Erasmus University Rotterdam

Master of Economics and Business

Master Thesis Urban, Port and Transport Economics Programme

Critical Success Factors of Establishing Green Shipping Corridors: the Rotterdam-Singapore Case

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November 1, 2023

Note: The views stated in this thesis are those of the author and not necessarily those of the supervisor, second assessor, Erasmus School of Economics or Erasmus University Rotterdam.

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Preface

This thesis marks the conclusion of my academic journey, which started with a Bachelor's degree in Economics and Business Economics at the University of Groningen, included an exchange semester at Lingnan University in Hong Kong, and eventually led me to the Master's program in Urban, Port, and Transport Economics at Erasmus University.

I would like to express my appreciation to my thesis supervisor, Maurice Jansen, for his guidance and support during this research process. I also want to extend my thanks to the second assessor, Wouter Jacobs, for his valuable feedback and his role in evaluating this thesis.

Additionally, I wish to acknowledge the academic community at Erasmus University, whose environment provided the backdrop for my studies. It has been an interesting academic year filled with (guest) lectures, field trips, and assignments which, altogether, have prepared me well for my post-graduation life.

Abstract

This research identifies the multilevel Critical Success Factors (CSFs) essential for establishing the Rotterdam-Singapore green shipping corridor in the frame of three alternative fuels. Namely, methanol, hydrogen and biofuels. Decreasing shipping's substantial contribution to greenhouse gas emissions needs innovative solutions. Therefore, green shipping corridors, catalysed by a combination of public and private actions which enable zero-emission ship operations, have been proposed as a response. However, while several green shipping corridors have been announced, none have been established beyond the initial stages. Moreover, scholarly research on their implementation remains scarce. This study employs a competition assessment and content analysis to provide information on the current state of play of green shipping corridors and determine the CSFs of establishing a specific case: the Rotterdam-Singapore green shipping corridor. This is done by reviewing the overarching themes of green shipping corridors to determine predefined categories that have been used in the content analysis. Namely, energy transition, sustainable shipping management, and public-private partnerships in ports. From the competition assessment it becomes clear that Rotterdam and Singapore are relatively well prepared for the transition towards alternative fuels in shipping and are both very active in creating green shipping corridors. Moreover, the most frequently mentioned CSF is organizational commitment, followed by relationship coordination, strategic alignment, safety, and knowledge transfer. Lastly, the outcomes of the content analysis have been externally validated by speaking to four industry experts.

Key words: shipping, alternative fuels, green shipping corridor, energy transition, sustainable shipping management, port competition, public-private partnerships, critical success factors, content analysis

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List of abbreviations

CO_2	Carbon Dioxide
CSF	Critical Success Factor
GHG	Greenhouse Gas
GW	Gigawatt
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LH_2	Liquid Hydrogen
LNG	Liquified Natural Gas
MDO	Marine Diesel Oil
MoU	Memorandum of Understanding
PA	Port Authority
PPP	Public Private Partnership
SSM	Sustainable Shipping Management
TEU	Twenty-Foot Equivalent Unit

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1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), to limit the average global temperature increase to 2°C, there should be a 40-70 per cent reduction in global greenhouse gas (GHG) emissions by 2050 compared to 2010 (IPCC, 2014). Furthermore, GHG emissions should be kept near zero by 2100. Failing to do so, may have negative effects on humans and ecological systems, including increased coastal flooding, beach erosion, and salinization of water sources (Buis, 2019). One of the current worldwide objectives is, therefore, to decrease GHG emissions (Wiegand, 2021). Although shipping is the most efficient mode of transportation in terms of energy usage (European Commission, n.d.; Yan et al., 2021) and a massive driver of the global economy, since it enables more than 80 per cent of the volume of internationally traded goods (Hoffmann et al., 2018), it is a substantial and expanding contributor to GHG emissions. In the year 2018, it accounted for 1,076 million tonnes of CO_2 emissions, constituting approximately 2.9 per cent of the total emissions caused by human activities worldwide (European Commission, n.d.; World Economic Forum, 2022). This share, for 2018, has increased by approximately 5 per cent since 2014 (IMO, 2020), and even more importantly, based on various realistic long-term economic and energy scenarios as analysed by the IMO (2020), these emissions are anticipated to increase from 90 per cent to as high as 130 per cent of the 2008 emission levels by 2050. The European Commission (2021) states that if the climate change impact of shipping activities would grow as projected by the IMO, it would undermine the European Union's (EU's) goals of the Paris Agreement. Therefore, decreasing the GHG emissions in shipping is an important challenge. To do so, the IMO has lined out a strategy and aims to cut international shipping's carbon intensity by 70 per cent and its overall yearly GHG emissions by at least 50 per cent by 2050, compared to 2008, while continuing its efforts to phase out these emissions as soon as feasible in this century (Xing et al., 2021).

The foremost source of all the GHG emissions in shipping comes from the combustion of fuel used by ships (Wang et al., 2023). Furthermore, most of the fuel used by container ships combusts while actively sailing at sea (Czermański et al., 2021). Replacing the current used fuels with cleaner alternatives or decreasing the current fuel usage, are therefore the main objectives to decrease GHG emissions in the shipping sector. However, the transition to alternative fuels in the shipping industry is a complex undertaking which poses several obstacles. For example, this transition requires enormous investments in the required infrastructure (H. Lindstad et al., 2015; Wang et al., 2023). Furthermore, until recently, the sector faced a lack of regulation (Lister et al., 2015), and the industry's international nature, including the presence of favourable taxation regimes (Edelenbosch et al., 2022), has further complicated the transition to sustainable practices. Moreover, a lack of cooperation among stakeholders has been identified as a significant impediment (Lister et al., 2015). Lastly, the pathway towards alternative fuels remains uncertain (Hervas, 2023; IRENA, 2021). Together, these factors contribute to the shipping sector's classification as a 'hard-to-abate' sector (Bergek et al., 2023; Edelenbosch et al., 2022; Franz et al., 2022; H. Liu et al., 2023), in which decreasing GHG emissions is considered extra challenging. To conclude, the industry faces several challenges in meeting the IMO's emissions reduction objectives. With the necessary development of entirely new zero-emission value chains, a complex interdependence arises, reminiscent of a 'chicken and egg' problem, where the investment decisions of each actor hinge on the decisions made by others (Fahnestock & Bingham, 2021).

A possible solution inspired by all these obstacles is green shipping corridors. Green shipping corridors are defined as "specific shipping routes where the technological, economic, and regulatory feasibility of the operation of zero-emission ships is catalysed by a combination of public and private actions" (Global Maritime Forum, 2022, p. 3). These corridors have the potential to create favourable conditions for decarbonization, as they enable policymakers to establish a framework that facilitates targeted regulatory measures, financial incentives, and safety regulations (The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping & McKinsey & Company, 2022a). Furthermore, policymakers can explore regulations and incentives that reduce the cost of producing alternative fuels, leading to an increase in demand for zero-emission shipping. Additionally, green corridors can result in secondary benefits, such as lower shipping emissions on other routes. Hence, once alternative fuel infrastructures are established on a green shipping corridor, they can be utilized for shipping on other routes as well.

Currently, governments and port authorities (PAs) among others are working to create green shipping corridors as the first step towards achieving zero GHG emissions in maritime shipping as a result of the recent increase in interest in this concept (U.S. Department of State, 2022). Initiatives to start green shipping corridors have been emerging across the globe, for example, between the ports of Halifax and Hamburg (Farguson, 2022), Antwerp and Montreal (Port of Antwerp-Bruges, 2021), and Rotterdam and Singapore (Port of Rotterdam, 2022c), among others. However, the great majority of these initiatives are still in their early stages (Global Maritime Forum & Getting to Zero Coalition, 2022; Hervas, 2023). Only a few have progressed far enough to initiate feasibility studies or implementation planning, but none have reached the operation phase in which the deployment of vessels and provision of scalable zero-emission alternative fuels are crucial (Global Maritime Forum & Getting to Zero Coalition, 2022).

Even though there is consensus among researchers, governments, and PAs about the potential importance of green shipping corridors, scientific research on what facets are crucial to the implementation of such corridors is still lacking. This research aims to fill in this gap and seeks to find the critical success factors (CSFs) required for the implementation of the Rotterdam-Singapore green shipping corridor. This specific case is investigated as a case study because of several reasons. It is, namely, located along one of the world's busiest shipping routes, the Asia-Europe trade route (UNCTAD, 2020). This route has the highest GHG emissions of any other trade route (Getting to Zero Coalition et al., 2021), emphasizing the importance of a transition along this route. Additionally, the port of Rotterdam is the largest bunkering port in Europe and one of the largest in the world (Port of Rotterdam, n.d.). Moreover, the port of Singapore is the largest bunkering port in the world (Shaw-

Smith, 2023). Both ports therefore have strong incentives to proactively engage in the energy transition because, as two of the largest bunkering ports in the world, they are more vulnerable to potential disruptions and financial losses as the shipping industry transitions to alternative fuels. After all, they have significant investments in and economic reliance on traditional fossil fuel bunkering activities. Both ports' national governments have also underlined the importance of establishing green shipping corridors by signing the Clydebank declaration (United Kingdom Department for Transport, 2022). Furthermore, since the shift to alternative fuels requires new infrastructure (H. Lindstad et al., 2015; Wang et al., 2023) and because port competition is based on infrastructure among others (Coeck et al., 1996; Notteboom et al., 2022; Parola et al., 2017), the Rotterdam-Singapore case is interesting since both ports face high competition in their respective regions, the Hamburg-Le Havre range and the strait of Malacca, resulting in fierce inter-port competition within Rotterdam and Singapore's respective port clusters (Notteboom et al., 2022). Because of the high competition both ports face, it becomes increasingly important for the ports of Rotterdam and Singapore to maintain their competitive edge by undertaking a proactive role in the energy transition.

To address this research's main aim and identify the CSFs of establishing the Rotterdam-Singapore green shipping corridor, a deductive content analysis is performed. This analysis examines press releases, project portfolios, annual-, strategy-, and policy reports from projects in alternative fuels in both the port of Rotterdam and Singapore as well as the viewpoints of relevant stakeholders in the greening of ports as defined by Notteboom et al. (2020). Moreover, it includes coding quotations related to predetermined categories so that the data can be quantified. For this approach, a literature review focused on green shipping corridors and four existing themes in the literature green shipping corridors as a concept emerged, namely sustainable shipping management (SSM), the energy transition, public-private partnerships (PPPs), and port competition has been conducted. The literature review aims to, among others, identify the factors that potentially influence the CSFs of establishing the Rotterdam-Singapore green shipping corridor, represented by predetermined categories or codes necessary for deductive content analysis (Berg, 2002). The research question that emerges from this context is:

What are the critical success factors of establishing a green shipping corridor in the Rotterdam-Singapore case?

This research question will be answered by conducting a deductive content analysis. Furthermore, The first sub-question that emerges from this context is

1. *What are the factors that influence the success of establishing a green shipping corridor?*

This sub-question will be answered by conducting a literature review regarding overarching themes that are strongly related to green shipping corridors. Findings from this literature review will form the basis for the predetermined codes necessary for deductive content analysis.

Furthermore, port competition plays a key role in green shipping corridors, since it depends on geographical factors, infrastructure and prices among others (Lirn et al., 2004; Notteboom et al., 2022; Parola et al., 2017; Tongzon, 2007). Moreover, part of ports' infrastructure is their environmental profiles (Notteboom et al., 2022; Parola et al., 2017). In addition, port networks have a great influence on port competition and ports' competitiveness (Parola et al., 2017). Because of this, green shipping corridors could serve as a means to improve ports' competitiveness. To capture these dynamics, a competition assessment is performed as well. Hence, the following sub-question is formulated

2. *What is the current state of play of green shipping corridor initiatives?*

This assessment aims to identify the current state of play in green shipping corridor initiatives. Doing so establishes a comprehensive view of the current industry dynamics and uncovers any potential relationships or dependencies between these elements.

Moreover, because the ports of Rotterdam and Singapore are active in different environments on two different continents, differences on both ends could result in different priorities in CSFs. Therefore, this thesis also aims to identify possible differences and similarities on each side concerning the CSFs of establishing a green shipping corridor between the two ports. This aim is captured by the third sub-question

3. *What are the similarities and differences in the critical success factors between the ports of Rotterdam and Singapore in the context of establishing the Rotterdam-Singapore green shipping corridor?*

This sub-question will be answered by segregating the results of the deductive content analysis per port.

Additionally, the fuel pathway is uncertain and each fuel has different components (Hervas, 2023; IRENA, 2021). Therefore, the potential differences and similarities in CSFs between the alternative fuels of methanol, hydrogen and biofuels are explored as well. Therefore, the fourth sub-question is formulated

4. *What are the similarities and differences in the critical success factors between the different alternative fuels of methanol, hydrogen and biofuels in the context of establishing the Rotterdam-Singapore green shipping corridor?*

The last sub-question will be answered by segregating the results of the deductive content analysis per alternative fuel type.

In conclusion, considering the urgent need to reduce GHG emissions in shipping and address the challenges it poses in meeting global climate goals, green shipping corridors have emerged as a possible solution. These corridors have the potential to catalyse the operation of zero-emission ships through a combination of public and private actions (Getting to Zero Coalition et al., 2021; Joerss et al., 2021), thus reducing GHG emissions in shipping. More research on the factors that influence the successful implementation could help lead green shipping corridors towards the operation phase in which the deployment of vessels and provision of scalable zero-emission fuels are vital (Global Maritime Forum & Getting to Zero Coalition, 2022).

In the next chapter, the literature review will be presented containing more information about the challenges of GHG emission abatement in the shipping sector, the four overarching themes that are strongly related to green shipping corridors, namely, the energy transition, PPPs, SSM and port competition. Moreover, more context is given regarding bunkering ports and their role in the energy transition. Additionally, more information about green shipping corridors is given in this chapter. Finally, the literature review concludes by providing more information on CSFs. The literature review is followed by the methodology chapter in which the methods regarding the competition assessment and the content analysis are elaborated in more detail. This chapter is followed by the results in which the outcomes of the competition assessment and the content analysis are lined out. Lastly, in Chapters 5 and 6, the conclusion and the discussion will be presented.

2. Literature review

2.1 Decarbonizing the maritime industry

As outlined in the introduction, the maritime industry is responsible for a significant part of worldwide GHG emissions (European Commission, n.d.; World Economic Forum, 2022), which is even expected to grow (IMO, 2020). To effectively reduce these emissions and align with the IMO's ambition to become net-zero in 2050, transformations in this sector are imperative. Nevertheless, existing literature shows that there are several challenges associated with reducing GHG emissions in shipping.

According to Wang et al. (2023), the primary source of emissions from marine operations is the combustion of marine fuel. Replacing the currently used fuels with cleaner alternatives is, according to the authors, the primary objective to decrease marine emissions. Moreover, there are clear distinctions between conventional fuels such as Marine Gas Oils (MGO) and fuels with zero or low GHG footprints made from renewable energy sources (wind, solar, etc.), such as E-hydrogen and E-ammonia (E. Lindstad et al., 2022). Alternative fuels are produced using resources other than petroleum, some of which are renewable (The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping & McKinsey & Company, 2022a). Furthermore, they frequently have less of an effect on the environment than fossil-based hydrocarbons that are currently used in marine fuels. The latter is imperative for the green shipping corridor's facet of the operation of zero-emission ships.

