeholders view that more funding is required to help the sustainable transition in the shipping industry, the uncertainty regarding subsidy availability is not important for the shipowners and shipyards. This is because the investment needed for methanol transition is mostly for the production of methanol. For the shipyards, their company cannot depend on the subsidy itself, and their decision is based on the request of their customers, which are the shipowners. For the shipowners, they have allocated funding to build their ships that can be used for a long-term, with methanol as one of the considerations to make their ships applicable. However, the fuel suppliers really need the incentives to make the price of methanol more affordable for the other stakeholders. Therefore, the subsidy is not important for the shipowners and the shipyards, but it is really important for the fuel suppliers. These findings have been discussed and confirmed in a few stakeholder review discussions with a shipowner, a shipyard, and a fuel supplier.

Furthermore, the study investigates the opportunities that drive the methanol transition. Almost half of the interviewees discussed that emissions reduction and strict regulations are an important opportunity that supports the consideration for methanol. The strict regulations in limiting the number of emissions allowed from the ships and the fact that methanol can reduce the emissions in complying with the government's ambition for emissions reduction will drive the methanol transition. Additionally, the status of methanol that has a high technological readiness level and good future trajectory, the sustainable feedstock, the positive social perception, and the fact that methanol is a popular choice for retrofits can also drive the methanol transition. The study also discovered certain requirements that are necessary to support the methanol transition. The methanol transition requirements consist of the methanol availability that needs to be increased, the engine range that needs to be broadened, the equipment that requires to be developed to be applicable with methanol, more training opportunities for the crew members on board, and the willingness to invest more from the shipping stakeholders. The finding will be useful for shipping stakeholders to take some actions in supporting the methanol transition. Compared to the literature review, the requirements of broadening engine range, developing equipment, and the willingness to invest more are expected, because the stakeholders need to invest for the engine and equipment to be developed, or even newbuilt, to be applicable with methanol. However, the methanol availability that needs to be increased and more training opportunities required are new and interesting findings that are obtained from the stakeholders' insights regarding their current condition in the shipping industry. These are different from the literature review because it is found from the literature that methanol is available globally (Harmsen, 2021; Gerritse and Harmsen, 2023), and there are no barriers found in the literature regarding the lack of qualified personnel for the crew members on board (see section 2.5.).

The assessment of this study indicates that methanol relates to the shipping industry's needs, is a viable option in the shipping industry, and has some favourable opportunities for its application. Methanol's viability is supported by feasibility across political, economic, social, technological, and environmental aspects. The study also reveals that methanol is being supported by many shipping stakeholders that are making efforts to make their infrastructure applicable with methanol and it is deemed feasible based on the barriers evaluated. The anticipated timeline for commercial deployment is around 2028, and most shipping companies have switched their use of conventional fuel to methanol, to comply with the government's ambition regarding emissions reduction in 2030. The study underscores the importance of stakeholders' relationships in reducing uncertainties, as illustrated by the proposed value network map, which shows how stakeholders' engagement can enhance investment decisions. There are diverse perceptions of uncertainties, such as the significant importance of methanol availability for shipowners and technical readiness for shipyards. The differences highlight the necessity for customised recommendations to address specific uncertainties. These recommendations are essential for developing effective solutions to foster the methanol investment process. Finally, even though methanol presents a promising solution to reduce emissions, the success of its transition depends on continuous stakeholders' engagement, strategies to overcome the barriers, and alignment with the regulatory bodies.

Based on the interview and survey findings, a value network map is created, that maps the shipping stakeholders' relationships of financial flow in terms of methanol, as well as the most important uncertainties to methanol transition for certain main stakeholders. The map was visualised based on what the researchers see regarding what is happening in the methanol consortium. It seems that the stakeholders are doing a lot of things to support the methanol transition, but actually they do very little. As an example, different types of stakeholders, especially the shipowners, are mitigating their risks of methanol availability by applying dual-fuel engines, so their ships can potentially sail on methanol. However, it is not uncertain for the suppliers regarding the methanol demand, because the dual-fuel engines enable the shipowners to use other types of fuels more, not relying solely on methanol, especially because green methanol has a higher price than conventional fuels. The shipowners ended up only mitigating the risks for themselves, but not solving the demand issues towards the fuel suppliers. Thus, the whole value chain is potentially disrupted. These situations created a 'chicken and egg' issue, as the fuel suppliers cannot supply the energy without demand, but the shipowners mitigate the risks of insufficient availability of methanol by purchasing the dual-fuel engines, making the methanol demand limited.

Several lessons can be learned from this research. First, it is crucial that a conclusion derived based on the findings is supported by the actual data, not just the assumptions concluded based on the findings. As an example, the explicit statement from the participants regarding a specific aspect of feasibility will enable stronger confidence obtained in formulating a conclusion regarding the feasibility, rather than concluding based on the assumptions made from the findings. Second, it is important to update the interview questions accordingly after conducting several interviews, if necessary, to ensure that the questions asked are suitable to answer the research questions. Lastly, survey draft testing from internal and external stakeholders is important to receive feedback and adjust the survey according to the respondents' points of view. Based on the lessons learned, if the research were done over again, the main difference is to question the interviewees explicitly from the beginning, about whether they think methanol is feasible from various aspects. The feasibility can be rated from 1 to 5, which rates the methanol feasibility from the current time, short-term feasibility in five years, and long-term feasibility in 10 years. This change aims to gain a stronger final conclusion related to the methanol feasibility over time.

5.3. Limitations

The methanol viability investigation involves interviews and a survey as the primary data. However, the number of data used in this study, especially for the survey, is relatively small. The accuracy and confidence level of the statistical results will increase along with the larger sample size. Moreover, the data collected was mainly from the shipping stakeholders within the Green Maritime Methanol Consortium. Therefore, the first limitation of this research is regarding the sample amount for the survey data. By including a larger number of participants from broader stakeholders within the shipping industry, the findings from the study would have a higher confidence level in giving a more comprehensive understanding regarding methanol's viability as a sustainable fuel.

Furthermore, the outputs obtained from this study are from the stakeholders that are involved in the Green Maritime Methanol consortium that has been partly biased towards methanol. Some of the stakeholders are already positive in their final investment decision to methanol, while others are doing feasibility assessments for the investment consideration. Therefore, even though there were some insights related to the challenges of methanol transition, especially in the financial aspects, there were also a lot of insights regarding the investment decision and the activities that are already towards methanol. Most of the stakeholders stated that they prefer methanol to other types of fuels, such as ammonia, hydrogen, and LNG. To further clarify the findings, validation was done by discussing the research findings towards the related shipping stakeholders and the researchers outside the methanol consortium. Further research is therefore suggested, with the larger sample taken also from the stakeholders outside the methanol consortium.

In addition to the PESTE feasibility assessment of the CETIAS tool, the depth of assessment in this study is limited. This study assesses the feasibility from the political, economical, social, technological, and environmental qualitatively. Additionally, an excel sheet has been filled out that calculated the feasibility percentage. However, it is not in the scope to assess the weight. The feasibility percentage is automatically generated based on the selected options regarding a particular situation, which includes four to five options for a specific criterion that can be chosen based on the situation of a specific technology. Therefore, it is important to do further research regarding additional assessment relative to these elements, which extensively research the weight for each aspect.

In the management research of understanding the viability of methanol transition, it is important to study the development of methanol transition in the shipping industry, because the industry is rapidly adapting to the changing needs. It would be relevant to study the changing perception regarding methanol viability along with the increased investment from the shipping stakeholders over time. It was previously conducted in this research to understand when methanol can be a viable option in the shipping industry. However, little is known from the current shipping stakeholders regarding the timeline because there are still a lot of uncertainties that they face for the transition. By conducting a simulation to make the prediction of the methanol transition timeline based on the current methanol situation, the research would offer a better understanding regarding the feasibility timeline in facing the uncertainties of the methanol transition.

Moreover, the research is mainly conducted by one researcher, which drives a potential limitation regarding the conclusion formulation as it relies on the interpretation of one person. Particularly, this research uses judgment sampling in choosing the interviewees who are expected to be experienced in their fields and have sufficient knowledge regarding methanol transition. However, the conclusion derived from this study is based on the researcher's interpretation of the study outcomes. Therefore, the interpretation limitation might lead to bias, affecting the validity of the findings. A validation method can be taken to enhance objectivity, such as data triangulation to validate the research outcomes.

5.4. Theoretical Implications
Many studies have investigated alternative fuels to reduce emissions in the shipping industry, including methanol. Although there is limited research regarding the feasibility of methanol transition in the shipping industry, many initiatives have been taken to develop the knowledge. One of the initiatives is the Green Maritime Methanol project, which studies the feasibility of methanol and the steps towards the implementation. This study expands it to include the feasibility assessment from different aspects, understanding the uncertainties of methanol transition, and the relationships between the shipping stakeholders within the Green Maritime Methanol project.

Methanol is a fuel that is being considered to be used in the shipping industry because it complies with emissions regulations, is readily available globally, and has a high energy density (Harmsen, 2021; Gerritse and Harmsen, 2023). The study found that methanol aligns with the national government's ambitions in reducing emissions and is preferred by many organisations due to methanol's energy density, less toxicity, and easier to handle, compared to other type of fuels such as ammonia, hydrogen, and LNG. However, one of the most occurring barriers is the price of methanol and the methanol availability because green methanol is still limited and hard to get at this moment, and is more expensive than diesel fuels. The findings assess the extent of methanol's viability by combining the clean energy technology assessment criteria and the barriers to fuel transition.

Furthermore, the findings contribute to clarifying the barriers faced by the current shipping stakeholders in considering methanol transition, how important is the barriers, and the relationships between stakeholders. Aligned with the list of uncertainties to maritime fuel transition (Hajonides, 2023), the study confirmed that this framework is relevant to identifying the barriers and uncertainties to the methanol transition. From the interview, it is discovered that the price of fuel, methanol availability, overall pace and direction of the maritime energy transition, and the training challenges are the barriers that occur the most in the shipping stakeholders. Furthermore, from the survey, it is found that the uncertainty regarding the long-term stability of the regulation and government policy support concerning sustainable fuels is the most important uncertainty for the shipping stakeholders.

5.5. Practical Implications

The outcome of the interview and survey findings were used to develop the value network map that shows how the engagement between the shipping stakeholders can reduce the uncertainties of methanol transition. Through the value network map (see section 4.3.), it can be seen that each stakeholders have different most important uncertainties, which indicates that stakeholders with different roles have different uncertainties prioritisation. With the help in reducing the uncertainties, it can increase the stakeholders' willingness to invest in methanol and thus foster the methanol transition within the value network. These recommendations are suggested for the specific stakeholders.

Shipowners and Fuel Suppliers

- A contractual agreement in the form of an indexed price agreement with flexibility clauses between the shipowners and fuel suppliers is recommended. The agreement agrees about the amount of fuel that the shipowners will order along with the agreed price, and the amount of fuel that the fuel suppliers will supply in every period of time. With this agreement, it is expected to help reduce the methanol availability uncertainty of the shipowners and the willingness to pay uncertainty of the fuel suppliers, by making the fuel suppliers get a guaranteed income and the shipowners get a guaranteed fuel for their vessels.

Shipyards

- A contractual agreement between the shipyards and the classification societies is recommended. The agreement can consist of the agreed amount of time required for the certification process by the classification societies, which involves a clear timeline and a dedicated team jointly created by both parties. With this agreement, it is expected that the certification process can be fostered, thus, reducing the uncertainty of technical readiness of the shipyards.
- Additionally, the knowledge institutions can help to do research on material compatibility and safety assessment.

Original Equipment Manufacturers and Suppliers

- To reduce the uncertainty of long-term regulation stability, a CO_2 taxation policy impact calculation is recommended. If the calculations are being made, the policy can be assessed for whether it is suitable or need to be adjusted. In that way, the regulation can be more stable.
- To reduce the technology certification uncertainty, several actions are recommended.
    - First, the original equipment manufacturers and suppliers are suggested to allocation a certain amount of funding for product innovation.
    - Second, a contractual agreement between the original equipment manufacturers and suppliers, and the shipyards is recommended. The

agreement involves a guaranteed amount of quantity that the shipyards will purchase every period of time and the related collaborative efforts.
    - Lastly, the government is encouraged to give funding for the knowledge institutions to research on the technology certification standards and processes.

With these actions it is expected to foster the technology certification process and give a more certain condition to explore product innovation, including engines and equipment for the vessels to be applicable with methanol, for the original equipment manufacturers and suppliers.

5.6. Future Research

Based on the limitations of this study, several recommendations can be given for future research. For future research, it is recommended to conduct a longitudinal study which evaluates how the methanol performances can affect the methanol investment decision of the stakeholders over time. The survey data can be used as the basis for making a prediction regarding when methanol is a viable option based on the current investment decision of the shipping stakeholders and the uncertainties regarding the uptake of sustainable methanol. Moreover, the proposed value network map will be helpful in understanding the stakeholders' relationships and how the interaction can reduce the uncertainties of the other stakeholders in facing a cleaner energy investment decision.

The recommendations for future research topics that are not covered in this study are as follows. These future studies can enhance the understanding regarding the viability of methanol in the shipping industry.

- Investigate the business case of sustainable methanol as a clean fuel in the shipping industry. One of the major barriers to methanol is the lack of knowledge regarding its business case, and not much is known yet regarding its profitability. While methanol might be profitable in the future compared to the use of conventional fuel, especially if there is a regulation that charges taxes for those who do not use cleaner fuel, little is known regarding the future business strategy for methanol investment. Currently, the specific issue is related to the business case calculation of methanol in the long-term. If methanol can be proven beneficial in the long-term by calculating the impact of emissions regulation policy that gives taxes to the use of high-emission fuels, then the investment decision considerations towards methanol can be increased.
- Investigate the shipping stakeholders' relationships into a broader scope. There are several types of shipping stakeholders that are directly and indirectly affected or can be impacted by a specific maritime fuel transition, in this case, methanol. While this study only covers the major shipping stakeholders from the commercial parts and the financial flow between them, it is important to extend it to include the other aspects and expand the network into a broader scope of stakeholders. In this research, the questionnaire was only distributed within the Green Maritime Methanol consortium, and thus, provided bias to the results because the respondents are the stakeholders that are mostly already biased towards methanol. Therefore, by expanding the questionnaire distribution outside the methanol consortium with a broader type of stakeholders, it is expected to get a richer insight into the diverse stakeholders' roles and viewpoints.
- Research on the weight assessment of the methanol feasibility. This research covers the feasibility assessment qualitatively; however, the depth is limited, especially regarding the weight assessment. Therefore, further research that explores the weight assessment for each criterion applicable to methanol is recommended. With the

extensive research on the weight, it is expected to get a stronger conclusion regarding the readiness of methanol in the shipping industry.

- Research on the relationship between the importance of uncertainties to methanol transition and methanol investment stage. To analyse whether the perceived importance of a specific uncertainty in methanol transition influences the methanol investment decision, the relationships between these two variables can be analysed. The relationship analyses can be done on a local and global level, to see the differences in the results. These relationship analyses will give an understanding regarding the uncertainties to methanol transition that affect the methanol investment decision consideration.

6. Conclusion

In reducing the emissions produced by the shipping industry, the transition to a cleaner fuel, such as green methanol, is being considered. Green methanol is promising due to its potential in reducing emissions, it is readily available, and has a favourable energy density. However, research regarding the feasibility of green methanol applications in the shipping industry is still limited, with a remarkable gap regarding the feasibility of methanol transition from PESTE perspectives and the prioritisation of uncertainties affecting the methanol investment decision. To address this gap, the study implemented exploratory research that incorporates both qualitative and quantitative research, by conducting semi-structured interviews and formulating a survey. Eleven interviewees and thirty-nine respondents from different types of shipping stakeholders participated in this study.