Besides the costly infrastructural requirements for alternative fuels, there are other obstacles to decreasing the GHG footprint in the maritime industry. One factor is that the life expectancy of a merchant ship is around 25 years, this slows the process of decarbonization because already-made investments are often depreciated first (Dinu & Ilie, 2015). Additionally, Bach and Hansen (2023) argue that the IMO has not succeeded in implementing consistent and comprehensive policy instruments to support the organization's objectives to decrease shipping emissions. Furthermore, the authors highlight that the difficulties in regulating cleaner fuel technologies originate from various factors. These include the limited capacity of the IMO to handle such regulations, uncertainties surrounding its regulatory authority, and the lack of political agreement during negotiation processes.

All in all, it becomes clear that there are several difficulties in decarbonizing the maritime sector. Therefore, this sector is considered one of the hard-to-abate sectors (Bergek et al., 2023; Edelenbosch et al., 2022; Franz et al., 2022; H. Liu et al., 2023). According to a report by the Netherlands Environmental Assessment Agency constructed by Edelenbosch et al. (2022), this is caused by several reasons. Firstly, implementing policies that reduce emissions is complicated due to the global character of the shipping industry and its associated favourable taxation regime. Furthermore, the shipping industry has a symbiotic relationship with the fossil fuel industry, relying on it for affordable bunker fuel as a byproduct of oil refineries and as a service provider in the fossil fuel trade by shipping oil products. Moreover the authors argue that the transition to alternative and more expensive fuels poses a significant challenge for the shipping industry, particularly for low-value-added goods such as dry bulk and liquid bulk. Finally, the availability of numerous potential alternative fuels could cause issues in standardization. In conclusion, the uncertainty of the pathway to achieving emissions reduction goals in shipping remains uncertain (McKinlay et al., 2021).

Furthermore, there is the risk of greenwashing in shipping, the practise of organizations making misleading claims about their environmental credentials to develop a green image (Mitchell & Ramey, 2011). This risk is described by several sources (Gordon, 2021; Safety4Sea, 2023; Transport & Environment, 2021). It forms a serious risk in sustainable transformation (Yildirim, 2023) which is necessary to decrease GHG emissions in shipping.

One component of decarbonizing the maritime sector that has received much attention from global regulatory bodies, industry actors, and academics is SSM (Chua et al., 2023). SSM is a series of efforts conducted by shipping companies to address environmental and socioeconomic challenges arising from operations (Tran et al., 2020). Furthermore, it is a dynamic capacity that increases a company's competitiveness and, as a result, leads to higher organizational performance. The latter proves to be relevant given the high competition between ports, as explained in section 2.4 in this chapter.

2.2 Energy transition

2.2.1 Introduction and definition

As aforementioned, the combustion of marine fuel constitutes the primary source of emissions in the shipping sector (Wang et al., 2023). Additionally, when ships are not actively sailing at sea, they use, on average, 8 per cent of their fuel. Consequently, 92 per cent of the fuel used by container ships combusts during their time actively sailing at sea (Czermański et al., 2021). Therefore, replacing the currently used fuels like HFO and marine diesel oil (MDO) with cleaner alternatives is the primary objective to decrease emissions in shipping. Recent research has examined potential pathways for decarbonization, assessing the CO_2 reduction capabilities of alternative marine fuels, including liquified natural gas (LNG), methanol, biofuels, hydrogen, and ammonia, with abatement potentials ranging from 20 to 100 per cent, depending on the specific type of fuel (Balcombe et al., 2019; Gilbert et al., 2014). It is therefore technically possible to match the IMO's objectives to become net zero, however, the pathway towards this remains unclear (McKinlay et al., 2021). In practice, shipbuilders prefer to take a "wait-and-see" attitude until a clear technological route is established since making improvements to large ship-building projects to reduce GHG emissions involves too much patience and risk (Wan et al., 2018).

Each alternative fuel poses its benefits and drawbacks and in this thesis, the focus for alternative fuels will be on methanol, (green) hydrogen, and biofuels. Furthermore, the transition to alternative fuels requires investments in new infrastructure. This choice of the three alternative fuels and necessary infrastructure are elaborated on hereafter.

2.2.2 Methanol

Based on a review of recent literature and a multi-dimensional decision-making framework, (Xing et al., 2021) identified the most promising alternative fuel for low-carbon maritime transportation towards 2050. According to their analysis, methanol (fossil/renewable) appears to be the most promising alternative fuel for international shipping. Other research supports this finding (Ellis & Tanneberger, 2015). Furthermore, an increasing order book for methanol-fuelled ships shows the sector's interest in this potential alternative fuel (DNV, 2023). However, Ellis (2019) lines out that methanol production presently primarily relies on fossil fuels with a worldwide annual output of 98 million tons, leading to the emission of 0.3 gigatons of CO_2 annually. This emission figure constitutes 10 per cent of the total emissions within the chemical sector. Projections indicate that methanol demand is anticipated to grow to 500 million tons by 2050 (IRENA & Methanol Institute, 2021). It is nevertheless also possible to produce methanol 100 per cent renewable. In this case, all feedstocks must originate from biomass, solar, wind, hydro, or geothermal sources. Renewable methanol, often referred to as green methanol, can be generated through two distinct pathways: bio-methanol and e-methanol. Bio-methanol is derived from the gasification of biomass feedstocks, including materials such as agricultural waste, biogas from landfills, sewage, municipal solid waste, forestry residues, and paper among others (Enerkem, 2016; IRENA & Methanol Institute, 2021). On the other hand, e-methanol is manufactured using captured CO_2 and green hydrogen, both of which are produced from renewable electricity sources. Furthermore, it is important to note that methanol has low emissions and low environmental and health effects when utilised as an engine fuel (Túner, 2015). Methanol is recognised as the most advanced fuel, with current solutions already being used on a small scale and retrofit and new build investment costs are expected to be reasonable (Ellis, 2019). Lastly, methanol has received interim approval from the IMO as a safe fuel for ships (Wingrove, 2020). Despite the benefits, the transition to methanol as a shipping fuel presents drawbacks as well. Firstly, the fuel's low energy density results in ships needing to bunker at a 2-3 times higher frequency compared to currently used liquid fossil fuels (Hsieh & Felby, 2017; Svanberg et al., 2018). Furthermore obtaining enough carbon feedstock from renewable sources for green methanol presents long-term difficulties (IRENA & Methanol Institute, 2021).

2.2.3 Hydrogen

Moreover, hydrogen is also mentioned as a promising alternative fuel. In a study conducted by (Atilhan et al., 2021), the viability of hydrogen as an alternative fuel for the shipping industry was examined extensively. The authors found that green hydrogen offers a substantial reduction in CO_2 emissions compared to traditional fuels utilized within the maritime sector. This environmentally friendly fuel is produced through the process of electrolysis, which relies on carbon-neutral electricity sources (Osman et al., 2022). A study from the Global Maritime Forum (Fahnestock & Bingham, 2021) has found that approximately half of 106 zero-emission projects examined in maritime shipping focused on hydrogen as an alternative fuel, showing the industry's interest in this fuel. Shell, one of the world's largest fuel producers, committed to hydrogen and stated that it has advantages over other potential alternative fuels for shipping (Saul & Chestney, 2020).

However, the process of producing green hydrogen requires a lot of green electricity generated by, for example, wind and solar panels (Atilhan et al., 2021). Therefore, the process and its emissions must be considered. The two most frequent methods used for producing hydrogen are electrolysis using renewable electricity and fossil hydrogen produced by desulfurizing and reforming natural gas (Hansson et al., 2019). Currently, the majority of hydrogen is made using the latter method, which results in high CO_2 emissions across its supply chain. Therefore, scaling up the renewable method is vital for hydrogen to decrease GHG emissions in shipping. This type of hydrogen is referred to as green hydrogen. Furthermore, there are also two main options for utilizing hydrogen: liquified and non-liquified. Each type has its benefits when it comes to safety and health concerns. Atilhan et al. (2021) describe these in their paper. Firstly, although hydrogen or liquid hydrogen (LH_2) is nontoxic, due to the fuel's characteristics as an asphyxiant gas, it needs to be handled carefully. Moreover, LH_2 has a higher energy density than HFO (2.8 times higher on a megajoules per kilogram basis), which has benefits for transportation. However, it is crucial to recognise that LH_2 can provide increased fire and explosion hazards because of lower boiling and flash temperature and broad flammable limit range. The danger of fire and explosion can be reduced by the favourable chemical features of LH_2, such as its greater auto-ignition temperature and lower vapour density, on the other hand. To conclude, the hydrogen chain consists of import, production, transport, storage, and bunkering (Vopak, 2022).

2.2.4 Biofuels

Biofuels are made from biomass. There are different types of biofuels. For example, biodiesel, biogas, bioethanol, and biobutanol (Government of the Netherlands, n.d.). There is a great deal of opportunity for biofuels to increase their percentage of overall marine fuel use and help the maritime sector meet the

EU and IMO's GHG reduction goals (Hsieh & Felby, 2017; Laursen et al., 2022). Furthermore, the 'drop-in' characteristics of biofuels, which enable them to substitute currently used fuel based on petroleum-refined hydrocarbons without necessitating significant (or, in some cases, any) adjustments to engines, fuel tanks, pumps, or supply systems, may present an appealing and cost-effective solution for the ships that are already in use (Laursen et al., 2022). Biofuels have similar characteristics as fossil fuels, however, they are created from biomass feedstocks.

The EMSA conducted three hazard identifications and concluded that there are no dangers that cannot be resolved, preventing the use of biodiesels such as hydrotreated vegetable oils (including Fischer Tropsch Diesel), fatty acid methyl esters, and dimethyl ether mixes as fuels for maritime fuel applications (Laursen et al., 2022).

In conclusion, this paragraph has lined out the three different alternative fuels methanol, hydrogen, and biofuels. Furthermore, each fuel’s zero and low-emission potentials were elaborated. Notably, each of these fuels poses different advantages and disadvantages. As the pathway to achieving emissions reduction goals in shipping remains uncertain (McKinlay et al., 2021) and consequently the fuel pathway is uncertain as well (Hervas, 2023; IRENA, 2021), the choice of these specific alternative fuels frames this thesis. Focusing on every alternative fuel available in this research would be impracticable, given the complexity of the transition to alternative fuels and the wide variety of alternative fuels. Whatever the alternative fuel of the future will be, green shipping corridors have the potential to guarantee enough customers for the fuel producers by linking them with shipping companies and therefore overcoming the ‘chicken and egg’ problem (Hervas, 2023), as highlighted in the introduction.

2.3 Bunkering ports and their role in the energy transition

Nowadays, a port is a transport, digital and energy node (Lind et al., 2023). On average, 40 per cent of commodities passing through ports are energy-related (Royal Haskoning DHV, 2022). However, not all ports prioritize energy transportation. A diverse array of port types exists, including feeder ports, gateway ports, fishing ports, cruise ports, dry ports, and bunkering ports, among others. Given their distinct functions and services, these different port types do not all engage in direct competition. Given this and considering the energy transition's context in shipping, different port types hold different degrees of importance. Four global ports—Singapore, Rotterdam, Fujairah and Houston—constitute the epicentres of bunker fuel trading worldwide (CE Delft, 2011). Due to their current involvement in the distribution of high GHG-emitting fuels used for shipping, these four bunkering ports, among others, play a crucial role in the energy transition. These bunkering ports will likely be significantly impacted by the transition to alternative shipping fuels. This is caused by the fact that a switch from current fuels like heavy fuel oil and marine diesel oil to greener alternatives necessitates changes in infrastructure requirements and trading patterns (H. Lindstad et al., 2015; Wang et al., 2023).

Bunker fuel is the fuel that provides power to operate a vessel, while bunkering refers to the process of delivering this fuel from a bunkering supply facility to the vessel. The Port of Rotterdam (n.d.) explains the steps for oil, from crude to bunker fuel. The crude oil is processed in refineries. This crude oil is used to produce diesel, gasoline and fuel oil components among others. After refining the oil, it is stored and or blended with other components. At this stage, possible imports enter the value chain. These imports are either directly stored as fuel oil or blended with refined oils in the port to create fuel oil. The next and last step in the process is to deliver the bunker fuel to vessels in a port.

The bunkering supply chain is complex, involving several stakeholders (CE Delft, 2011; Lind et al., 2023). Furthermore, it encompasses refineries, traders, suppliers, storage and handling firms, as well as shipowners (CE Delft, 2011). Notably, there is a certain overlap between these roles, with some trading entities also functioning as suppliers. The distinctions between these stakeholders are somewhat blurred. Several traders also operate as suppliers, and increasingly, traders also manage their own storage and transhipment terminals. Additionally, large oil corporations have a significant presence across all sectors of this value chain. Lastly, the bunkering market is dynamic with new entrants often entering the market and where companies are frequently acquired by others.

While understanding the important role of bunkering ports and their intricate energy-related operations is crucial, it is equally important to examine how other relevant stakeholders navigate the challenges presented by the energy transition in shipping. Notteboom et al. (2020) conducted research regarding the role of seaports in Green Supply Chain Management in the Rhine-Scheldt Delta. In their research, the authors established a list of stakeholders involved in the greening of ports.

Table 1: Overview of stakeholders in the greening of ports in the Rhine Scheldt Delta (Notteboom et al., 2020)

Port authorities
Port and terminal operating companies
Supply chain and transport organizers
Companies involved in (semi-) industrial activities in the port area
Associations, government agencies, and non-governmental organizations (NGOs)
Industry and branch organizations
Port community associations, branch organizations
Environmental groups
Service providers (banks, insurance companies, classification and certification societies, rating agencies, IT companies etc.)
Research institutes, universities, and innovation centres.

The transition from fossil fuels to cleaner alternatives can set in motion several disruptions. According to Kivimaa et al. (2021), disruption can speed up or assist sustainability changes, which is highly beneficial for the environment. However, the authors also point out that disruptions, while they could be advantageous for environmental sustainability, may also have disadvantageous effects from many other angles such as the competitiveness of actors affected by the transition. Therefore, transitions should be approached with a proactive policy tactic. Taking into account that part of ports' competitiveness depends on geographical factors (Coeck et al., 1996; Notteboom et al., 2022; Parola et al., 2017), the transition to alternative fuels might lead to a decreased competitiveness of the current largest bunkering ports and result in a shift towards other ports that turn out to be more suitable for the trade, storage and production of alternative fuels. Considering the fierce port competition, PAs must strategize their role in the energy transition to remain competitive.

2.4 Port competition

Increased globalization of production and consumption, coupled with the establishment of a global transport network, and changes in inter-port relationships, port-hinterland dynamics, and logistical frameworks, has increased competition between ports (Notteboom et al., 2022). Port competition is defined as "competition for trades, with terminals as the competing units, logistics, transport, and industrial enterprises as the chain managers of the respective trades and port authorities and port policymakers as co-developers of the broadly defined port complex" (Notteboom et al., 2022, p. 366). Furthermore, (Parola et al., 2017) point out that the rise of port networks also has a great influence on port competition and the competitiveness of ports.