This study presented new insights regarding the viability of methanol transition from the PESTE aspects feasibility and the transition uncertainties assessment. Green methanol can be considered a viable option if it is feasible based on the assessments from the PESTE aspects; has powerful actors that support the transition; offers a favourable performance for advancements; and is deemed feasible based on the barriers assessed. Based on the interview result assessment, methanol transition is politically, socially feasible, technologically feasible, and environmentally feasible, but partially economically feasible. The interview also discovers the opportunities and superiority of methanol compared to the other types of fuels, which suggests positive technology advancements for future methanol application. Methanol can significantly reduce emissions, has a good future trajectory, has a sustainable feedstock source, and is a popular choice for retrofits. Furthermore, strict regulations and awards for the front runners can foster the methanol transition process. Methanol is also easier to adopt, integrate, store, and handle, since it is less toxic compared to other types of fuels, such as ammonia, hydrogen, and LNG. Six out of eleven interviewees stated explicitly that they prefer methanol compared to other alternatives.

Both interview and survey discover the stakeholders' relationships in relation to methanol, and how the uncertainties to methanol transition can be reduced with the engagement of the shipping stakeholders. The survey discovers that the shipping stakeholders are in the moderate methanol investment stage, driven by the desire for sustainability. These findings complement the assessment of methanol viability from the stakeholders' support side. Finally, the survey result regarding the prioritisation of the uncertainties affecting the methanol investment consideration complements the viability assessment, which indicates that the methanol transition is doable based on the barriers assessed, because the uncertainties can be reduced with the help of other stakeholders. Based on the assessments of this study, methanol is a viable option in the shipping industry.

One important discussion point is the perception variation in the perceived uncertainties among shipping stakeholders. Methanol availability and feedstock availability are some of the most important perceived uncertainties for the shipowners, but less so for the shipyards. This disparity is because the availability of the fuel and its feedstock is highly relevant for the shipowners, especially for those who have ships applicable with methanol. However, it is not relevant for the shipyards that focus on the design and build the ships as requested by the shipowners. Furthermore, an interesting finding is found regarding the least important uncertainty for both shipowners and shipyards, which is the subsidy availability. The subsidy availability uncertainty is also one of the least important for the original equipment manufacturers and suppliers. However, this uncertainty is highly important for fuel suppliers. These varied stakeholder perceptions have been brought up through a few stakeholder review discussions. It is found that the subsidy availability is indeed the least important for the shipowners and the shipyards in the actual situation. For the shipyards, their decision depends on the shipowners, and they do not think that they can build companies on subsidies. For the shipowners, the subsidy is less relevant for them because they have funding allocated for building ships, taking methanol into account as one of the fuels that the ships will be applicable with. The available subsidy schemes are mostly for the production of methanol, which is also not relevant for both shipyards and shipowners. However, the fuel suppliers need subsidies to produce the methanol at a more affordable price compared to the current methanol price.

Another important point is the role of stakeholder engagement in reducing the uncertainties to support the methanol transition. The study proposes a value network map that illustrates the relationships between the main shipping stakeholders in relation to the methanol transition and how these can reduce uncertainties, which positively affects the methanol investment decision. This framework can guide the shipping stakeholders in deciding actions to foster the investment decisions to methanol. Seven recommendations are suggested for the shipping stakeholders to consider taking actions, in supporting to reduce the most important uncertainties of some specific stakeholders, which has a critical role within the value network map. One of which is to establish a contractual agreement between the shipowners and the fuel suppliers in the form of an indexed price agreement with flexibility clauses. The agreement can consist of the minimum of fuel that is required in every period of time, with the agreed fuel prices that can be adjusted according to the specific fuel purchased, to make the price remain competitive in the market.

Despite the interesting findings obtained, the relatively small sample size, especially for the survey responses, might affect the generalisability of the findings in the shipping industry. This exploratory research provides valuable insights but suggests the need for further research with larger and more diverse samples to expand upon the findings.

In conclusion, green methanol is a favourable option for the shipping industry to meet emissions reduction regulations while maintaining business continuity, promoting operational sustainability and economic resilience, and contributing towards a greener industry. The study offers a framework to understand how stakeholders' engagement might affect the investment decisions in methanol positively, providing guidance for future investment decisions and policy-making.

References

Anika, O. C., Nnabuife, S. G., Bello, A., Okoroafor, R., Kuang, B., & Villa, R. (2022). Prospects of low and zero-carbon renewable fuels in 1.5-degree net zero emission actualisation by 2050: A critical review. *Carbon Capture Science & Technology*, *5*, 100072. https://doi.org/10.1016/j.ccst.2022.100072

Anyanova, Ekaterina. (2008). The changing role of classification societies in international shipping practice. *International Journal of Private Law*. https://doi.org/10.1504/IJPL.2008.021235

Bergsma, J., & van Son, L. (2022). *MAGPIE – D7. 1: Barriers Analysis in Preparation of selection of Non-Tech Innovations* [PDF files]. TNO.

Bertagna, S., Braidotti, L., Bortuzzo, V., Marinò, A., & Bucci, V. (2023). A fast feasibility tool for the assessment of fuel switch in the concept design of merchant ships. *Procedia Computer Science*, *217*, 1386–1395. https://doi.org/10.1016/j.procs.2022.12.337

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brooks, M. R., Knatz, G., Pallis, A. A., & Wilmsmeier, G. (2022). Transparency in port governance: setting a research agenda. *Journal of Shipping and Trade*, *7*(1). https://doi.org/10.1186/s41072-021-00103-4

Calado, H., Bentz, J., Ng, K., Zivian, A., Schaefer, N., Pringle, C., Johnson, D., & Phillips, M. (2012). NGO involvement in marine spatial planning: A way forward? *Marine Policy*, *36*(2), 382–388. https://doi.org/10.1016/j.marpol.2011.07.009

Cîrstea, Ş. D., Moldovan-Teselios, C., Cîrstea, A., Turcu, A., & Dărab, C. (2018). Evaluating renewable energy sustainability by Composite Index. *Sustainability*, *10*(3), 811. https://doi.org/10.3390/su10030811

Danyluk, M. (2019). Fungible Space: Competition and Volatility in the Global Logistics Network. *International Journal of Urban and Regional Research*, 43(1), 94-111. https://doi.org/10.1111/1468-2427.12675

De Fournas, N., & Wei, M. (2022). Techno-economic assessment of renewable methanol from biomass gasification and PEM electrolysis for decarbonisation of the maritime sector in California. *Energy Conversion and Management*, *257*, 115440. https://doi.org/10.1016/j.enconman.2022.115440

Deng, S., & Mi, Z. (2023). A review on carbon emissions of global shipping. *Marine Development*, 1(4). https://doi.org/10.1007/s44312-023-00001-2

Donker, J., Schaarsberg, M. G., Halstead, M., & Gavrilova, A. (2020). The Clean Energy Technology Investment Attractiveness Scan (CETIAS). https://doi.org/10.13140/RG.2.2.11428.81281

European Community Shipowners' Associations. (2017). *Shipping and Global Trade: Towards an EU External Shipping Policy* [PDF file]. Retrieved December 20, 2023, from https://www.ecsa.eu/sites/default/files/publications/2017-02-27-ECSA-External-Shipping-Agenda-FINAL.pdf

European Commission. (2018). *EU funding possibilities in the energy sector* [PDF file]. Retrieved December 20, 2023, from https://energy.ec.europa.eu/topics/funding-and-financing/eu-funding-possibilities-energy-sector_en

Geels, F. W., & Schot, J. J. (2007). Typology of socio-technical transition pathways. *Research Policy*, *36*(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of Transport Geography*, *24*, 471–482. https://doi.org/10.1016/j.jtrangeo.2012.01.021

Gerritse, E., & Harmsen, J. (2023). Green Maritime Methanol 2.0 WP4 Final Report: A Call to Action. *TNO Report*. https://greenmaritimemethanol.nl/sample-page/

Hajonides, T. (2023). *Matching van onzekerheden en actoren in de brandstoftransitie zeevart* [PowerPoint slides]. TNO.

Halstead, M., Schaarsberg, M. G., Donker, J., Boonman, H., & van Tilburg, X. (2021). *Clean Energy Technology Attractiveness Scan Assessment Tool.* [Excel sheets]. TNO.

Harahap, F., Nurdiawati, A., Conti, D., Leduc, S., & Urban, F. (2023). Renewable marine fuel production for decarbonised maritime shipping: Pathways, policy measures and transition dynamics. *Journal of Cleaner Production, 415,* 137906. https://doi.org/10.1016/j.jclepro.2023.137906

Harmsen, J., Nesterova, N., Bekdemir, C., & Van Kranenvurg, K. (2020b). Green Maritime Methanol: WP2 Initiation and Benchmark analysis. *TNO Report*. https://repository.tno.nl/islandora/object/uuid%3A2d6c88ba-7b1a-4d83-a3dd-4a9a451be219

Harmsen, J. (2021). *Green Maritime Methanol: Towards a Zero Emission Shipping Industry* [PDF file]. Retrieved September 14, 2023, from http://resolver.tudelft.nl/uuid:0542ccdc-00fc-4229-a39f-401688d3ee03

Harris, K., Grim, R. G., Huang, Z., & Tao, L. (2021). A comparative techno-economic analysis of renewable methanol synthesis from biomass and CO2: Opportunities and barriers to commercialisation. *Applied Energy*, *303*, 117637. https://doi.org/10.1016/j.apenergy.2021.117637

Hellemans, I., & Hajonides, T. (2023). *KIP Green and Sovereign Industries: Exploring PMC energy infrastructure coordination* [PowerPoint slides]. TNO.

Hussain, J., Zhou, K., Khan, A., Akhtar, R., Rashid, A., & Yin, Y. (2023). Proposing a sustainable investment index for measuring economic performance and sustainability: A step toward clean and affordable energy. *Sustainable Energy Technologies and Assessments*, *60*, 103564. https://doi.org/10.1016/j.seta.2023.103564

International Maritime Organization. (2021). *Fourth IMO Greenhouse Gas Study*. Retrieved December 22, 2023, from https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20Executive-Summary.pdf

International Maritime Organization. (2023). *2023 IMO Strategy on Reduction of GHG Emissions from Ships*. Retrieved December 22, 2023, from https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf

Intergovernmental Panel on Climate Change. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp. https://doi.org/10.59327/IPCC/AR6-9789291691647

International Renewable Energy Agency. (2021). *A Pathway to Decarbonise the Shipping Sector by 2050*. Retrieved December 21, 2023, from https://www.irena.org/Publications/2021/Oct/A-Pathway-to-Decarbonise-the-Shipping-Sector-by-2050

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for Systematic Reviews and Meta-Analyses: the PRISMA statement. *PLOS Medicine, 6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Morrison, A., Bhatelia, T., Acquarola, C., & Shah, M. T. (2024). Low-carbon methanol production using solar thermal energy: A techno-economic assessment. *Green Technologies and Sustainability, 2*(1), 100059. https://doi.org/10.1016/j.grets.2023.100059

Netherlands Enterprise Agency. (2023). *Energy Investment Allowance - EIA*. Retrieved December 21, 2023, from https://english.rvo.nl/subsidies-financing/eia/entrepreneurs

Nusselder, R. (2024). *Toepasbaarheid energidragers en aanvullende technieken, voor verschillende scheeptypes. Concept formats* [PDF files]. TNO.

Okumus, D., Gunbeyaz, S. A., Kurt, R. E., & Turan, O. (2023). Towards a circular maritime industry: Identifying strategy and technology solutions. *Journal of Cleaner Production, 382*, 134935. https://doi.org/10.1016/j.jclepro.2022.134935

Organisation for Economic Co-operation and Development. (2022). *Analysis of the marine equipment industry and its challenges*. Retrieved April 22, 2024, from https://one.oecd.org/document/C/WP6(2022)15/FINAL/en/pdf

Park, J. S., Seo, Y., & Ha, M. (2019). The role of maritime, land, and air transportation in economic growth: Panel evidence from OECD and non-OECD countries. *Research in Transportation Economics, 78*, 100765. https://doi.org/10.1016/j.retrec.2019.100765

Reddy, V. J., Hariram, N. P., Maity, R., Ghazali, M. F., & Sudhakar, K. (2023). Sustainable E-Fuels: green hydrogen, methanol and ammonia for Carbon-Neutral transportation. *World Electric Vehicle Journal, 14*(12), 349. https://doi.org/10.3390/wevj14120349

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. john wiley & sons.

Sheng, W., Li, C., Hu, Y., Wang, H., Xu, G., Zhao, G., & Wang, S. (2024). Assessing the prospect of bio-methanol fuel in China from a life cycle perspective. *Fuel*, *358*, 130255. https://doi.org/10.1016/j.fuel.2023.130255

Shi, J., Zhu, Y., Feng, Y., Yang, J., & Xia, C. (2023). A prompt decarbonisation pathway for shipping: green hydrogen, ammonia, and methanol production and utilisation in marine engines. *Atmosphere*, *14*(3), 584. https://doi.org/10.3390/atmos14030584

Stirling, A. (2010). Keep it complex. *Nature*, *468*(7327), 1029–1031. https://doi.org/10.1038/4681029a

Svanberg, M., Ellis, J., Lundgren, J., & Landälv, I. (2018). Renewable methanol as a fuel for the shipping industry. *Renewable & Sustainable Energy Reviews*, *94*, 1217–1228. https://doi.org/10.1016/j.rser.2018.06.058

Tabibian, S. S., & Sharifzadeh, M. (2023). Statistical and analytical investigation of methanol applications, production technologies, value-chain and economy with a special focus on renewable methanol. *Renewable & Sustainable Energy Reviews*, *179*, 113281. https://doi.org/10.1016/j.rser.2023.113281

TNO Research Presentation. (2024). *Zelfgemaakte afbeeldingen voor in de presentatie* [PowerPoint slides]. TNO.

United Nations Conference on Trade and Development. (2023). *Review of Maritime Transport 2023*. Retrieved December 21, 2023, from https://unctad.org/system/files/official-document/rmt2023_en.pdf

United Nations Framework Convention on Climate Change. (2016). *Paris Agreement*. Retrieved December 12, 2023, from https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf

Van Antwerpen, J., Khan, M. H. A., Shepherd, J., Tan, T. H., Grundy, S., MacGill, I., Amal, R., & Daiyan, R. (2023). A model for assessing pathways to integrate intermittent renewable energy for e-methanol production. *International Journal of Hydrogen Energy*, *48*(78), 30221–30237. https://doi.org/10.1016/j.ijhydene.2023.04.177

Van Lieshout, P., De Jonge, V., Vredeveldt, A., & Finner, S. (2020). Green Maritime Methanol: WP3 factsheet and comparison with diesel and LNG. *Report: TNO 2020*. https://repository.tno.nl/islandora/object/uuid%3A31be5cf6-3b22-4405-a911-982ec5f902fd

Walker, G. H., Stanton, N. A., Salmon, P. M., & Jenkins, D. P. (2008). A review of sociotechnical systems theory: a classic concept for new command and control paradigms. *Theoretical Issues in Ergonomics Science*, *9*(6), 479–499. https://doi.org/10.1080/14639220701635470

Zero Carbon Shipping. (2022). *Maritime Decarbonization Strategy 2022* [PDF file]. Retrieved January 16, 2024, from https://cms.zerocarbonshipping.com/media/uploads/publications/Maritime-Decarbonization-Strategy-2022.pdf

Zhang, Z., Song, C., Zhang, J., Chen, Z., Liu, M., Aziz, F., Kurniawan, T. A., & Yap, P.-S. (2023). Digitalisation and innovation in green ports: A review of current issues, contributions and the way forward in promoting sustainable ports and maritime logistics. *Science of the Total Environment*, 912, 169075. https://doi.org/10.1016/j.scitotenv.2023.169075

Appendices

A. Tables Regarding Literature Review

Table 17. List of Literature of Green Methanol Viability in the Shipping Industry