Nowadays, ports must accommodate and manage larger container ships to meet the demands of global supply chains (ECLAC, 2020). Additionally, ports have become more market-oriented, inventive, and sensitive to the demands of all parties involved in the trades that pass through the port as a result of these developments and the increase of the private sector's involvement in port activities (Notteboom et al., 2022). Researchers have defined several common drivers of inter-port competition (e.g. competition between different ports). Although the order of importance differ, there is consensus among researchers that port infrastructure, port costs, and geographical location are the most important drivers of port competition (Lirn et al., 2004; Notteboom et al., 2022; Parola et al., 2017; Tongzon, 2007). Part of ports' infrastructure is their environmental profiles (Notteboom et al., 2022; Parola et al., 2017). Furthermore, Coeck et al. (1996) made a notable contribution by introducing a framework that guides the strategies of PAs regarding inter-port competition. It suggests focusing on competencies that are inimitable by process, as here port competition is most fierce. These competencies include, for example, applying a dynamic construction process aimed at improving accessibility, including the gradual expansion of hinterland networks as well as the systems for the production and distribution of fuel that are dependent on infrastructure. Considering the energy transition and its implications for bunkering ports, the latter competency plays an important role for ports in fierce competitive paradigms.

Intra-port competition (e.g. competition between different actors in the same port) increases the competitiveness of ports (Pallis, 2022). Furthermore, it acts as a driver of innovation and specialization in ports, ultimately resulting in the establishment of economies of scope and dynamic multi-service organization structures that are vital to modern seaports.

In conclusion, inter-port competition is influenced by prices, geography and infrastructure. Furthermore, high intra-port competition is an important driver of innovation. Together, inter and intra-port competition lead ports in securing their competitiveness among competitive forces and changing market dynamics. High competition within and between ports pushes ports for efficiency and influences the adoption of sustainable practices and green alternatives, such as green shipping corridors, as ports aim to meet changing demands in a highly competitive environment in addition to the IMO's desire for decarbonization. To that end, green shipping corridors can be a tool for ports to increase their competitiveness while meeting the objectives of decreasing GHG emissions in shipping.

2.5 Public-private partnerships in ports

The energy transition requires the commitment and cooperation of both public and private actors (Pinilla-De La Cruz et al., 2022). PPPs have demonstrated their effectiveness in facilitating the development of transportation infrastructure, particularly in the context of extensive projects like ports (Cabrera et al., 2015). A PPP is a structured collaboration between public and private actors that, driven by their individual goals, join forces to achieve a common objective (Nijkamp et al., 2002). PPPs in the port sector have evolved into a procedure for more efficient port operations management and the development of new port infrastructure, roles that were traditionally exclusively undertaken by the government (The World Bank, n.d.). More, specifically regarding green shipping corridors, Wärtsilä (2023) states that these should be PPPs by design. Moreover, in all ports related to a green shipping corridor, governmental collaboration is vital to establish regulations and incentives that promote and incentivize zero-emission shipping activities, such as the use of alternative fuels.

PPPs are common in ports as Van Hooydonk (2022) explains that in the EU, public PAs often award private operators with terminal contracts. These operators then undertake substantial capital investment in the port superstructure, e.g. handling equipment and warehousing for containers, but terminals for the handling of dry-, liquid-, and breakbulk are operated and constructed similarly.

2.6 Green shipping corridor

Several parties mention one possible solution that could overcome the current impediments and catalyse decarbonization in the shipping industry: green shipping corridors. The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping and McKinsey & Company (2022) identified three green shipping corridor types. A single-point corridor is a corridor that establishes zero-emission shipping around a particular location. A point-to-point corridor is a corridor between two ports. Lastly, network green shipping corridors establish zero-emission shipping routes between at least three ports.

Green shipping corridors have the ability to streamline the difficulties of coordinating fuel infrastructure and ships in the value chain and between different countries and even continents, making them more manageable (American Bureau of Shipping, 2022). Furthermore, these corridors enable collaborative efforts to substantially cut emissions by bringing together several stakeholders and, as a result, create financial opportunities for each link of the value chain. In conclusion, green shipping corridors could be used as a first phase to roll out infrastructure for fuel alternatives and could lead the way to zero-carbon shipping (Chalofti et al., 2022).

There are already various initiatives to start green shipping corridors. For example, in Chili, there is the Chilean Green Corridors Network Project (The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping & McKinsey & Company, 2022b), between the between Rotterdam and Singapore (Port of Rotterdam, 2022c), and between the ports of Gdynia, Hamburg, Rønne, Rotterdam and Tallinn a project is launched called the European Green Corridors Network (Maritime Executive, 2022a).

Much has been written on green shipping corridors, however, academically substantiated literature on this concept is limited. Prause and Hunke (2014) researched the interaction and development of sustainable entrepreneurship activities along green transport corridors and concluded that, particularly for start-ups and established small and medium-sized businesses in the logistics industry, they build a coherent entrepreneurial environment and set the framework for sustainable development. De Moura and Botte (2019) investigated the challenges of establishing a green sea corridor in Brazil and emphasized the need for policy including public and private partnerships to increase this type of transportation. Even though these papers touch upon the green corridor concept, they do not describe green shipping similar to those emerging currently. Wang et al. (2023) mention a more similar concept of green shipping corridors and conducted a comprehensive supply chain analysis in which the authors designed a global network of ammonia-based corridors. However, this study focuses more on potential green ammonia production and bunkering locations instead of focusing on what needs to be in place to establish a successful green corridor.

In the cases of a point-to-point corridor and network corridor, there is cooperation between at least two ports. Port cooperation emerged in the early 1990s and is becoming increasingly more common (Notteboom et al., 2022). Cooperation between ports occurs between those that are proximate and non-proximate. Ports may look to gain a competitive edge by learning cutting-edge technologies, developing novel commercial prospects, or acquiring superior knowledge (Notteboom et al., 2020). Additionally, ports may seek a competitive advantage by acquiring advanced knowledge, cutting-edge technologies, or pursuing new business opportunities. Notteboom et al. (2022) describe this strategy for port cooperation in detail. It can go beyond just cooperating with nearby ports in at least two different ways. The first step is collaboration between two points along a logistics corridor to enhance the flow of goods between the two areas. Secondly, agreements to share information about port operations, management, structure, and technology are part of port collaboration. PAs that are more independent and have a structure that is more like a business take on a more entrepreneurial role that includes internationalisation initiatives and alliances that form legally through the signing of a memorandum of understanding (MoU), in addition to commercial growth.

In conclusion, a green shipping corridor, whether a single point, point-to-point, or network corridor, is a micro-level representation of the broader energy transition. Furthermore, it acts as a proactive step to decarbonize the maritime sector, making it a crucial component of SSM. In the definition of a green shipping corridor, the Global Maritime Forum (2022) has emphasized the combination of public and private actions. Thus, a green shipping corridor may be categorically classified as a PPP. This categorization is underscored by Wärtsilä (2023), who states that green shipping corridors should be designed as PPPs. Through combined efforts of public and private actions, a green shipping corridor can streamline the complexities associated with coordinating fuel infrastructure and ships, thus paving the way for the operation of zero-emission ships (Getting to Zero Coalition et al., 2021; Joerss et al., 2021). By taking this approach, green shipping corridors offer a potential pathway towards a future for the maritime industry with emission reduction, in which different stakeholders work together to address these challenges and promote the use of zero-emission fuels and ships.

2.7 Critical Succes Factors

The definition of green shipping corridors in section 2.6 implies, that for a green shipping corridor to be successful, it must be technologically, economically, and regulatory feasible to operate zero-emission ships in/between the port(s) involved in a green shipping corridor. This indicates these ports must have infrastructure in place for zero-emission fuels to accommodate this. Furthermore, the port(s) involved must have enough access to alternative fuels, and ships on the specific corridor must be equipped with appropriate technology to effectively utilize these fuels. To determine which factors influence success, this thesis will examine CSFs of green shipping corridors. CSFs are defined by Bullen and Rockart (1981, p. 7) as “the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department or organization”. CSFs of establishing the Rotterdam-Singapore green shipping corridors will therefore be the limited areas in which satisfactory results will ensure successful competitive performance.

A report by the American Bureau of Shipping mentions four foundational elements that have a similar definition as CSFs, namely “ensure the successful launch of any green corridor and mitigate any associated risk” (American Bureau of Shipping, 2022, p. 6). These elements, however, lack any arguments regarding their origin. The same holds for the four critical building blocks that need to be in place to establish a green corridor, according to the Getting to Zero Coalition (2021). These building blocks again lack any substantive justification.

Further literature on the CSFs of green shipping corridors is non-existent. However, the concept of green shipping corridors is situated at a crossroads of other existing concepts, namely public-private partnerships, SSM, and the energy transition. Literature on CSFs of these concepts does exist. Chua et al. (2023) performed a systematic review of academic journals and reviewed CSFs in SSM. In addition, Aerts et al. (2014) conducted research on the CSFs for successful implementation of PPPs in ports and initially found more than seventy CSFs in PPPs. Consequently, they have condensed this list and established a final twenty-one CSFs of PPPs specifically in the port setting. Outside the port setting, B. Hwang et al. (2013) have identified eight CSFs in PPPs in Singapore. Lastly, Bai et al. (2023) have defined CSFs in the energy transition in Southeast Asia.

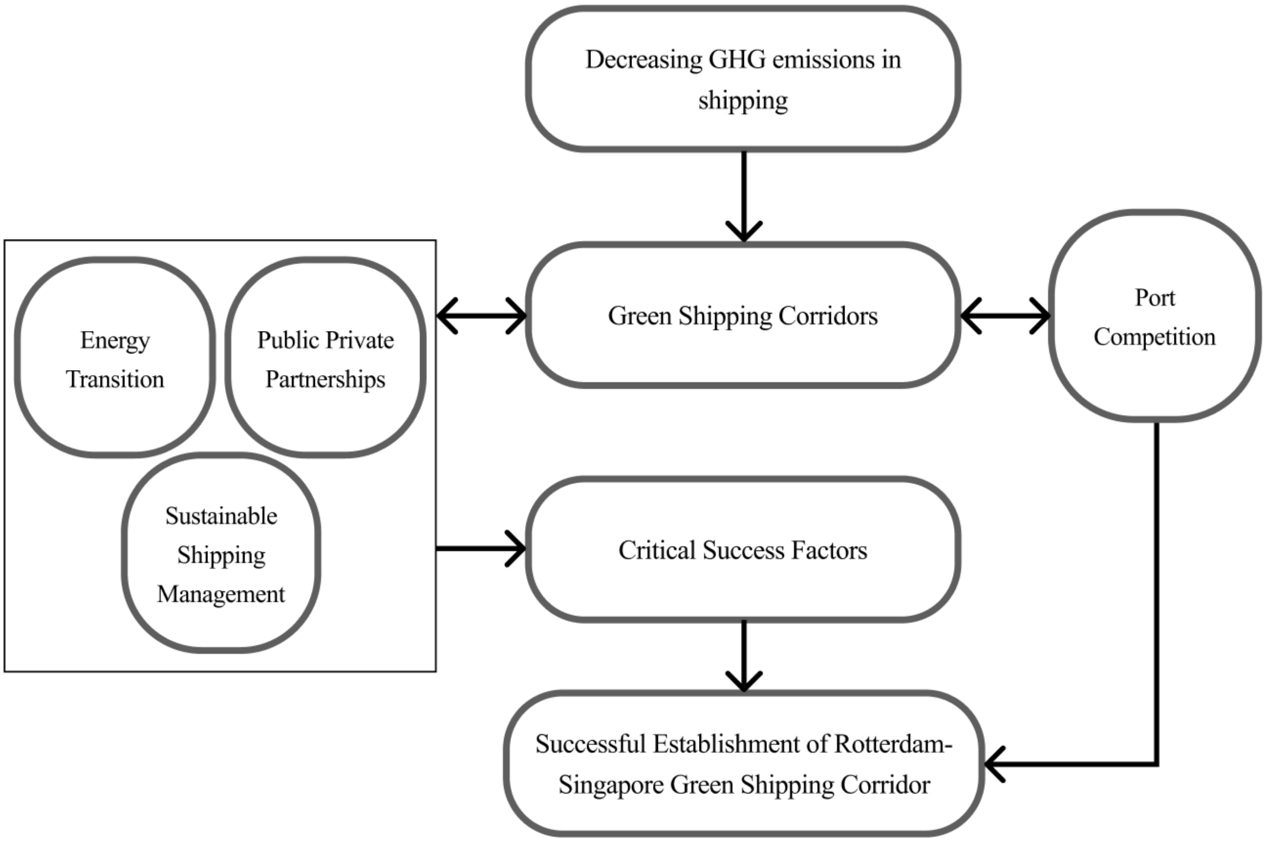
To meet this thesis' main objective and identify CSFs for establishing the Rotterdam-Singapore green shipping corridor, it becomes evident that literature specifically addressing CSFs for this context, is scarce. To overcome this scarcity, this thesis utilizes overarching topics that are related to green shipping corridors, where valuable insights into CSFs have been established. These topics include SSM, PPPs, and the energy transition. Although the CSFs from these topics may not directly apply to green shipping corridors in a one-to-one fashion, their importance comes from how closely they are linked to the general objectives and difficulties of these corridors. For instance, green shipping corridors must be PPPs by design (Wärtsilä, 2023). The latter is by definition an important component of green shipping corridors as green shipping corridors are established by a combination of public and private actions (Global Maritime Forum, 2022). Moreover, since establishing a green shipping corridor requires a shift from currently used fossil fuels to alternative zero-emission fuels, it is a micro-level representation of the energy transition.

Nonetheless, it is important to note again that not all CSFs from the aforementioned topics apply in the same way in the green shipping corridor context. Some CSFs from the overarching themes may exhibit overlap with each other, while others are irrelevant or require adaptation to align with the unique requirements of green shipping corridors. An overview of CSFs found in the aforementioned literature can be found in Appendix A1.

2.8 Conceptual framework

The conceptual framework, derived from the literature, links the IMO's aim of decreasing GHG emissions in the shipping industry to the emergence of green shipping corridors. These corridors are rooted in the concepts of energy transition, PPPs, SSM, and port competition. Since the literature on the CSFs of green shipping corridors is lacking, existing literature on energy transition, PPPs, and SSM is used to identify potential CSFs for establishing the Rotterdam-Singapore green shipping corridor. Implementing these CSFs, as suggested by the literature, ensures the successful establishment of the Rotterdam-Singapore green shipping corridor. Additionally, as explained in the literature, port competition also influences the establishment of the Rotterdam-Singapore green shipping corridor.

Figure 1: Conceptual framework that arises from literature review



3. Methodology

In this chapter, the methods used to answer the research question and the sub-questions are described. This research aims to get more insight into the CSFs of implementing the Rotterdam-Singapore green shipping corridor. Therefore, the choice for the specific Rotterdam-Singapore is explained as well. Additionally, this research aims to provide insight into the current state of play regarding green shipping corridors across the globe. Table 2 below provides an overview of the research objectives, data, data sources and methods.

Table 2: Overview of research objectives, data, data sources and respective methods.