Main Discussion	Literature Type	Author(s)
Prospects of renewable fuels, including methanol, to actualise net zero emission	Journal Article	Anika et al. (2022)
Analysis of pathways in optimising e-methanol projects	Journal Article	Antwerpen et al. (2023)
Fuel switch assessment of technical and economic feasibility	Journal Article	Bertagna et al. (2023)
Renewable methanol techno-economic assessment for decarbonisation	Journal Article	De Fournas and Wei (2022)
The exploration of green methanol application feasibility	Research Report	Harmsen et al. (2020)
The application of methanol assessment as an energy carrier for shipping	Research Report	Harmsen (2021)
Techno-economic analysis of renewable methanol for commercialisation	Journal Article	Harris et al. (2021)
Techno-economic assessment of low-carbon methanol production	Journal Article	Morrison et al. (2024)
Challenges of producing sustainable fuels	Journal Article	Reddy et al. (2023)
Analysis of green fuel application potential for shipping	Journal Article	Shi et al. (2023)
Challenges and opportunities of bio-methanol for maritime shipping	Journal Article	Svanberg et al. (2018)
Investigation of renewable methanol applications	Journal Article	Tabibian and Sharifzadeh (2023)
Development prospects of bio-methanol fuel from a life cycle perspective	Journal Article	Sheng et al. (2024)
Decarbonisation strategies in the maritime industry	Research Report	Zero Carbon Shipping (2022)

Table 18. Barriers to Green Methanol Transition

Author(s)	Barriers to Methanol Transition
Anika et al. (2022)	High storage and transport cost
	Higher transport and production costs than green ammonia
	Contains carbon
	It has a narrower application compared to green hydrogen
De Fournas and Wei (2022)	Higher price than existing marine fuels (HFO and MGO)
	High capital costs already invested in LNG bunkering infrastructure may discourage future investment in other technologies
	Alignment of national sustainable fuel policies implementation across the global maritime industry, which can be a slow and complex process due to the need for international coordination
Harmsen et al. (2020)	The need for ship design modifications
	Requires attention regarding safety for methanol utilisation
	Uncertain price of methanol development
	Unpredictable incentives
Harmsen (2021)	Research and publication of methanol application in combustion and engine performance is scarce
	Ship design challenges, such as more complicated and costlier conversion from fossil fuel to methanol, and ensuring bunker capacity in meeting ship autonomy
	Availability of sustainable methanol in every port around the world
	Methanol cannot be injected directly into a compression-ignited internal compression engine because of its chemical properties
Harris et al. (2021)	Higher price than other fuel options
	Feedstock challenges
Reddy et al. (2023)	Complex production process due to the involvement of capturing and converting CO2
	Safety and toxicity concerns
	Existing infrastructure and technologies must be adapted for the full implementation of green methanol
	Upfront investments and infrastructure upgrades result in a financial burden
	Resource requirements to produce green methanol
Shi et al. (2023)	Methanol is carbon-containing: when a ship uses methanol, other measures need to be taken to achieve near-zero carbon emissions
	High explosive risk
	Corrosive to some materials
Svanberg et al. (2018)	Challenge in optimising feedstock supply chains to reduce transport and logistic costs
	Higher cost of production than conventional fuel
	Uncertainty regarding the price of fuel
	Uncertainty regarding the availability of fuel
	Lack of bunkering facilities
	Cost for ship adaptation

Author(s)	Barriers to Methanol Transition
Svanberg et al. (2018)	Lack of demand for parallel distribution systems over long transport distances
	Policy for emissions reductions from shipping
Tabibian and Sharifzadeh (2023)	Barriers to scaling up and industrial developments
	Higher production costs than fossil-based fuels
	Large-scale renewable methanol production requires the removal of barriers to the affordable use of biomass, renewable energy, and CO2 raw materials
	A need to develop new fuel standards to increase methanol utilisation
	Complicated handling and storage due to the high flammability of methanol
Zero Carbon Shipping (2022)	The availability of green methanol is limited
	Methanol bunkering is not yet established at a large scale
	Availability of sustainable biomass to the shipping industry
	Ensuring biofuels deliver the intended environmental performance
	Frameworks to clarify the sustainability of biomass feedstocks are still under development
	Regulatory bodies' requirements regarding sustainability are getting stricter over time
	Future projection indicates that there might be methanol demand that is much higher than the supply in the coming years
	Fuel specification and certification need to be established for bio-methanol

B. Interview Protocol

Semi-structured Interview Set-up	
Question 0	What kind of organisation are you in, and what are your main responsibilities?
Question 1	Can you describe what activities related to green methanol (as a marine fuel) that have been done or are being done in your organisation?
Question 2	Do you think green methanol can be an alternative energy for the current shipping industry, and why?
Question 3	Can you describe how green methanol relates to the current shipping industry needs?
Question 4	When do you think green methanol can be a viable option in the shipping industry?
Question 5	What are the opportunities that can drive the transition to green methanol?
Question 6	What are the challenges faced for the transition to green methanol?
Question 7	What is the relationship between the stakeholders related to green methanol? (e.g., Who are your main partners?)
Question 8	Compared to other types of fuels, such as ammonia, hydrogen, LNG, or the others, do you think that green methanol is preferred by your organization?
Question 9	Do you think these aspects … (from the list below) play a role in green methanol transition?
Closing Question	Do you have any recommendations about a person I can talk with regarding methanol transition?

Aspects Related to the Green Methanol Transition

These are the example questions related to the aspects. Depending on the context of the discussion, some of the questions on this list might be asked in the interview.

Policy & Political	
National Government Ambition	To what extent does green methanol align with the national government's ambitions and plans for the clean energy transition?
Policy Design, Instruments and Uncertainty	Do you think the government encourages investments in green methanol? Do you think the available government support schemes are sufficient to stimulate the deployment of green methanol?
Market Design, Regulation and Legislation	Does government policy create predictable and consistent conditions for the green methanol transition?
Regulation & Legal: Administration & Permits	How likely are administrative risks leading to delays and cost overruns?

Economic & Financial	
Profitability	How profitable do you think the transition to green maritime methanol would be?
Payback Period	How long can you expect the return on investment for the green maritime methanol transition?
Capital Investment	How big is the initial capital investment needed for your organization for green methanol transition?
Operation & Maintenance	To what extent are data or models available for projecting future operation and maintenance costs?
Market Uncertainty	Do you see an indication of an existing market for green maritime methanol now or in the near future?
Investment Size	Suppose you are an investor in the renewable energy transition. How much range are you willing to invest for cleaner energy such as green methanol?
Strategic Opportunity	If the transition to green maritime methanol is successful, how big can the other potential markets be opened?
Investor Risk Appetite	Do you think the current risks of investing in green maritime methanol are still acceptable?
Asset Liquidity	How easily can green methanol or a project using green methanol be sold?

Social	
Societal Acceptance	How do you think society would react to the deployment of green maritime methanol?
Job Impact	How do you think the transition to green maritime methanol can influence the number of job employment in the shipping industry?
Social Impact	How do you think green maritime methanol utilisation can affect societal health?

Technological	
Technology Maturity	To what extent is the green methanol currently ready for commercial deployment?
Construction Risk	What do you think are the technical risks during the construction phase of the green methanol transition?
Operational Risk	What do you think are the technical risks during the operational phase of the green methanol transition?
Technical Know-how	What is the availability of local know-how on the technology?
Technical Excellence	How do you think green methanol's competitive advantage?
Critical Infrastructure	Do you think that currently, the necessary infrastructure for green maritime methanol transition has been supported in your organisation? Why or why not?

Environmental	
EU Taxonomy Status	What are green methanol's greenhouse gas emissions levels, compared to other fuels (ammonia, LNG, hydrogen, etc)?
Material Use	To what extent is the material used for green methanol sustainable?
Land Use	How much space is required by the green methanol in a vessel?
Environmental Incidents	What is the environmental impact of incidents from applications of the technology?

C. Informed Consent for Interview

Opening Statement

You are being invited to participate in a research study titled Socio-technical Analysis of Green Maritime Methanol in the Shipping Industry. This study is being done by Chatarina Petra Salim from the TU Delft in collaboration with TNO.

The purpose of this research study is to provide an understanding about the viability of green maritime methanol in the shipping industry, and will take you approximately 45 minutes to complete. The data will be used for the master thesis of Chatarina Petra Salim. We will be asking you to provide information related to your understanding or opinion related to the viability of the transition to green maritime methanol, including the barriers and opportunities for the transition.

As with any online activity, the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by keeping your answers and personal information strictly confidential. The interview results published in the thesis will be coded and completely anonymous. Personal information, such as name, contact information, and occupation, will only be collected for thesis-related purposes (e.g., informing the study's supervisor). With your permission, the interview will be recorded and if via online meeting, the text will be automatically transcribed using Microsoft Teams. I will manually adjust the automatic transcription to match the original interview. The original transcripts and recordings will only be available to the thesis supervisors, will not be published anywhere, and will be removed approximately two years after the completion of the study, at the latest. Your participation in this study is entirely voluntary, and you can withdraw at any time. You are free to omit any questions.

Below you can find the informed consent form of the research. Please tick the boxes to indicate your consent.

The contact details of the researchers are as follows.

Corresponding Researcher
Chatarina Petra Salim

Responsible Researcher
Jan Anne Annema

Explicit Consent points

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information above, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: • The interview will be semi-structured with open-ended questions related to the viability of green maritime methanol in the shipping industry. • A recorded interview that will be conducted via Microsoft Teams or Face-to-Face. • If via Microsoft Teams, the recording will be transcribed as a text directly from Microsoft Teams and the researcher will edit the text by listening to the interview recording and adjusting the written transcription to the original spoken text. • The interview recording will be stored on the personal storage of Chatarina Petra Salim on the TU Delft OneDrive and will be destroyed the maximum of two years after the study has been completed.	☐	☐
4. I understand that I will not be financially compensated for my participation.	☐	☐
5. I understand that the study will end by September 2024.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. I understand that taking part in the study involves the following risks. • The risk of leaked business/organisation strategies. • The risk of leaked information. • The risk of reputation damage from leaked information. I understand that these risks will be mitigated by storing the important data, such as personal information and original interviews securely, will not be made available publicly and only available to the thesis supervisors, and will be removed after the research is finished. The interview results that will be published on the thesis only in the form of aggregated data (e.g., coded interviews, codebook, and combination of analysis of all the interviews). Furthermore, I can choose how to respond to each question that may be detrimental to me or my organisation. I may choose not to respond to any of them and I have an option to end the interview at any time.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
7. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) (name, occupation, contact information) and associated personally identifiable research data (PIRD), with the potential risk of my identity being revealed, the risk of re-identification and the subsequent risk of affecting my public or professional reputation.	☐	☐
8. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically job position and political, economic, social, technological, or environmental view.	☐	☐
9. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach. The interview will be conducted anonymously. Personal information of the interviewees will not be published to anyone who is not involved in the research. After the research is completed, the personal data will be deleted.	☐	☐
10. I understand that personal information collected about me that can identify me, such as my name and contact information, will not be shared beyond the study team.	☐	☐
11. I understand that the (identifiable) personal data I provide will be destroyed after the research has ended, which will be conducted the maximum of two years after the graduation of the researcher.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. I understand that after the research study the de-identified information I provide will be used for the following purposes. The anonymise interview results will be published along with the master thesis on the TU Delft Repository and TNO Green Maritime Methanol website, including the anonymised coding of the interviews.	☐	☐
13. I agree that my responses, views or other input can be quoted anonymously in research outputs.	☐	☐
D: (LONG-TERM) DATA STORAGE, ACCESS AND REUSE		
14. I give permission for the de-identified interview results that I provide to be archived in the TU Delft repository (https://repository.tudelft.nl/) and Green Maritime Methanol website (https://greenmaritimemethanol.nl/) in the form of anonymous coded interviews so it can be used for future research and learning. The original transcribed interviews will not be made available to the public or be stored on the TU Delft repository and Green Maritime Methanol website.	☐	☐
15. I understand that access to the repository where the master thesis is stored is openly available on the internet.	☐	☐
16. I understand that the collected data may be reused for future scientific publication and educational activities on the topic of alternative fuels for the maritime industry.	☐	☐

Signatures

Name of participant	Signature	Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name [printed]	Signature	Date

Study contact details for further information:
Chatarina Petra Salim
+31627254733
ChatarinaPetraSalim@student.tudelft.nl

D. Qualitative Codes

Table 19. Codes Assigned in Qualitative Data Analysis

Concepts	Themes	Aggregate Dimensions	Interviewee ID
Early Adopter	Current Methanol Condition	Methanol Transition Status	C1
Already Huge Scale Up			B1
Industry Competition			B2
More Decision To Methanol			A2
Communicate Steps to Uptake Methanol	Methanol Activities		G1
Fuel Monitoring			E2
Research and Development			D1, F1, G1
Setting Up Value Chain			C1, E1, E2
Ship Adaptation			A1, A2, B1, B2
Subsidies Pilot Project			F1
Technical Feasibility Study			A1, A3
Broaden Engine Range	Methanol Transition Requirements		B1
Equipment Development			A1
More Training Opportunities			E1, E2
Willingness To Invest More			B1
Award Front Runners	Methanol Opportunities	Transition Drivers	F1
Clear Fuel Pathway			C1
Emissions Reduction			A3, B2, C1, D1
Good Future Choice for Retrofits			E2
Positive Social Perception			A3, E2
Strict Regulations			A2, A3, B2, E1, F1, G1
Sustainable Feedstock Source			D1
Easier To Adopt	Methanol Superiority		A2, C1
Easier To Handle			B2, C1, E1
Easier To Integrate			B1, B2, E1
Easier To Store			B1
Less Pollution			A1
Less Space			B1
Less Toxic			A1, A3, E1
Lowest Ownership Cost Option			D1
Methanol Preference			A1, A2, A3, B1, B2, E1
Most Promising Alternative			A1
Bunkering Challenge	Methanol Barriers	Transition Constraints	C1, E1
Business Case Required			A3, B1, B2
Carbon Mindset			A1, D1

Concepts	**Themes**	**Aggregate Dimensions**	**Interviewee ID**
Emissions Regulations			A1, B2
Energy Carriers Certification			D1
Energy Savings Effort			D1
Engine Availability			A3, B1, E1
Feedstock Availability			E1
Fuel Pricing			A1, A2, A3, B1, C1, D1, F1, G1
Fuel Production and Distribution Regulations			A3, B1, C1
Government Incentives			B2, E1
Know How			A2, D1
Level Playing Field			G1
Market Demand Fulfilment			A3, C1, D1
Methanol Availability			A1, A2, B1, D1, E2, F1
Production Technology			A3, D1, G1
Scalability Required			A3, B1, D1, E2, G1
Ship Design Modification			C1
Training Challenge			A2, A3, D1, E1
Safety	Points of Attention		A2
Scalability			D1
Vessel Size			A1
Aligns Net Zero Ambition	Alignment with Government Ambition	Political Feasibility	A1, A2, A3, C1, D1, E2, F1
Methanol Lifecycle Policy Fit			E1
Limited Regulatory Enforcement	Market Design		B1
Predictable Methanol Transition			A2, B1
Difficult to Get Investors			A3
Existing Emissions Regulation	Policy Instruments		B1
Existing European Trading System			A2, A3, B1, B2
Existing Government Subsidies			A1
Existing Methanol Production Subsidies			C1
Exploring Further Subsidies Schemes			F1
More External Funding Needed			A2, A3, E1
Low Administrative Risks	Regulation Administration		A1, A2
Delay in Supply Chain			E2

Concepts	Themes	Aggregate Dimensions	Interviewee ID
Difficult License for Bunkering			A3
Undetermined Administration Waiting Time			F1
Uncertain Costs Projection	Operation and Maintenance	Economic Feasibility	B1
Mainly More for Better Emissions	Profitability		A3
Might be Profitable in Long-term			A3, F1
10 years Return On Investment			B1, B2
No Return On Investment			A1
Chemical Market	Strategic Opportunity		A1
Methanol Uses in Aviation			C1
Start-up Companies			A1
Sustainable Shipping Market			B2
Vessel Supplier			E2
Wind Industry			A2
Acceptable Investment Risks	Willingness To Invest		B2, E2
Customer Base Dependency			C1
Demand-Supply Dynamics			C1
Ensuring Investment Confidence			A2
Existing R&D Investment			B1
Not Financially Beneficial			B2
Increasing Job Opportunity	Job Impact	Social Feasibility	C1, F1, G1
More to Training Necessity			E2
Similar Job Employment			A1, B2
Emission Reduction Benefit	Social Impact		E1, E2
Increase Air Quality			B2, G1
Positive Society Reaction	Societal Acceptance		A2, A3, B1, C1, E1, E2, F1, G1
Broad Feedstock Range	Competitive Advantage	Technological Feasibility	C1
Can Use Existing Infrastructure			E2
Possible for Retrofit			E1
Versatile Power Generation Use			B1
Clearance on Regulations	Construction and Operational Risks		F1
Energy Substitution Efficiency			D1
Equipment Availability and Reliability			A2, B1, D1, E1
Investment in Limited-Use Technologies			D1