Objective	**Data**	**Data source**	**Method**
Determine the CSFs of the green shipping corridor in the Rotterdam-Singapore case Validate results of content analysis	CSFs	Press releases Project portfolios Sustainability reports Fact sheets Industry experts	Content analysis Interviews
Determine the factors that influence the success of implementing a green shipping corridor and compose a list of predetermined codes for content analysis Validate if the list is complete with industry experts	Predetermined codes	Literature Industry experts	Literature review Interviews
Determine the current state of play of competition in green shipping corridors Provide an overview of bunker port strongholds Provide assessment of bunker readiness of ports involved in green shipping corridors	Green shipping corridor initiatives Bunker locations	Reports Press releases	Qualitative analysis
Analyse differences and similarities of CSFs between data segregated per Rotterdam and Singapore	CSFs segregated per port	CSFs	Comparison of outcomes
Analyse differences and similarities of CSFs between data segregated per alternative fuel	CSFs segregated per alternative fuel	CSFs	Comparison of outcomes

3.1 Literature review

Firstly, the goal of the literature review is to identify the forces that influence the success of a green shipping corridor and use these to determine the predetermined codes used for the deductive content analysis. Since academically substantiated literature on this topic is lacking, the CSFs of overarching themes from which the concept of green shipping corridors emerges, namely SSM, the energy transition, and PPPs, form the basis for the codes in the deductive content analysis.

In addition, port competition is identified as a driver of innovation in ports and cooperation between ports. These dynamics in turn influence the successful implementation of green shipping corridors and are therefore described more in-depth.

Moreover, the frame regarding the three alternative fuels of methanol, hydrogen and biofuels in this thesis is advocated.

Lastly, the conceptual framework that arises from the literature is presented in section 2.8

The table below presents an overview of the research sub-questions and the parts of the literature they are covered in. Table 3 below offers a synopsis of the research questions and the corresponding sections of the literature that address them.

Table 3: Overview of sections in literature review covering each sub-question

Research sub-question	**Related section of literature review**
What are the factors that influence the success of implementing a green shipping corridor?	2.1 2.2 2.5 2.6 2.7
What is the current state of play of competition in green shipping corridors?	2.3 2.4
What are the similarities and differences in the critical success factors between the ports of Rotterdam and Singapore in the context of implementing the Rotterdam-Singapore green shipping corridor?	2.7
What are the similarities and differences in the critical success factors between the different alternative fuels of methanol, hydrogen and biofuels in the context of establishing the Rotterdam-Singapore green shipping corridor?	2.2 2.7

3.2 Competition assessment

The competition assessment aims to identify the current state of play of green shipping corridor initiatives. This will encompass an overview of the world's largest bunker ports, considering the substantial impact expected due to the transition to alternative shipping fuels, involving changes in infrastructure and trading patterns. In addition, it includes an outline of all current green shipping corridor initiatives. Lastly, it incorporates information regarding the bunker readiness of alternative fuels (methanol, hydrogen and biofuels) of ports involved in green shipping corridors. The first two components will be depicted in a visual world map, highlighting geographic information. This list comprising all green shipping corridors can be found in Appendix C1. In addition, this list also includes the readiness to bunker alternative fuels of ports involved in green shipping corridors.

This assessment provides insights into the dynamics in port competition, within the context of these emerging corridors, offering insights into their potential influence on the success of the Rotterdam-Singapore green shipping corridor.

The American Bureau of Shipping (2022) has provided a list including ports' readiness to bunker certain alternative fuels, however, it is limited to just fourteen ports (Antwerp, Dampier, Houston, Kashima, Los Angeles, Montreal, New Orleans, Oita, Port Hedland, Rotterdam, Seattle, Shanghai, Singapore and Vancouver). Since this list does not encompass all ports involved in the green corridor initiatives this thesis presents, the missing ports' alternative fuel bunkering readiness is analysed manually. This is done by analysing each PA's website and the maritime news media websites of Offshore Energy, Maritime-Executive, and Ship & Bunker. These sources often publish news articles when bunkering of either of these fuels happens. For example, the Maritime Executive wrote about methanol bunkering in Antwerp-Bruges (Maritime Executive, 2023b) and in Gothenburg, its PA published a press release about methanol bunkering (Port of Gothenburg, 2023). Google site search is used to examine these websites. The Google site search allows search results to be narrowed down to specific websites only (Karch, 2022; Strikingly, 2021). Furthermore, it makes a systematic web search within these data sources possible. Table 4 provides search examples that were used to determine whether ports involved in green shipping corridors have alternative fuel (methanol, hydrogen and/or biofuels) bunker facilities in place.

Table 4: Examples of Google site search to determine ports' alternative fuel bunkering readiness

Port	Search term
Shanghai	Site: www.offshore-energy.biz "shanghai" AND "hydrogen" OR "methanol" OR "biofuel"
Hong Kong	Site: www.hkmpb.gov.hk "biofuel" OR "hydrogen" OR "methanol"
Gothenborg	Site: www.portofgothenburg.com "biofuel" OR "hydrogen" OR "methanol"
Houston	Site: www.maritime-executive.com "Houston" AND "hydrogen" OR "methanol" OR "biofuel"

3.3 The Rotterdam-Singapore Green Shipping Corridor Case

In this thesis, a single-case study design is utilized. This method provides the benefit of being less time-consuming than multiple case studies (Bryman, 2012; Yin, 2018). Additionally, such a study enables researchers to gain a more in-depth understanding when investigating a specific topic. Furthermore, it is well suited for theory building (Mariotto et al., 2014). Lastly, because of the novelty of green shipping corridors as a concept in the literature, a single-case study is suited because of its exploratory nature (De

Langen, 2023). The joint project between the ports of Rotterdam and Singapore to establish a green shipping corridor between the two can be seen as a single case. However, since this corridor is a point-to-point corridor, requiring infrastructure at both points, it can also be seen as two cases. One encompassing the Rotterdam side and the other the Singapore side. Therefore, the outcomes of the content analysis for each port are segregated and compared to answer the third sub-question. Furthermore, this research is framed by the three alternative fuels methanol, hydrogen and biofuels. The outcomes of the content analysis are also segregated by alternative fuel and compared accordingly to answer the fourth sub-question. Therefore, this study also incorporates facets of a multiple case study, albeit in the framework of a single specific green shipping corridor and the three alternative fuels. This comparison utilizes the major advantage of a multiple case study over a fully individual case study, namely that it allows researchers to compare their findings (Hunziker & Blankenagel, 2021). Hunziker and Blankenagel (2021) also explain that this results in more robust outcomes.

The choice of this specific green shipping corridor is based on several arguments. First of all, the Asia-Europe trade route, of which Rotterdam and Singapore are key players, has the highest GHG emissions compared to any other global trade route (Getting to Zero Coalition et al., 2021). Approximately 3 per cent of the world's shipping emissions can be attributed to the approximately 11 million tonnes of fuel burned in 2019 along this route (Faber et al., 2021). This resulted in 35 million tonnes of CO_2 emissions. Underscoring the importance of decarbonization efforts along this route. The Suez Canal, which provides the shortest maritime route between Europe and Asia, accounts for 12 per cent of global trade and 30 per cent of worldwide container trade (Sinay, 2023). In 2020, approximately 23 million twenty-foot equivalent units (TEU) containers were handled in containerized trade along the Asia-Europe trade route (UNCTAD, 2020). This number is just below the 25 million TEU containers that were handled in containerized trade along the trans-Pacific route the same year (UNCTAD, 2020). The three main shipping alliances, 2M Alliance, Ocean Alliance, and THE Alliance, are all operating this route and together account for about 82 per cent of the global shipping market in terms of TEU (Nerja & Sánchez, 2023). The high concentration of ships and the presence of these three industry giants accelerate the competition along this route.

Nevertheless, despite the emissions along the Asia-Europe container route, this route presents favourable circumstances for the development of a green shipping corridor. The Getting to Zero Coalition et al. (2021) bases this statement on several key arguments. To begin, there is a huge potential for recently announced green hydrogen projects in Europe, the Middle East, and Australia, which seek to build 62 GW (gigawatt) of hydrogen electrolyser capacity by 2030. This capacity is expressly designed to suit Asia's bunkering requirements, implying that the corridor has adequate resources to help it transition to sustainability if green hydrogen is chosen as an alternative fuel. Second, there is an increase in demand for decarbonization measures throughout the value chain linked with this trading route. This demand includes a wide range of players, from end users to goods forwarders and transportation companies. The common desire for decarbonisation demonstrates a strong commitment to lowering greenhouse gas emissions and promoting sustainable practices in the business. Third, because of the nature of the goods delivered along this route, participants may be able to share costs with end consumers without significantly increasing retail prices, making it a potentially commercially viable operation. Furthermore, officials along the route have increasingly recognised the need to make maritime decarbonization a priority.

As mentioned previously, the ports of Rotterdam and Singapore are two of the four largest bunkering ports in the world. Rotterdam is the largest bunkering port in Europe and per year, approximately 9.5 million tons of fuel are delivered to the shipping industry in Rotterdam (Port of Rotterdam, n.d.). The port holds a 50 per cent market share for fossil fuel products in North-Western Europe (Bosman et al., 2018). Moreover, Rotterdam has the most competitive bunker prices globally, encompassing both fuel oil and marine petrol oil (NOVE, n.d.). Several container ships strategically choose Rotterdam as their refuelling destination for their journeys between Europe and Asia, making it an important stop on their round-trip voyages. Intra-competition regarding the petrochemical industry and fuel production in Rotterdam is high. There are, for example, six large refineries and nine tank terminals for oil products, (Port of Rotterdam, 2021a). The port of Rotterdam is an important hub for the transhipment of sea containers in the world (Centraal Bureau voor de Statistiek, n.d.) and claims the third position in terms of the number of direct connections to other ports (node degree) and the first position in terms of its importance for trade between other ports that are interconnected via transhipment (node betweenness) (Hoffmann & Hoffman, 2020).

The port of Rotterdam's PA is a semi-public organization responsible for the port of Rotterdam's smooth operation, development, and safety. It aims to enhance the port's global competitiveness as an industrial hub. Owned 70 per cent by the municipality of Rotterdam and 30 per cent by the Dutch government (Port of Rotterdam, 2023a). In 2022, it had a turnover of approximately €783 million. Furthermore, it generated total employment of 183,004 people in 2021 (Streng et al., 2022). Its main revenues come from rentals and port fees (Port of Rotterdam, 2023a). The Authority also leases port sites and invests in infrastructure, including roads and customer-specific facilities. Additionally, it allocates funds for patrol vessels, a traffic supervision system, and emergency control to ensure effective shipping operations. Moreover, Rotterdam is considered to be the largest transhipment

Lastly, the PA claims to be an accelerator of sustainability in the port and aims to contribute to the Dutch CO_2-reduction target of 55 per cent by 2030 compared to 1990. In addition, the manager of Electrification and Hydrogen at the Port of Rotterdam Authority, Randolf Weterings, explains that the port of Rotterdam has the ambition to be the hydrogen hub of Europe (Port of Rotterdam, 2021b). By 2030, the port wants to realise a production capacity of 2 to 2.5 GW of hydrogen. Of this number, 10 per cent will be produced on-site in Rotterdam. The remainder will be imported.

The port of Singapore, claims the undisputed status as the world's largest bunkering port (Ha et al., 2023) and accounts for approximately 50 million tonnes of shipping fuel sold (MPA Singapore, 2023; Shaw-Smith, 2023). Resulting in representing approximately 21 per cent of the global bunker market in 2019 (Tolson, 2021). Singapore houses extremely high intra-port competition in bunkering, including 41 licensed bunker suppliers (Lim et al., 2021). In addition, the port ranks fifth in the world port ranking in terms of node degree and 23rd in the ranking on node betweenness (Hoffmann & Hoffman, 2020). Singapore's PA is a direct subsidiary of Singapore's ministry of transport (Ministry of Transport Singapore, n.d.) and is called the Maritime and Port Authority of Singapore (MPA). It oversees and regulates various port and marine services, focussing on operational efficiency and environmental standards. Furthermore, it aims to position Singapore as a prominent global hub and top-tier international maritime centre. This includes attracting major shipowners and terminal operators to establish their presence in Singapore. Lastly, the MPA serves as the government's advisor on matters pertaining to sea transport, as well as maritime and port services and infrastructure. Notably, the MPA pledged to contribute to Singapore's commitments to the Paris Agreement limiting global warming to below 2°C above pre-industrial levels and the initial IMO strategy on the reduction of GHG emissions from ships (Maritime and Port Authority Singapore, 2022).

Conspicuously, both the governments of the Netherlands and Singapore have signed the Clydebank Declaration for green shipping corridors. Part of this declaration is the objective to support the establishment of at least six green corridors around 2025 (United Kingdom Department for Transport, 2022).

In conclusion, because of its location along one of the busiest shipping routes in the world with the highest GHG emissions of all shipping routes, the Rotterdam-Singapore green shipping corridor presents a compelling case to focus on. Furthermore, both ports' positions as two of the largest bunkering ports in the world, and their governments' objectives regarding decreasing GHG emissions in shipping make this case interesting. In addition, both ports' locations in two of the world's largest container ports clusters, for Rotterdam the Rhine-Scheldt Delta and Singapore the Strait of Malacca, results in a high level of inter-port competition within the two ports' respective clusters (Notteboom et al., 2022). As two of the largest bunkering ports globally, Rotterdam and Singapore have substantial investments and economic dependencies tied to traditional fossil fuel bunkering activities. This makes them vulnerable to potential disruptions and economic losses as the shipping industry shifts towards alternative fuels, providing strong incentives for both ports to proactively engage in the energy transition. Furthermore, both ports are also two of the largest container ports in the world (United Nations, 2022a)

To facilitate low and zero-carbon shipping, as a means to proactively engage in the energy transition, the two ports signed an MoU in 2022 to create the world's longest green and digital shipping corridor (Port of Rotterdam, 2022c). Rotterdam's PA declares its desire to cooperate with Singapore's MPA as a means to address the issues regarding the price, availability, safety, and restrictions on alternative fuels for shipping (Port of Rotterdam, 2022c). The project is by definition a point-to-point green shipping corridor, i.e. a joint project between two ports to establish technological, economic, and regulatory feasibility of the operation of ships using zero-emission fuels that is catalysed by a mix of public and private actions. For the success of this project, both the Port of Rotterdam and Singapore must attain technological, economic, and regulatory feasibility for the operation of zero-emission ships, ultimately leading to the establishment of a green shipping corridor. This thesis aims to determine the CSFs of this specific green shipping corridor and compare the results per port and per alternative fuel type.

3.4 Content analysis

3.4.1 Critical success factors

The CSFs for the Rotterdam-Singapore green shipping corridor are the essential areas where successful performance is critical to ensure the seamless operation and achievement of zero-carbon shipping along this route. By definition, these areas encompass technological readiness, economic viability, and regulatory compliance, requiring coordinated efforts from both public and private stakeholders (Global Maritime Forum, 2022).