Concepts	**Themes**	**Aggregate Dimensions**	**Interviewee ID**
Limited Larger Space Required			A2, B1, B2
Low Flashpoint Fuel			A1, C1
Low Technical Risks			E2
Methanol Dynamic Behaviour			A3
Regulatory Compliance			B1
Safety Measures			B2
Training Gap			A2, A3
Vessel Design Suitability			B1, C1
Infrastructure Development	Critical Infrastructure		A2
Similar Infrastructure			A1, B2, E2
Sufficient Infrastructure			C1, E1
Knowledge Sharing is Crucial	Technical Know How		C1
More Knowledge Gained			A1, A2, C1, F1
Not Much Experience Yet			B2
Existing On Board Implementation	Technology Maturity		E1
Existing Safety Procedures			E1
Front Runners Willing To Pay Premium Price			F1
Increasing Methanol Adoption			A2
Guidelines Need to be Simplified			A3
No Standardisation between Bunkering and Ports			F1
Unready Engines for Small Ships			B2
Vessels Development			A2
Biodegradation of Leaks	Environmental Impacts	Environmental Feasibility	B2, C1
Significant Emissions Reduction			A3, B1, F1, G1
Transport Risks			E1
Feedstock Efficiency Evaluation	Material Use		A1
Sustainable Feedstock			B2, G1
2023 Engine Adoption	Adoption Starting Time	Viability Approximation Time	A1
2030 Regulatory Impact			F1
2028 Switch to Green Methanol	Full Implementation Time		C1
2030 Full Implementation			A1
Ready in Two or Three Years			A3
More Fuel Availability in Five Years			E2
Already Technically Viable	Viability Timeframe		B1, B2, E1

E. Survey Protocol

1. About this survey

Thank you for participating in this survey! The survey is conducted by a team from TNO and TU Delft as a part of the 'Green Maritime Methanol' project. In this project, a group of Dutch and international maritime companies and knowledge institutes have joined forces to investigate the application of renewable methanol as a maritime fuel. The goal of the survey is to discover the most important uncertainties affecting potential investment in methanol as a marine fuel. We will analyse all responses to study the opinions on investment and uncertainties around methanol as a marine fuel in the entire supply chain.

This survey is divided into two parts.

- The **Investment** part contains questions about your willingness to invest in "sustainable" methanol as a marine fuel.
- The **Uncertainties** part is about uncertainties related to the development of "sustainable" methanol.

You can save your progress in the survey by clicking the “Save as Draft” button on the right bar if you are not yet finished filling out the form. Remember to copy or save the link given after saving so that you can continue filling it out later.

(By filling out this survey, you agree to share your responses with TNO and TU Delft. The responses will be analysed for research purposes. Individual responses will be treated as confidential.)

2. About your organization

*2.1 What is the name of your organization?

*2.2 How big is your organization?

- o Small or medium-sized enterprise (<250 employees; and turnover <50M euro or 43M assets on the balance sheet)
- o Large enterprise (>250 employees; and/or >50M euro turnover)

*2.3 What type of organization is it?
Please pick the option that describes your company best. If none of the available options describe your company accurately, please choose 'other'.

- o Shipowner and charterer / user of methanol as a marine fuel
- o Shipyard
- o Original equipment manufacturer and supplier
- o Fuel producer
- o End customer
- o Fuel supplier / bunker party
- o Fuel storage and transfer
- o Shipper / cargo owner / logistic service provider
- o Port authority
- o Financier / investment company
- o Trade association
- o Consultancy
- o Other

*2.4 What is your role in the organization?

3. Investment in methanol as a marine fuel

The **Investment** part is about your interest in investing in methanol as a marine fuel. It helps us assess interest in investing in methanol in different parts of the supply chain.

*3.1 How important is investing in sustainable shipping to your company?

- o One of our main concerns
- o Of major importance for us
- o Of minor importance for us
- o Not important at all

3.2 Please explain your answer (optional)

*3.3 What are your reasons for considering investment in 'sustainable' methanol as a marine fuel?

- ▪ Customer demand
- ▪ Desire for sustainability
- ▪ Regulatory compliance
- ▪ None

3.4 Please explain your answer (optional)

*3.5 What main investments are you considering in the short term (up to five years)?

- ▪ Sustainable sourcing of transport services
- ▪ Operational measures
- ▪ Use of sustainable fuels
- ▪ Investment in alternative power trains
- ▪ Offering sustainable fuels
- ▪ Offering sustainable fuel infrastructure
- ▪ Other

3.6 Please explain your answer (optional)

*3.7 In what stage are you in relation to the investments for methanol?

- o 1. Not involved at all
- o 2. Explorative
- o 3. Feasibility assessment
- o 4. Moving towards Final Investment Decision (FID)
- o 5. Already positive Final Investment Decision (FID)

3.8 Please explain your answer (optional)

4. Uncertainties

In the **Uncertainties affecting investment attractiveness** part, we ask questions about uncertainties related to the uptake of "sustainable" methanol and how important these are to you.

Please indicate how important the perceived uncertainties are for your organization, from 1 (not important for us at all) to 5 (very important for us).

Science and Technology Uncertainties
Science and technology category refers to the uncertainties of the technology's functionality development and its surrounding standards which have a direct impact on the economic results.

*4.1 Technical readiness to the use of required technology in your intended operational environment (TRL) (e.g., ships for shipping companies and/or production facilities for energy producers)
- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.2 Chance that other energy carriers (e.g. ammonia, biodiesel) will prove to be a better investment
- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.3 Availability of feedstock for production of low-emission methanol
- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.4 Availability of sufficient amounts of green methanol for maritime use, when considering green methanol demand from other sectors
- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.5 Level of infrastructure (distribution, storage) readiness at ports for your intended use of methanol
- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

4.6 Do you have any comments or additional uncertainties related to the Science and Technology category? If so, please describe them here.

Policy and Regulation Uncertainties

Policy and regulation category refers to the uncertainties of the political system's influence connected to the methanol investment decision, such as the political events that can affect the investments value.

*4.7 Compliance of methanol with national, EU, and global climate goals (e.g. IMO greenhouse gas reduction targets)

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.8 Long-term stability of the regulation and government policy support concerning sustainable fuels

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.9 Availability and/or applicability of clear safety regulation for production and storage of methanol

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.10 Availability and/or applicability of clear safety regulation for bunkering and use of methanol as a marine fuel

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.11 Rate and/or clarity of technology certification for the use of technologies related to methanol (e.g., type approval engine)

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.12 Capacity and ability to enforce emission and methanol related regulation

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.13 Level playing field between the EU and rest of the world
- o 1. Not important for me / my organization at all
- o 2. Slightly important for me / my organization
- o 3. Neutral
- o 4. Moderately important for me / my organization
- o 5. Very important for me / my organization

4.14 Do you have any comments or additional uncertainties related to the Policy and Regulation category? If so, please describe them here.

Social and Environmental Uncertainties
Social and environmental category refers to the uncertainties of the potential influence from the community and climate that might affect the investment attractiveness of methanol.

*4.15 Social acceptance of methanol as an alternative energy carrier by the wider public
Social acceptance is the extent to which society or local community accepts the use of this technology
- o 1. Not important for me / my organization at all
- o 2. Slightly important for me / my organization
- o 3. Neutral
- o 4. Moderately important for me / my organization
- o 5. Very important for me / my organization

*4.16 Ability to attract and/or train qualified staff necessary for the production or use of methanol
- o 1. Not important for me / my organization at all
- o 2. Slightly important for me / my organization
- o 3. Neutral
- o 4. Moderately important for me / my organization
- o 5. Very important for me / my organization

*4.17 Uncertainty of actual emission reduction from the use methanol as a marine fuel
- o 1. Not important for me / my organization at all
- o 2. Slightly important for me / my organization
- o 3. Neutral
- o 4. Moderately important for me / my organization
- o 5. Very important for me / my organization

4.18 Do you have any comments or additional uncertainties related to the Social and Environmental category? If so, please describe here.

Economic and Financial Uncertainties
Economic and financial category refers to the uncertainties of the aspect that impact the business case for the typical use of technology under consideration for methanol, in relation to the economic aspect for the investment.

*4.19 Uncertainty or lack of return on investment
- o 1. Not important for me / my organization at all
- o 2. Slightly important for me / my organization
- o 3. Neutral
- o 4. Moderately important for me / my organization
- o 5. Very important for me / my organization

*4.20 Impact of capital intensity in comparison to alternatives (both fossil and non-fossil)

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.21 Impact of operational expenses in comparison to alternative energy carriers (both fossil and non-fossil)

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.22 Availability and quantity of subsidies towards sustainability applicable to methanol

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

*4.23 Lack of, or uncertain, customer willingness to pay more for sustainable transport using "sustainable" methanol

- 1. Not important for me / my organization at all
- 2. Slightly important for me / my organization
- 3. Neutral
- 4. Moderately important for me / my organization
- 5. Very important for me / my organization

4.24 Do you have any comments or additional uncertainties related to the Economic and Financial category? If so, please describe here.

*4.25 What are your most important direct partners in relation to solving the uncertainties related to investing in methanol?
Please choose 3-5 stakeholders which are the most important partners of your organization.

- Shipowners and charterers
- International regulating bodies
- Shipyards
- Financier / investment companies
- Original equipment manufacturers and suppliers
- National government(s)
- Fuel producers
- Classification societies
- End customers
- Research and development
- Fuel suppliers / bunker parties
- Trade associations
- Fuel storage and transfers
- Consultancy companies
- Shippers / cargo owners / logistics service providers
- NGOs
- Port authorities
- Other

4.26 From the selection above, what is your most important one and why?

4.27 Do you have any final comments in overall?

F. CETIAS Assessment

In this section, the options selected that can describe the current methanol situations the best are listed, along with the final score of feasibility assessment that was automatically calculated by the CETIAS excel sheet tool that was developed by Halstead et al., (2021). The weight score of each aspects is built upon the assumption that all criterion has the same weight, and the final score is also built upon the assumption that all aspects weight the same.

Policy and Political

Criterion 1	National Government Ambition
Indicator 1.1	Consistency with national government ambition on energy and climate
Score: Strong alignment	Signals high opportunity and low risk: The technology fits in the government vision, is one of the ingredients of the energy transition, and a core component of agreements, strategies and plans, possibly with explicit targets, budget allocations, and/or supportive regulation in place.
Criterion 2	Policy Design
Indicator 2.1	Effective design of government policy support schemes for deployment of the technology
Score: Positive and sufficient	Signals low risk, because the technology is actively supported and forms part of the strategy to reach current government ambition.
Indicator 2.2	General policy conduciveness
Score: Largely conducive	A long-term vision for the energy transition is emerging but priority technologies and timelines are still under discussion.
Criterion 3	Government Administration & Permitting
Indicator 3.1	Administrative risk
Score: Moderate risk	The administrative risk is moderate e.g. because there is some expertise and a track record in permitting and legislative processes for this technology.

Percentage of total points in political aspect: 78%.

Economic and Financial

Criterion 1	Project Profitability and Payback
Indicator 1.1	Expected net present value
Score: Not applicable	The indicator is not applicable for this technology.
Indicator 1.2	Expected internal rate of return
Score: Not applicable	The indicator is not applicable for this technology.
Indicator 1.3	Payback period
Score: Long	It takes a long time to pay back the upfront capital investment (e.g. 5-15 years)
Criterion 2	Required Capital Investment
Indicator 2.1	Capital intensity
Score: Moderate	The capital intensity is low enough to consider proceeding with the investment (e.g. 20-60%)
Indicator 2.2	Minimum investment ticket size
Score: Not applicable	The indicator is not applicable for this technology.

Criterion 3	Operations Risk Exposure
Indicator 3.1	O&M cost risk exposure
Score: High risk exposure	Costs are not easy to predict and impact of variation on profitability is high.
Indicator 3.2	Input energy supply risk exposure
Score: Moderate risk exposure	Supply costs and/or abundance can be predicted but impact of variation in costs on profitability is still high
Indicator 3.3	Energy sales price risk exposure
Score: Medium exposure	Energy prices can be predicted but impact of variation in prices on profitability is still high
Indicator 3.4	Off-taker risk exposure
Score: Medium exposure	The risk of not getting paid for output is low, but the impact on profitability is still high.
Criterion 4	Strategic Considerations
Indicator 4.1	Contribution of the investment in the technology to the investor's strategic objectives
Score: Medium contribution	The technology has an average contribution to the long-term strategic objectives of the investor.
Indicator 4.2	Liquidity of the asset
Score: Not applicable	The indicator is not applicable for this technology.

Percentage of total points in economical aspect: 48%.

Social

Criterion 1	Social Acceptance
Indicator 1.1	Sentiment of society towards technology
Score: Very positive	There is positive sentiment towards the technology and society shows supporting behaviour e.g. through peer adoption.
Indicator 1.2	Social maturity of deployment process
Score: Very mature	It is very well known under which circumstances the technology is socially acceptable: There is a lot of experience and track-record of integrating social aspects into the deployment process.
Criterion 2	Job Creation
Indicator 2.1	Job creation efficiency
Score: Not applicable	The indicator is not applicable for this technology.
Indicator 2.2	Workforce availability
Score: Some risk	Most of the skills required are available, but shortages can occur.
Criterion 3	Social Compliance
Indicator 3.1	Occupational safety and health issues (OSH)
Score: High with risk	Deployment of this technology might result in slightly less OSH-issues such as work-related health risks or sickness absence.
Indicator 3.2	Societal health, safety and comfort issues
Score: Better	Deployment of this technology will most likely result in less societal health, safety and comfort issues due to absence of e.g. noise or toxins.

Percentage of total points in social aspect: 83%.

Technological

Criterion 1	Technology Maturity
Indicator 1.1	TRL
Score: Demonstrating/ piloting	TRL 7-8; technology has been piloted and is ready for commercial deployment.
Criterion 2	Construction Risk
Indicator 2.1	Cost and time overruns during construction phase
Score: Better	The expected cost and time overruns are shorter, which shows from the long track records.
Criterion 3	Reliability of the Technology
Indicator 3.1	Certainty on operational performance
Score: Low performance certainty	There is relevant historical data on O&M performance. Future O&M performance can be projected with accuracy.
Criterion 4	Technical Know-how
Indicator 4.1	Availability of local know-how in both construction and operational phase
Score: Sufficient	There is sufficient expertise, workforce and training & education opportunities available
Criterion 5	Critical Infrastructure
Indicator 5.1	Availability of critical infrastructure in the area
Score: Mostly available	There is critical infrastructure in place that supports medium scale deployment

Percentage of total points in technological aspect: 73%.

Environmental

Criterion 1	Climate Change Mitigation
Indicator 1.1	Reduction and avoidance of greenhouse gas emissions
Score: Slightly lower	Greenhouse gas emissions of this technology are slightly lower compared to other clean energy technologies.
Criterion 2	Sustainable Use and Protection of Water and Marine Resources
Indicator 2.1	Water use (withdrawal and consumption)
Score: Not applicable	The indicator is not applicable for this technology.
Criterion 3	Transition to a Circular Economy, Waste Prevention and Recycling
Indicator 3.1	Material use
Score: High sustainability	The technology uses no critical materials, and other materials that are used are recovered, recycled or repurposed.
Criterion 4	Pollution, Prevention and Control
Indicator 4.1	Environmental incidents (emissions to air, water and soil)
Score: Minor	No contamination, localised effects (i.e. minor dust or odour).
Criterion 5	Protection of Healthy Eco-systems
Indicator 5.1	Land use
Score: Not applicable	The indicator is not applicable for this technology.
Indicator 5.2	Environmental impact on flora and fauna
Score: Limited	Some damage to flora and fauna, localised effects of short duration.

Percentage of total points in environmental aspect: 83%.