This research organises the CSFs using the multi-level analysis of CSFs as lined out by Leidecker and Bruno (1984). The authors explain that each level of analysis is a potential source of CSFs. Furthermore, Leidecker and Bruno (1984) explain the following about the three levels of analysis. Firstly, firm analysis of CSFs focuses on internal factors (micro level). Second, industry analysis of CSFs concentrates on variables in the industry's basic structure that have a major influence on the success of any organisation operating in that industry (meso level). Lastly, the environment level of CSFs extends its scope beyond the boundaries of a single industry. This perspective includes that continuous environmental scanning (including economic and socio-political factors) is essential to identify the key determinants of success for both individual organizations and entire industries (macro level). This multilevel perspective proves to be relevant because Mander (2017) lines out that technology transitions, crucial for low-carbon shipping, must involve actions from these multiple levels. The author continues by explaining that these changes must occur at these levels accordingly, ranging from the micro-level within individual firms/organizations, to the meso-level encompassing specific sectors or industries and extending to the macro-level which includes broader socio-economic and political components. In addition, all CSFs are linked to supporting theories if applicable. To this end, the macro-level CSFs are grouped utilizing a PESTLE analysis. Such an analysis is often carried out to analyse the macroenvironmental factors in which an industry operates (Iacovidou et al., 2017). These factors affect the decision-making process of the managers of any organization (Srdjevic et al., 2012). Furthermore, the meso-, and micro-level CSFs are linked to supporting theories from the strategic management literature. Appendix C4 provides an overview of CSFs and the supporting theories they are linked to. Hereafter the choice of each supporting theory linked to the meso-, and micro-level CSFs if applicable is explained. Note that several CSFs stem from the research by Chua et al. (2023) on SSM and that in that research CSFs are also linked to supporting theories.

Capital investment stems from the real options theory. This theory implies that investment decision-makers should consider the flexibility to make choices in an unpredictable environment (Leslie & Michaels, 1997). Establishing a green shipping corridor involves large capital investments, to build, for example, new infrastructure. Using real options theory, decision-makers can consider these investments as options that can be implemented or delayed based on changing circumstances, ensuring that their investments are spent effectively, therefore mitigating risks and maximizing investments' long-term value.

Concrete and precise concession agreement originates from the contract theory. Contract theory is vital to establishing green shipping corridors. These projects involve several stakeholders with various interests, making contract design and negotiations crucial. The international nature of shipping (Edelenbosch et al., 2022), further enhances the importance of the contract theory. The theory guides the structuring of contracts to reduce conflicts and allocate risks effectively and provides a framework for adapting contracts to evolving project dynamics (Bolton & Dewatripont, 2005).

The dynamic capabilities theory focuses on organizations' ability to adapt, change, and dynamically adapt resources and processes in response to changing external circumstances (Y. Liu, 2022). It is therefore connected to infrastructural resilience which is described as the resilience of the infrastructure to external shocks (e.g., climate events, geopolitical tensions etc.) that alternative fuel infrastructure might face (Y. Baay, personal communication, 16 October 2023). Resilient infrastructure will mitigate potential disruptions from these external circumstances.

In SSM, strategic alignment encompasses the process of harmonizing the objectives of a shipping company with the dynamic interplay of its internal and external contextual factors (Chua et al., 2023). It is associated with the contingency (fit) theory. This theory underscores the importance of ensuring that a strategy is effectively aligned with its specific context or environment to achieve optimal outcomes (Donaldson, 2001). Within the scope of green shipping corridors, strategic alignment plays a vital role in ensuring that organizational objectives and strategies are seamlessly adjusted, both within an organization and with its external partners. Given green shipping corridors involve coordinated actions from both private and public actors (Global Maritime Forum, 2022), strategic alignment proves relevant.

Relationship coordination originates from the relational view theory. Relationship coordination revolves around establishing strong relationships with different stakeholders (Chua et al., 2023). The relational view theory emphasizes the creation of strong inter-firm connections and the development of resources that extend across multiple organizations (Dyer & Hatch, 2006). Given the complexity of bunker value chains encompassing several different actors (CE Delft, 2011), this is vital to establishing a green shipping corridor.

The factor of renewable energy supply is linked to the resource dependence theory. This theory is based on the concept that an organization has to interact with other organizations within its environment to acquire and secure necessary resources (Katz & Kahn, 1978). In the context of establishing a green shipping corridor, it, for example, implies that firms must secure access to renewable energy sources necessary for the production of alternative fuels.

Risk allocation and risk sharing are linked to the enterprise management theory. This theory encompasses strategic methods to identify and manage risks across organisations (Fraser, 2015). In the concept of establishing a green shipping corridor, it is applicable because these corridors require a comprehensive approach to manage risk because of their involvement of multiple, cross border, stakeholders.

Organizational commitment is related to an organization's dedication to implementing a project. Since it incorporates support from the management and cooperation from all employees, it is vital (Chua et al., 2023). It is connected to organizational culture (Al-Jabari & Ghazzawi, 2019) and in accordance with the resource-based view theory, culture is considered an intangible asset. It underlines the success of a sustainable competitive edge by making optimal and proficient use of an organization's internal resources, whether tangible or intangible (Day, 2011). Therefore, organizational commitment is connected to the resource-based view theory.

The safety factor can be associated with the normal accident theory. This theory, established by Perrow (2011), addresses complex and high-risk systems and how accidents can occur because of inherent system complexities, making it highly applicable to the safety considerations in the operation of the green shipping corridor considering the safety risks fuel handling poses.

Lastly, knowledge transfer and new technology acceptance both stem from the organizational learning theory. Yukl (2009) argues that collaborative learning by members of the organisation is a key component of this theory. The discovery of relevant new information, the distribution of this new information and knowledge to individuals in the organisation who need it, and the use of the knowledge to enhance internal operations and external adaption are all essential activities related to organizational learning theory and these are captured by the two factors of knowledge transfer and new technology acceptance.

3.4.2 Planning and research progress

To identify the CSFs of establishing the Rotterdam-Singapore green shipping corridor, content analysis will be utilized. Content analysis is defined as "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Krippendorff, 2019, p. 24). By utilizing content analysis, researchers can examine the existence, meanings, and relationships of particular words, themes, or concepts (Krippendorff, 2019). Furthermore, it is an approach of examining text by systematically and objectively coding information to analyse the content of documents in a trustworthy manner (Guthrie et al., 2004) The data used for content analysis are interview transcripts, reports, and other relevant texts (Mayring, 2023).

Bengtsson (2016) describes the steps for the research process of content analysis. First, the author explains that it commences with planning the research. This starts with identifying the aim. As aforementioned, this research aims to identify the CSFs of establishing the Rotterdam-Singapore green shipping corridor.

The next step is to determine who/what can best answer the queries set out. Notably, the Rotterdam-Singapore green shipping corridor is a joint project managed by two port authorities and several parties along the complex bunkering value chain as explained in section 2.3. This value chain is even more complex because uncertainty exists regarding the dominant alternative fuel choice (Hervas, 2023; IRENA, 2021), as each fuel option has its benefits and drawbacks. In addition, the bunker value chain involves various firms at different stages (CE Delft, 2011). For green shipping to be established in 2027 along the route, all links must be in place for at least one of the alternative fuels in both ports. Therefore, all parties directly involved in hydrogen, methanol, and biofuels projects in both the ports of Rotterdam and Singapore are best suited to answer the queries set by the aim. Press releases, project portfolios, and annual and sustainability reports regarding these projects will be evaluated. Furthermore, as mentioned, Notteboom et al. (2020) constructed a list of stakeholders involved in the greening of ports in the Rhine-Scheldt delta. Given the importance of public and private actions, as is incorporated in the definition of green shipping corridors (Global Maritime Forum, 2022), and the complexity of the bunker value chain (CE Delft, 2011), data on these stakeholders are incorporated in the analysis as well. A tabulated overview of all data documents used in the content analysis is given in Appendix B1. This overview indicates whether a document is related to the port of either Rotterdam or Singapore, identifies the respective stakeholder according to Notteboom et al. (2020), and associates the document with the link within the value chain.

The third planning step, as explained by Bengtsson (2016), encompasses how the information should be collected. Organizations often publish press releases on their websites when they engage in, for example, a coordinated project to start hydrogen imports or biofuel production. This publicly available data will be used for this specific content analysis and for consistency, only data made available by the organization directly engaged in the subject matter under discussion is used. Data published by third parties, for example newspapers, are disregarded.

The fourth step of this process is to choose the method of analysis (Bengtsson, 2016). Firstly, this thesis performs deductive reasoning and follows predetermined codes. Berg (2002) explains that in this process, the researcher utilizes these code categories by testing hypotheses or principles. The studies lined out in section 2.7 enhance the understanding of CSFs in SSM, energy transition, and PPPs. As explained, green shipping corridors are located at the crossroads of these concepts. Therefore, in the content analysis, the CSF of PPPs, SSM, and the energy transition as described in the literature review will be used as a foundation for the predetermined codes. In addition, the list of predetermined codes is presented to four industry experts, as means of validation. This step is explained in more detail in Section 3.3.4. Furthermore, this thesis focusses on latent content i.e. the underlying connotations. Instead of exploring manifest meanings i.e. what the text explicitly says (Berg, 2002). Words, phrases, and sentences with particular themes are then coded using the predefined codes, and the frequency of these codes is then quantified. This quantification enables a more thorough and detailed analysis of the data. This numerical, quantitative approach allows a structured and replicable exploration of written data (Huxley, 2020). The code labelling and the quantification of codes will be done using Atlas.ti. This software is used to perform qualitative data analysis and is often used in academic research of social sciences. It allows for the management of encoding and access to text in combination with sophisticated searches (S. Hwang, 2007).

After planning the research, data must be collected (Bengtsson, 2016). As explained in the second planning step, publicly available data is used. These texts are copied and uploaded to Atlas.ti. Hereafter, the data must be analysed. This analysis comprises of four stages (Bengtsson, 2016). The first stage is decontextualization. In this step, researchers familiarize themselves with the data and read all relevant texts. Additionally, the texts are broken down into smaller meaning units (e.g. sentences of paragraphs) and these are labelled with a code. Codes enable the identification of concepts that the data can be built upon to form blocks and patterns during the analysis process (Catanzaro, 1988). The next stage as described by Bengtsson (2016) is recontextualization. In this stage, the researcher must accordingly verify if every component of the content has been covered in connection to the objective (Burnard, 1991). In the light of this research, it is important that the research frame is upheld and therefore the focus should remain on the three alternative fuels as selected. If the data do fit the frame, the text should be included and excluded if otherwise. The third stage starts with condensing the meaning units (Bengtsson, 2016), i.e. reducing the number of words of each unit without losing its content (Graneheim & Lundman, 2004). The final stage is the compilation. In this stage, the analysis and writing process commences (Bengtsson, 2016). In conclusion, CSFs in this context are the codes that are linked to quotations in the data most frequently.

After the analysis, the CSFs will be grouped in the macro, meso and micro levels as lined out in section 3.4.1. Furthermore, the CSFs will be linked to concepts in strategic management literature to provide each factor with more context.

3.4.3 Data

As aforementioned, this thesis will investigate data related to infrastructural projects in both Rotterdam and Singapore concerning methanol, hydrogen, and biofuels so that ships can bunker these alternative fuels along this route. For this, ships need to be fitted with the right engines as well. Therefore, data on ship owners and manufacturers regarding these alternative fuels will also be examined. Lastly, the definition by the Global Maritime Forum (2022) refers to the influence of a combination of public and private actions. To capture this, the list of public and private stakeholders engaged in port greening as defined by Notteboom et al. (2020) is used as a foundation. A tabulated overview of the data used in the content analysis can be found in Appendix B1. Note that the data is grouped per port (Rotterdam, Singapore, N/A). Furthermore, it is grouped per link in the value chain as described by Vopak (2022) (import, production, transport, storage and finally the customer. Note that bunkering has been replaced by the customer. This refers to the customers that ultimately use the fuels such as shipping lines). Finally, the data is grouped per stakeholder as described in Table 1. In total, the data consists of 65 different documents.

3.4.4 Predetermined codes

The findings in section 2.7 will form the basis for the predetermined used in the content analysis. However, in some cases, the CSFs that formed the basis of the predetermined codes in these concepts are not relevant to this research. Bai et al. (2023), for instance, conclude biological diversity is a CSF of the sustainable energy transition in Southeast Asia. This could be an effect of establishing a green shipping corridor, it is however not one of the limited number of areas in which satisfactory results will ensure a successful establishment of a green shipping corridor. It is therefore excluded. Furthermore, some CSFs were mentioned in more than one source. For example, Bai et al. (2023) mention limited government effort, Chua et al. (2023) mention government support, Aerts et al. (2014) mention political support and special guarantees by the government, and lastly, B. Hwang et al. (2013) mention well-organized public agency. In essence, these CSFs are the same and are therefore merged into the CSF of government support. Additionally, Bai et al. (2023) mention inadequate and uncoordinated policies and regulations as a CSF in the sustainable energy transition in Southeast Asia and Aerts et al. (2014) mention sound economic policy as a CSF in PPPs in ports. These two are merged into adequate and coordinated policies and regulations. Something similar was done regarding stakeholder management and knowledge management. These CSFs were mentioned by Chua et al. (2023) and Aerts et al. (2014), albeit in different words. Community support is also erected by merging difficulties in communication with local communities (Bai et al., 2023) into community support (Aerts et al., 2014). B. Hwang et al. (2013) mention clear defined responsibilities and roles, and Aerts et al. (2014) mention clear definition of responsibilities. These two are merged as well. Furthermore, Bai et al. (2023) mention disunity and concern for national interests as a CSF for the sustainable energy transition in Southeast Asia. This is however very much intertwined with government support. Namely, disunity and concern for national interest will lead to a lower form of government support. It is therefore excluded as a predetermined code. An overview of the initial codes emerging from the CSFs of literature described in section 2.7, is given in Appendix B2. The list of codes has been presented to industry experts. The outcomes of this validation, is explained in the next paragraph.

In total, the four papers reviewed offered 68 CSFs. After condensing this list, these were used as a foundation of predetermined codes for the deductive content analysis. Finally, this resulted in the 22 predetermined codes provided by the literature.

3.4.5 External validation

Bengtsson (2016) lines out the importance of a triangulation procedure within content analysis. This can be done by letting the content analysis be performed by at least two researchers independently (Burnard, 1991; Graneheim & Lundman, 2004). This is however not achievable in this research. Nevertheless, the triangulation procedure can also be achieved by using different sources for data collection (Catanzaro, 1988). Therefore, after finishing the content analysis, the results are presented to industry experts as a means to validate the completeness of the list and the final results of the content analysis. These results will be compared to the industry experts' views on the CSFs presented to them. This last step will contribute to the credibility of research and its outcomes (Bogner et al., 2009). Moreover, Eriksson and Lindström (1997) explain that with a deductive approach in content analysis, there is a risk of formulating categories based exclusively on an already established theory or model. The external validation aims to overcome this risk by gathering information outside of the theories on the energy transition, PPPs, and SSM.

The industry experts each represent a different stakeholder group as depicted in Table 1 and thus, are all different actors in the greening of ports (Notteboom et al., 2020). To these industry experts, I presented the condensed list of CSFs of green shipping corridors that emerged from the literature review. This list can be found in Appendix B2. Thereafter, the following three questions were asked.

1. *Do you agree with this list and consider the factors below important for the success of establishing a green shipping corridor?*
2. *Do you find the list of factors complete, or is there something significant missing?*
3. *From your perspective and knowledge, which five factors do you believe are the most important?*

The aim of asking these questions is to identify industry experts' takes on whether all factors in the list are relevant, whether the list is complete, and to determine which five factors they found most important.

From the interviews, I concluded that the initial list of codes used for the content analysis was incomplete. First, customer demand and safety were included since they are vital to establishing hydrogen infrastructure (M. Stoelinga, personal communication, 6 October 2023). Safety and customer demand are also mentioned as important factors in several reports concerning green shipping corridors (American Bureau of Shipping, 2022; Getting to Zero Coalition et al., 2021; The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping & McKinsey & Company, 2022a), underscoring the relevance of these two factors. In addition, these two aspects are also mentioned in an assessment of challenges and opportunities in implementing alternative fuels in the shipping sector (Foretich et al., 2021). Lastly, customer demand was also mentioned by two other interviewees as a potential CSF (S. Lucassen, personal communication, 24 October 2023; P. Walison, personal communication, 20 October 2023).

Second, the resilience of the infrastructure to external shocks (e.g., climate events, geopolitical tensions) came forward as a potential factor from the external validation (Y. Baay, personal communication, 16 October 2023). Therefore, the code of infrastructural resilience was added to the list. This factor is relevant because there is evidence that renewable energy sources, which are necessary for alternative fuels, are susceptible to climate events resulting from climate change (Gernaat et al., 2021). Furthermore, because of recent geopolitical tensions caused by Russia's invasion of Ukraine, the EU sanctioned Russia and installed an important ban on all Russian seaborne crude oil and petroleum products (European Commission, 2022). This ban had a great impact on the port of Rotterdam (Port of Rotterdam, 2023c), for example. Both these examples advocate for the relevance of a factor capturing the resilience of the infrastructure to external shocks.

Third, during the data validation, anti-corruption was mentioned as a potential CSF (S. Lucassen, personal communication, 24 October 2023). The importance of anti-corruption in PPPs outside of the port context is mentioned in the literature extensively (Iossa & Martimort, 2016; Zhao et al., 2023) furthermore, infrastructural provisions that involve large sums of public funds may be targeted by corrupt elites (Fazekas & Tóth, 2018). In addition, Seim and Søreide (2009) explain that PPPs may contribute to anti-competitive conditions when they are established under corruption. All in all, the risks and results of corruption and therefore, the importance of anti-corruption, are described extensively in the literature. Even though these connections may not be replicable directly to establishing the Rotterdam-Singapore green shipping corridor, because green shipping corridors should be PPPs by design (Wärtsilä, 2023), anti-corruption is included in the final code list. All four factors that were mentioned in the answers to question 2 in the external validation were added as codes and all data were analysed again using the revised code list. An overview of all predetermined codes used for the content analysis in Atlas.ti. can be found in Appendix B3

Table 5 below presents an overview of the four industry experts who were consulted for external validation of the CSFs. In addition, the table includes the name of each industry expert, their respective function, the organization to which they are affiliated, and the stakeholder category, as classified by (Notteboom et al., 2020) which best characterizes the organization they are working at. As can be seen in Table 5, each respondent is from a different stakeholder category as depicted by Notteboom et al. (2020).

Table 5: Overview of industry experts consulted for validation

Participant code	**Name**	**Function**	**Organization**	**Stakeholder category**
Respondent 1	Mark Stoelinga	Business Manager Hydrogen	Port of Rotterdam	Port authorities
Respondent 2	Patrick Walison	Consultant Maritime Strategy & Economics	Royal HaskoningDHV	Service providers (banks, insurance companies, classification and certification societies, rating agencies, IT companies etc.)
Respondent 3	Ylona Baay	Junior innovator	Netherlands Maritime Technology	Industry and branch organizations
Respondent 4	Suzanne Lucassen	Account manager	Royal Vopak N.V.	Companies involved in (semi-) industrial activities in the port area

4. Results

Chapter 4 presents the primary findings of this research. For clarity, these are categorized under the competition assessment and content analysis.

4.1 Competition assessment

4.1.1 Bunker ports

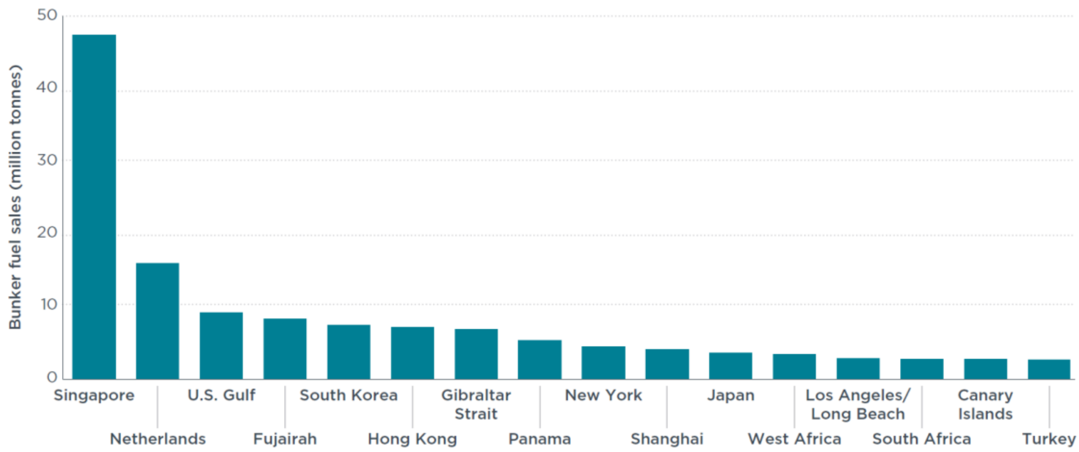
Acquiring data on bunker sales across various ports presented a significant challenge. Whereas certain port authorities, such as the Port of Antwerp-Bruges and the Port of Rotterdam, are transparent and periodically publish their bunker sales figures (Port of Antwerp-Bruges, 2023; Port of Rotterdam, 2022a), a substantial number of other ports does not share this information publicly. Fortunately, data concerning bunker sales on a broader scale, categorized by country/region, is accessible (Mao et al., 2022). Additionally, rankings that outline the world's largest bunkering ports are available. Nevertheless, the sources and methodologies of these rankings are not always clearly specified. Furthermore, there is ambiguity in the rankings of the largest bunker ports per source.

For instance, in their report about the bunker industry, CE Delft (2011) states that Singapore, Rotterdam, Fujairah and Houston are the four most prominent bunker ports. Moreover, in 2019, Maritime Fairtrade (2019) presented the following top 10 largest bunker ports in the world:

1. Singapore	3. Fujairah	5. Antwerp	7. Gibraltar	9. Algeciras
2. Rotterdam	4. Hong Kong	6. Busan	8. Panama	10. Los Angeles-Long Beach

In addition, Mao et al. (2022) presented a graph depicting marine bunker fuel sales in the world's top 16 bunker ports in 2019 (Figure 2). As can be seen, the graph contains several clusters on the x-axis instead of individual ports. For example, the Netherlands, U.S. Golf and South Korea.

Figure 2: Marine bunker fuel sales in the world's top 16 bunker ports in 2019 (Mao et al., 2022)



Moreover, in 2021, the list of 2020 global bunker rankings by port was released (Yu, 2021). According to this list, Singapore, Rotterdam, Fujairah, and Hong Kong were the four most prominent bunker ports. Followed by Panama, Zhoushan, Busan, Gibraltar, Antwerp, and Houston. Furthermore, the 2021 global bunker ranking by port top 10 was released in 2022 (Xu, 2022). This ranking showed that Singapore was the largest bunker port in 2021. Followed by Rotterdam, Fujairah, Hong Kong, Zhoushan, Panama, Busan, Antwerp, Gibraltar, and Los Angeles-Long beach. More recently, BunkerPay (2023) states that Singapore, Rotterdam, Fujairah and Houston are the most prominent bunker ports in the world. However, on their own website, the port of Rotterdam claims the be the third largest bunker port in the world (Port of Rotterdam, n.d.). Note that these rankings refer to Antwerp, instead of Antwerp-Bruges. The ports of Antwerp and Bruges merged in 2021 (Port of Antwerp-Bruges, n.d.).

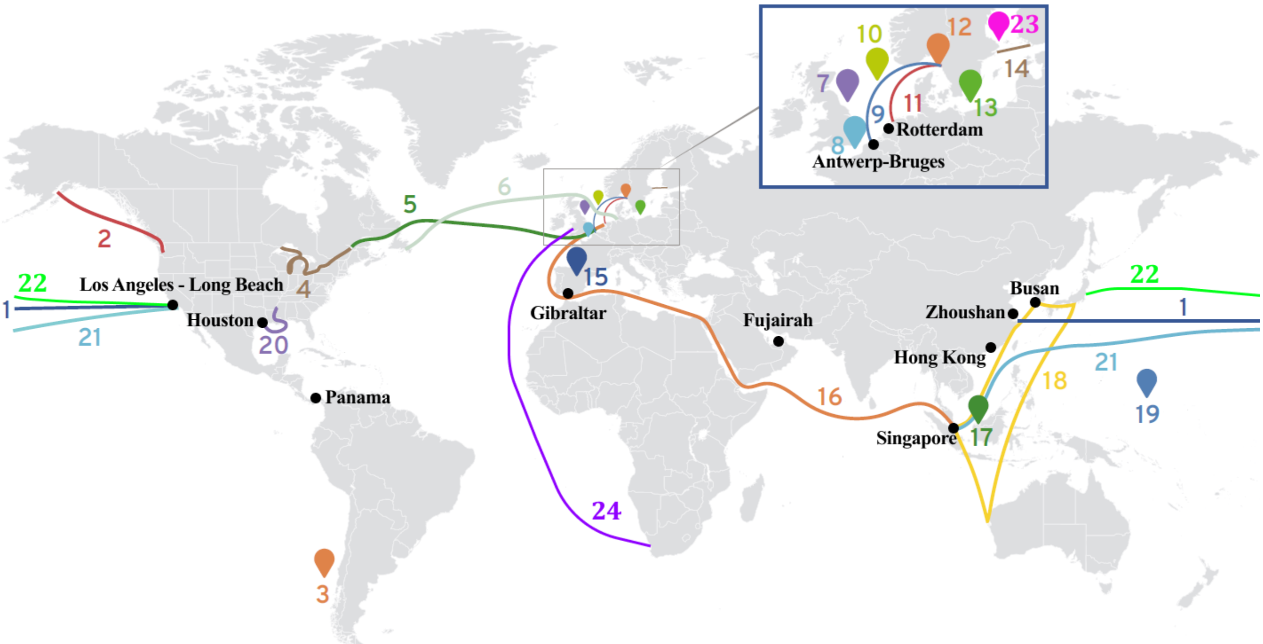
As mentioned, there is ambiguity regarding the exact ranking between sources and the rankings differ per year. Moreover, the sources and methodologies of these rankings are not specified. However, since this thesis merely aims to present the most prominent bunkering ports, not by rank or specifying their volumes, and link this to emerging green shipping corridor initiatives, the just presented data on the largest bunker ports is sufficient. In conclusion, this thesis specifies eleven prominent bunker ports. These can be found in Figure 3.

4.1.2 Green shipping corridor initiatives

Currently, 24 different projects are going on that are classified as green shipping corridors (Global Maritime Forum & Getting to Zero Coalition, 2022; Hervas, 2023). A total overview of all current initiatives, the ports involved, the type of corridor (i.e. single point, point-to-point, or network corridor), the corridor's name if applicable, and lastly, whether there are facilities in the port to bunker either methanol, hydrogen and/or biofuels is included in Appendix C1. Below, a visual representation of all current green shipping corridor initiatives is given in addition to the most prominent bunker ports in the world (Figure 3). The former is indicated by numbers and the corresponding legend (

Table 6) below the figure, and the latter is indicated by the black markers including the names of the ports.

Figure 3: Map containing the world's green shipping corridor initiatives and the most prominent bunker ports



Source: (Global Maritime Forum and Getting to Zero Coalition (2022, p. 11) With recent data and the addition of eleven major bunker ports manually added by author.

Note: This map is shown for indicative purposes only. The relative sizes and positions on it have been changed to improve clarity; they do not correspond to actual geographic accuracy.

Table 6: Legend of Figure 4 containing a numerical list of Green Shipping Corridor Initiatives

Green Shipping Corridor Initiatives		
1. Los Angeles-Long Beach-Shanghai	9. Gothenburg-North Sea Port	17. SILK Alliance
2. Pacific Northwest to Alaska Green Corridor	10. H2-powered North Sea Crossing	18. Aus-Asia Iron Ore
3. Chilean Green Corridor Network	11. Gothenburg-Rotterdam	19. QUAD Shipping Taskforce
4. Great Lakes - St. Lawrence	12. European Green Corridor Network	20. Gulf of Mexico
5. Antwerp-Montreal	13. Nordic Regional Corridors	21. Los Angeles-Long Beach-Singapore
6. Halifax-Hamburg	14. Decatrip	22. Los Angeles-Nagoya
7. Clean Tyne Corridor	15. Green Corridors Spain	23. Estonia-Finland Green Corridor
8. Dover-Calais/Dunkirk	16. Rotterdam-Singapore	24. South Africa Europe Iron Ore

From Figure 3, it becomes clear that the Rotterdam-Singapore green shipping corridor is the only corridor that spans between Asia-Europe. Furthermore, it is also the longest corridor of all these initiatives (Port of Rotterdam, 2022c). The route (although the routing in Figure 3 is not necessarily representative) passes the large bunker ports of Gibraltar, Antwerp, and Fujairah, albeit with a possible detour. Moreover, both the ports of Rotterdam and Singapore are, together with the port of Los Angeles, the most active ports when it comes to green shipping corridor initiatives. Singapore, Rotterdam, and Los Angeles are active in establishing three green shipping corridors in total. Note that in two of the three initiatives, the port of Los Angeles works together with its neighbouring port, the port of Long

Beach. Furthermore, of the eleven most prominent bunker ports, five are active in a green shipping corridor (Singapore, Rotterdam, Antwerp, Houston, and Los Angeles).

In addition, a cluster of several initiatives can be found in north-western Europe. A total of thirteen green corridors (either network corridors or one of the points in a point-to-point or single-point corridor) are being established in this region. This number is more than half of the total. These initiatives underline the EU's ambition to cut maritime emissions (European Parliament, 2023).

Regarding the three alternative fuels considered in this thesis (methanol, hydrogen, and biofuels), in the majority of ports involved in green shipping corridors, it is currently not possible to bunker these three fuels. However, in the ports of Singapore, Rotterdam (American Bureau of Shipping, 2022) and Antwerp (American Bureau of Shipping, 2022; Habicic, 2023; Maritime Executive, 2023b) all three alternative fuels can be bunkered already. Moreover, in the port of Los Angeles, it is possible to bunker hydrogen (American Bureau of Shipping, 2022). Furthermore, methanol bunkering in the port of Houston (Maritime Executive, 2023a) and in Gothenburg (Port of Gothenburg, 2023) has also taken place this year. An overview of this can be found in Appendix C1.

Note that not all green shipping corridors are the same. There are, for example, initiatives for green shipping corridors for ferry services. For instance, Decatrip (Maritime Executive, 2022b). Furthermore, there are green shipping corridor initiatives focusing on inland waterways, for example, the Great Lakes - St. Lawrence Green Corridor (U.S. Embassy & Consulates Canada, 2022). In addition, the Aus-Asia Iron Ore green shipping corridor focuses on bulk goods (Global Maritime Forum & Getting to Zero Coalition, 2022). Moreover, there are initiatives to start short-sea green shipping corridors such as Gothenburg-Rotterdam (Port of Rotterdam, 2022d) and the Dover-Calais/Dunkirk green shipping corridors (Bruno, 2022). Lastly, there are several deep sea green shipping corridor initiatives, such as the Hamburg-Halifax, the Los Angeles-Long Beach-Shanghai, and the Rotterdam-Singapore green shipping corridor initiatives (Global Maritime Forum & Getting to Zero Coalition, 2022).

4.2 Content analysis

4.2.1 Main results

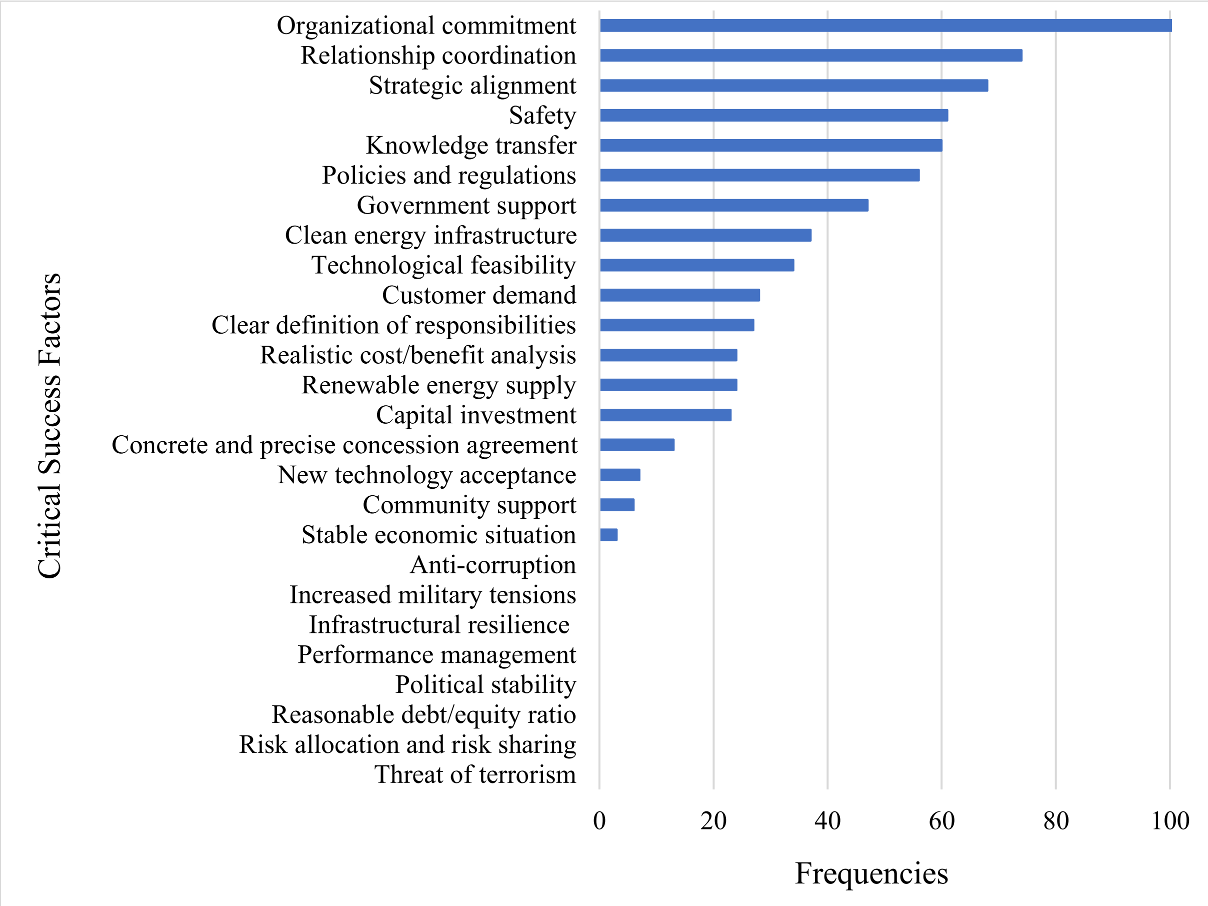
Regarding the data used for the content analysis to determine the CSFs of establishing the Rotterdam-Singapore green shipping corridor, a descriptive overview of each category can be found in Appendix C1. This table gives more information about the port(s) the data focusses on, namely Rotterdam, Singapore or not applicable. Moreover, which link(s) in the value chain it encompasses. In addition, on which alternative fuel(s) it focusses. Lastly, which of the nine different stakeholders denoted by Notteboom et al. (2020) it regards. Note that some of the totals per category differ, since some texts used are relevant for more than one subgroup per category e.g., several projects encompass more than one link in the value chain. In the content analysis, 65 documents were analysed, ultimately leading to

471 different quotations. These quotations were labelled with codes, amounting to a final 694 coded instances. Note that this implies that several quotations are coded multiple times.

Figure 4 below shows the outcomes of the content analysis. As can be seen in Figure 4, organizational commitment is the most mentioned CSF in the analysed data by a stretch. The top eight are concluded by relationship coordination, strategic alignment, safety, knowledge transfer, adequate and coordinated policies and regulations and finally government support. An overview of all CSFs, their respective frequencies and their level of analysis can be found in

Appendix C3. Note that seven of the predetermined codes were not mapped to any quotations in the analysed data. These include anti-corruption, increased military tensions, infrastructural resilience, performance management, political stability, reasonable debt/equity ratio, risk allocation and risk sharing, and the threat of terrorism.

Figure 4: Ranking of CSFs resulting from content analysis

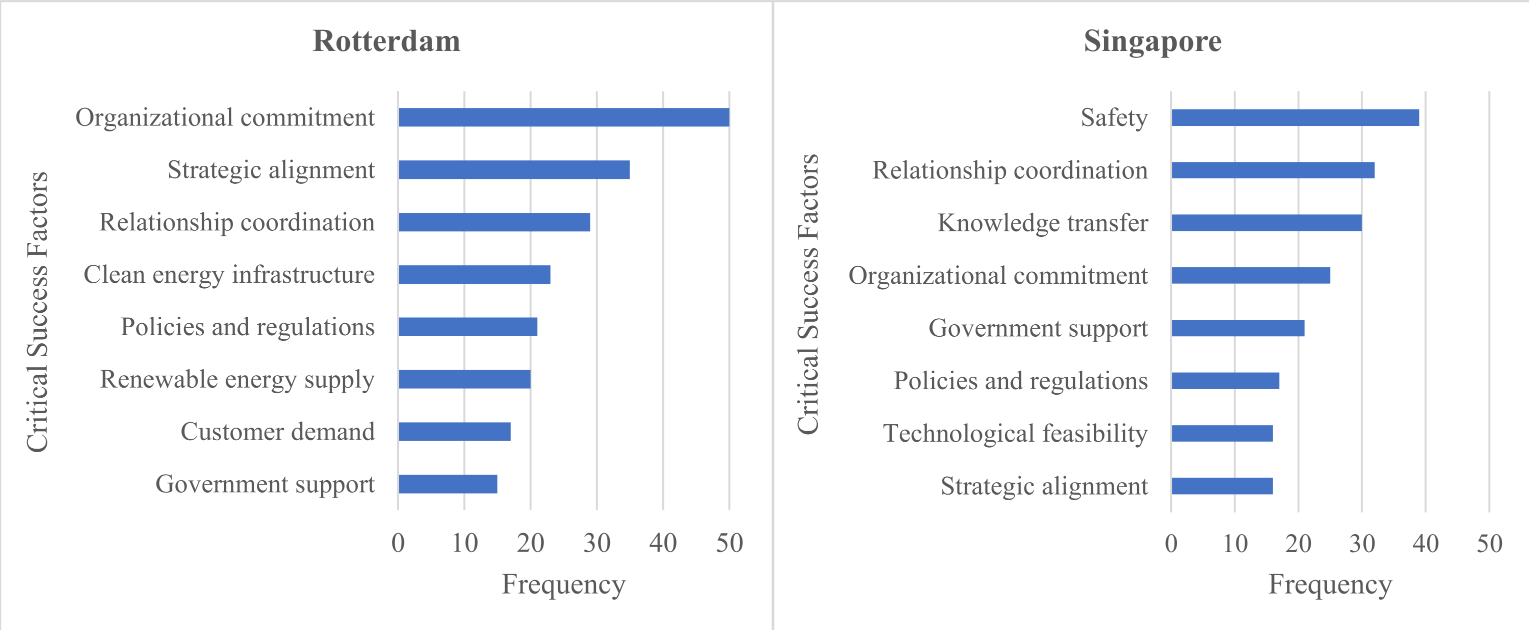


Note: Adequate and coordinated policies and regulations has been shorted to policies and regulations so that it fits the figure.

Since a multi-level analysis of CSFs is performed in this research, as lined out in the methodology chapter, the CSFs are grouped within one of the three levels of analysis (macro, meso, and micro). From the sum of total frequencies per level of analysis as depicted in Appendix C4, it becomes clear that the meso-level CSFs have the highest total frequency (327), relative to the macro-level CSFs (174) and the micro-level CSFs (193).

To answer the third sub-question, the results per port are segregated. This provides noticeable differences. The respective rankings of CSFs resulting from the content analysis segregated per Rotterdam and Singapore can be found in Figure 5. First of all, safety, knowledge transfer, and technological feasibility are in Singapore's top eight CSFs, whereas in Rotterdam, these factors are not placed in the top eight. Safety is even ranked the highest CSF in terms of frequency in Singapore. On the other hand, in Rotterdam, clean energy infrastructure, renewable energy supply, and customer demand are in the top eight, while these are not in Singapore's top eight CSFs. A complete overview of CSF frequencies and rankings segregated per port is provided in Appendix C5.

Figure 5: Top eight ranking of CSFs resulting from content analysis segregated per port



Note: Adequate and coordinated policies and regulations has been shorted to policies and regulations so that it fits the figure.

Next, to answer sub-question four the results segregated per alternative fuel are presented inUpon segregating the results per alternative fuels, noteworthy patterns emerge in the top eight ranking CSFs for each of the alternative fuels. Four CSFs, namely, knowledge transfer, organizational commitment, safety, and strategic alignment appear in the top eight for all three alternative fuels. These shared CSFs have been underlined in the table for clarity. Moreover, it is noteworthy that government support and relationship coordination rank within the top eight factors for both methanol and hydrogen. Similarly, customer demand and adequate policies and coordinated regulations hold positions among the top eight for both methanol and biofuels. Lastly, clean energy infrastructure ranks among the top eight for both hydrogen and biofuels.

Table 7: Top eight ranking of CSFs resulting from content analysis segregated per alternative fuel

Ranking	Methanol	Hydrogen	Biofuels
#1	Safety	Organizational commitment	Policies and regulations
#2	Organizational commitment	Relationship Coordination	Organizational commitment
#3	Relationship Coordination	Strategic alignment	Strategic alignment
#4	Strategic alignment	Government support	Capital investment
#5	Policies and regulations	Knowledge transfer	Customer demand
#6	Knowledge transfer	Clean energy infrastructure	Knowledge transfer

#7	Government support	Renewable energy supply	Safety
#8	Customer demand	Safety	Clean energy infrastructure

Note: Adequate and coordinated policies and regulations has been shorted to policies and regulations so that it fits the table.

Upon segregating the results per alternative fuels, noteworthy patterns emerge in the top eight ranking CSFs for each of the alternative fuels. Four CSFs, namely, knowledge transfer, organizational commitment, safety, and strategic alignment appear in the top eight for all three alternative fuels. These shared CSFs have been underlined in the table for clarity. Moreover, it is noteworthy that government support and relationship coordination rank within the top eight factors for both methanol and hydrogen. Similarly, customer demand and adequate policies and coordinated regulations hold positions among the top eight for both methanol and biofuels. Lastly, clean energy infrastructure ranks among the top eight for both hydrogen and biofuels.

Table 7: Top eight ranking of CSFs resulting from content analysis segregated per alternative fuel

Ranking	Methanol	Hydrogen	Biofuels
#1	Safety	Organizational commitment	Policies and regulations
#2	Organizational commitment	Relationship Coordination	Organizational commitment
#3	Relationship Coordination	Strategic alignment	Strategic alignment
#4	Strategic alignment	Government support	Capital investment
#5	Policies and regulations	Knowledge transfer	Customer demand
#6	Knowledge transfer	Clean energy infrastructure	Knowledge transfer
#7	Government support	Renewable energy supply	Safety
#8	Customer demand	Safety	Clean energy infrastructure

Note: Adequate and coordinated policies and regulations has been shorted to policies and regulations so that it fits the table.

4.2.2 Quotation examples

The overview below presents examples of the top five CSFs in general (i.e. not segregated per port or fuel) and an example of quotations the corresponding codes were mapped to.

For **organizational commitment**, these are an example of quotations:

- *"Holland Hydrogen I demonstrates how new energy solutions can work together to meet society's need for cleaner energy. It is also another example of Shell's own efforts and commitment to become a net-zero emissions business by 2050," said Anna Mascolo, Executive Vice President, Emerging Energy Solutions at Shell. "Renewable hydrogen will play a pivotal role in the energy system of the future and this project is an important step in helping hydrogen fulfil that potential."* (10:5)
- *"MPA has set a target for Singapore's domestic harbour craft sector to achieve net-zero emissions by 2050. From 2030, MPA will also require all new harbour craft operating in our port waters to be fully electric, be capable of using B100 biofuels, or be compatible with net zero fuels. Our port operators are similarly targeting net-zero emissions by 2050."* (42:3)
- *"Our target is to reduce our CO2e emissions by 50% by 2030 (from a 2019 baseline) in respect of our Scope 1, 2 and 3 emissions related to business travel. In the longer-term, we aim to be carbon-neutral by 2050."* (45:12)

For **relationship coordination**, these are an example of quotations:

- *"On the Maasvlakte, HES operates a strategic location with quayside capacity and direct access from the sea. Gasunie has at this location infrastructure of existing storage tanks and a system of pipelines. Vopak, with six ammonia terminals around the world, has extensive experience in the safe storage of ammonia. By joining forces, an attractive starting point will be established from which within just a few years, the partners will be able to realise the import location for green ammonia in Rotterdam."* (2:5)
- *To underscore the importance of collaboration in solving the climate change issue, we became a founding partner of the Global Centre for Maritime Decarbonisation, joining hands with six other industry partners and the Maritime and Port Authority of Singapore."* (58:3)
- *"A key pillar of Singapore's multi-fuel future development is the safe handling of alternative new marine fuels. MPA, together with various research agencies and the industry, are developing the necessary safety standards and procedures to ensure safe and efficient bunkering operations of new fuels, including methanol and ammonia"* (48:5)

For **strategic alignment**, these are an example of quotations:

- *"As part of Neste's growth strategy, we continue to focus on innovation, with renewable hydrogen and Power-to-X being two of our key development areas. Demonstrating green hydrogen production at our refinery in Rotterdam within the MultiPLHY project is one of the initiatives through which we further promote the development of new sustainable technologies"* (Original text in Dutch) (9:4)
- *"The Advanced Methanol Rotterdam plant matches very well with our long-term vision for the transition of the industry in the Port. This development also shows the importance of clear and reliable governmental policies regarding the energy transition. In this case, regulations regarding the use of sustainable transport fuels make companies confident they can invest in plants like this."* (24:7)
- *"We operate in coastal areas and that's why it is essential to reduce the emissions of our vessels. Besides CO2, the implementation of biofuels also realizes significant reductions in sulphur, nitrogen and particulate matter. Other than that, it is highly important that the biofuels used are produced in a sustainable way, and from sustainable feedstocks. Therefore, GoodFuels is the right partner for us."* (33:5)

For **safety**, these are an example of quotations:

- *"Vopak, with six ammonia terminals around the world, has extensive experience in the safe storage of ammonia."* (2:6)
- *"Shell also remains committed to the safe and efficient operations of the vessel."* (21:8)
- *"When appropriate safety measures are followed, we know that methanol is safe to ship, store, handle and bunker using procedures similar to conventional fuels."* (26:3)

For **knowledge transfer**, these are examples of quotations:

- *"A feasibility study together with PoR has been completed. The focus of the feasibility study was to assess the development of an industrial scale 500MWel green hydrogen production facility at Uniper's Maasvlakte site with full operations before 2030."*(11:6)
- *"Under the MOU, PSA Corporation Limited (PSA), Jurong Port Pte Ltd (Jurong Port), City Gas Pte Ltd, Sembcorp Industries Ltd, Singapore LNG Corporation Pte Ltd, Chiyoda Corporation (Chiyoda) and Mitsubishi Corporation (Mitsubishi) will develop ways to utilise hydrogen as a green energy source. This involves the research and development of technologies related to the importation, transportation and storage of hydrogen."* (22:3)
- *"To achieve zero-emission ships, it will not be enough simply to apply solutions that are already available. Research institutions and industry are already investing in research and*

development, but existing efforts need to be accelerated considerably. The government could play a facilitating role in this regard. One further advantage of R&D acceleration is the competitive advantage it would give to the Dutch private sector." (58:8)

4.2.2 External validation

Table 8 below presents an overview of each respondent's five most important CSFs. As can be seen, adequate and coordinated policies and regulations, and customer demand are mentioned three times by the respondents. Furthermore, organizational commitment, clean energy infrastructure, government support, and a clear definition of responsibilities are mentioned by two respondents. Respondent 1 emphasizes the digital component of the Rotterdam-Singapore green shipping corridor (M. Stoelinga, personal communication, 6 October 2023). The respondent explains that streamlining digital services in both ports can lead to higher efficiency and lower GHG emissions. Furthermore, respondent 2 explains that the different ports might have different CSFs (P. Walison, personal communication, 20 October 2023). The respondent explains this by stating that Rotterdam is, compared to Singapore, more experienced in handling alternative fuels and therefore the ports might have different priorities when it comes to alternative fuel infrastructure. Therefore, the respondent assumes Rotterdam and Singapore to have different priorities, leading to different CSFs. Moreover, respondent 4 emphasizes that it is likely that new factors emerge over time, given the evolving nature of the technology and regulatory landscapes of green shipping corridors (Y. Baay, personal communication, 16 October 2023).

Table 8: Overview of each respondent's five most important CSFs

Industry expert	Five most important CSFs
Respondent 1	Community support Customer demand Government support Organizational commitment Safety
Respondent 2	Adequate and coordinated policies and regulations Concrete and precise concession agreement Customer demand Government support Organizational commitment

Respondent 3	Adequate and coordinated policies and regulations Clear definition of responsibilities Clean energy infrastructure Relationship coordination Technological feasibility
Respondent 4	Adequate and coordinated policies and regulations Capital investment Clean energy infrastructure Clear definition of responsibilities Customer demand

5. Conclusion

A possible solution inspired by all obstacles related to the imperative GHG emission reduction in the maritime sector is green shipping corridors. Numerous green shipping corridors have been announced, but not a single one has reached the operational phase, which requires the supply of scalable alternative fuels and the deployment of ships suited for these fuels (Global Maritime Forum & Getting to Zero Coalition, 2022). There is currently an absence of scientific literature on what factors are critical to the successful establishment of such corridors. Therefore, this thesis aims to fill in this gap by determining the CSFs of a specific case, namely the Rotterdam-Singapore green shipping corridor. The research question that emerges from this context is "What are the critical success factors of implementing a green shipping corridor in the Rotterdam-Singapore case?".

From the deductive content analysis performed to answer this research question, it becomes clear that the following eight factors are the CSFs of establishing the Rotterdam-Singapore green shipping corridor: organizational commitment, relationship coordination, strategic alignment, safety, knowledge transfer, adequate and coordinated policies and regulations, and finally, government support.

Furthermore, because green shipping corridors can be seen as a means for bunker ports to remain competitive or even increase their competitiveness, this research presents a competition assessment to identify the current state of play of green shipping corridor initiatives. This assessment shows that there are currently 24 different green shipping corridor initiatives. Moreover, five of the eleven most prominent bunker ports are active in establishing green shipping corridors. In addition, in the majority of the ports active in green shipping corridors, it is currently not possible to bunker either methanol, hydrogen or biofuels. On the other hand, in the ports of Singapore, Rotterdam (American Bureau of Shipping, 2022) and Antwerp (American Bureau of Shipping, 2022; Habicic, 2023; Maritime Executive, 2023b) this is currently possible.

Additionally, this thesis aims to identify possible differences and similarities between Rotterdam and Singapore in CSFs of establishing the Rotterdam-Singapore green shipping corridors by segregating the results per port. From this, regarding the similarities, the ports both have organizational commitment, relationship coordination, strategic alignment, adequate and coordinated policies and regulations, and government support as their top eight CSFs. However, regarding the differences, in Rotterdam, the top eight also include clean energy infrastructure, renewable energy supply and customer demand. Whereas in Singapore, it includes safety, knowledge transfer, and technological feasibility.

Finally, this research aims to identify possible differences and similarities between the three alternative fuels (methanol, hydrogen and biofuels) in CSFs of establishing the Rotterdam-Singapore green shipping corridors by segregating the results per fuel type. This shows that knowledge transfer, organizational commitment, safety, and strategic alignment appear in the top eight for all three alternative fuels. Moreover, government support, relationship coordination, customer demand, adequate and coordinated policies and regulations, and clean energy infrastructure rank in two of the top three alternative fuels top eight.

6. Discussion

In this chapter, the discussion, the implications, and this research's limitations are presented.

6.1 Discussion

Apart from the results discussed before, it is likely that there are other developments that influence the establishment of the Rotterdam-Singapore green shipping corridor. These developments are discussed in this section.

Some alternative fuels have different energy densities than the currently used fossil marine fuels. Methanol, for example, has a lower energy density and therefore could lead to methanol-powered ships having to bunker more often (Svanberg et al., 2018), and LH_2 has a higher energy density than HFO (Atilhan et al., 2021). Furthermore, Solakivi et al. (2022) explain that prices of alternative low-carbon and carbon–neutral fuels are likely to remain high compared with fossil fuels. Since Acosta et al., (2011) identified that the factors affecting bunkering competitiveness encompass low prices, few legal restrictions, quick bunkering and geographical advantages, this could lead to different bunker strategies of shipping lines when it comes to alternative fuels. Because of these distinct differences between currently used fossil marine fuels and alternative fuels, the transition towards these alternatives may cause a number of disruptions. Kivimaa et al. (2021), line out that, although disruptions may accelerate or facilitate environmentally sustainable changes, disruptions may also have negative consequences from a variety of other perspectives. For example, the competitiveness of actors is affected by the transition. From the competition assessment it can be concluded that, given the frame of the three alternative fuels in this thesis, both Rotterdam and Singapore are relatively well prepared for the transition towards alternative fuels in shipping. Together with the port of Antwerp-Bruges, these three ports are ready to bunker either methanol, hydrogen and biofuels. These three ports take on the most proactive roles in facilitating alternative fuel bunkering of all ports involved in green shipping corridor initiatives. Therefore, these ports are deemed the most green shipping corridor-ready ports (American Bureau of Shipping, 2022).

Furthermore, the competition assessment shows that Rotterdam and Singapore are, together with the port of Los Angeles, the most active ports in initiating the establishment of green shipping corridors. Even though the green shipping corridor initiative between Rotterdam and Singapore is signed by the PAs of these ports only, the activity of both ports in developing more green shipping corridors could lead to an overarching green shipping network corridor, albeit indirectly. On Rotterdam's side, this includes the ports of the European Green Corridor Network and Gothenburg. In Singapore, this includes the ports of Los Angeles, and Long Beach and regional ports in Asia linked to the SILK Alliance (note that the SILK alliance focusses on establishing a single point corridor from Singapore (Lloyd's Register, n.d.)). If these green shipping corridors are finally established, it would be possible to, for example, ship goods carbon neutrally from, Tallinn to Long Beach, via Rotterdam and Singapore. Rotterdam and Singapore would serve as the main two links in this example. This complies with the secondary benefits of green shipping corridors as mentioned (The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping & McKinsey & Company, 2022a). Furthermore, because of both Rotterdam and Singapore's high rankings in terms of node degree and node betweenness (Hoffmann & Hoffman, 2020), these secondary effects can spillover to a large number of other trade routes as well.

Since it is not possible to bunker either one of the three alternative fuels of methanol, hydrogen or biofuels in the majority of the ports involved in green shipping corridor initiatives, the degree of determination to which the initiators are willing to actually establish the corridors they are working on is questionable. It is important to note that this might imply that for some initiators, green shipping corridors remain a concept with limited substance and efforts to establish necessary alternative fuel infrastructure. As a sector, the shipping industry should be aware of greenwashing and as described briefly in Section 2.1, greenwashing is a serious risk in green transformations (Yildirim, 2023).

The differences in CSFs between Rotterdam and Singapore can possibly be explained by different experience levels of implementation of alternative fuel infrastructure. This suggestion is also mentioned by respondent 2. This respondent mentions that, from his perspective, he thinks that Rotterdam is more experienced in handling alternative fuels compared to Singapore. This explains that in Singapore, safety, knowledge transfer, and technological feasibility are part of the eight CSFs, whereas in Rotterdam they are not. In Rotterdam, on the other hand, clean energy infrastructure, renewable energy supply, and customer demand are part of the eight CSFs, unlike in Singapore. Safety, knowledge transfer and technological feasibility are perhaps factors that are more associated with less experienced ports in terms of alternative fuel handling and might indicate that Singapore is more in the test phase of handling alternative fuels. While in Rotterdam, the CSF of renewable energy supply indicates that actors in the port are already considering scalability of alternative fuels, and with customer demand, the actors are already considering the market side of the alternative fuels.

Furthermore, the sums of CSFs per level of analysis shows that the meso-level CSFs have the highest total frequency (327), compared to the macro-level CSFs (174) and the micro-level CSFs (193). This indicates that as a whole, meso-level CSFs are the most important to establish the Rotterdam-Singapore green shipping corridor emphasizing the importance of the total industry's efforts to establish this corridor. However, it is important to note that without focusing on the macro and micro levels, establishing a green shipping corridor between Rotterdam and Singapore would be impossible.

In this research, external validation with industry experts is performed as means to validate the outcomes of the content analysis. Comparing the top eight CSFs from the content analysis with the external validation shows that adequate and coordinated policies and regulations were mentioned by three respondents. In addition, clean energy infrastructure, government support, and organizational commitment by two respondents. Lastly, safety and relationship coordination by one respondent. This underlines the importance of these six factors.

Furthermore, the results of the content analysis are categorized by alternative fuel type, enabling a comparison that highlights both similarities and differences upon comparing to the overall findings of the content analysis. This shows that organizational commitment, knowledge transfer, strategic alignment, and safety consistently rank in the top eight CSFs in both the overall assessment and the specific rankings for each alternative fuel. Ultimately underscoring the importance of these factors as well.

6.2 Implications

As mentioned, geographical factors play a significant role in port competition (Lirn et al., 2004; Notteboom et al., 2022; Parola et al., 2017; Tongzon, 2007), these can, however, not be changed. The latter factor seems to be playing a role already in the PAs' strategies of Rotterdam and Singapore to secure alternative fuel supply, for example, Rotterdam, for instance, has signed several MoUs to secure hydrogen imports from other geographical locations such as southern Europe (Port of Rotterdam, 2022b, 2023b). Furthermore, Singapore signed an MoU with Indonesia to import renewable energy such as hydrogen (Singapore Economic Development Board, 2023). Given that the operational phase of green shipping corridors requires establishing a scalable alternative fuel supply and the deployment of ships suited for these fuels (Global Maritime Forum & Getting to Zero Coalition, 2022), the PAs of Rotterdam and Singapore must continue to secure alternative fuel supplies in order to get their green shipping corridors into the operational phase.

The two initiators of the Rotterdam-Singapore green shipping corridor, the Rotterdam PA and the MPA Singapore should be aware of the CSFs of implementing the green shipping corridor so that they can influence its success. By definition, "CSFs are the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department or organization" (Bullen & Rockart, 1981, p. 7). This definition therefore implies that if the Rotterdam PA and the MPA Singapore focus on the CSFs and achieve satisfactory results in them, it will ensure a successful competitive performance. More specifically, looking at the results, this implies that the PAs of Rotterdam and Singapore should put efforts into integrating organizational commitment into their overall strategies. A dedicated and engaged organizational culture, in accordance with the resource-based view theory, can, according to the outcomes of this research, significantly contribute to the success of the green shipping corridor initiative. Furthermore, because of the complex value chain in bunker fuels that encompasses many different actors (CE Delft, 2011; Lind et al., 2022), the PAs should focus on improving organizational culture and inter-firm management of companies involved in this value chain as well.

Moreover, both PAs should focus on enhancing their relationship coordination. This implies that they should bring together different actors in the alternative fuel value chain and serve as a facilitator or coordinator so that different actors can learn from one another and improve their efforts in establishing scalable alternative fuel supply and the deployment of ships suited for these fuels necessary for the operational phase of green shipping corridors (Global Maritime Forum & Getting to Zero Coalition, 2022)

In addition, they should focus on strategic alignment. Strategic alignment stems from the contingency (FIT) theory as lined out in Section 3.4.1 and implies that organizational objectives and strategies must seamlessly be adjusted, both within an organization and with its external partners. Therefore, the PAs should aim to align their strategies with relevant stakeholders such as fuel producers and shipping lines, for example, to promote the use of alternative fuels and the deployment of ships ready to use these alternative fuels.

Furthermore, the PAs should focus on the safety CSF and the safe handling of alternative fuels. Together with relevant stakeholders, they should, for example, coordinate pilots in alternative fuel bunkering to show the industry that safe handling of these fuels is possible. This might result in higher demand for alternative fuels, potentially leading to lower prices and, if sufficient supply is secured, could lead to the scalability of alternative fuels.

Moreover, the PAs must focus on knowledge transfer. This CSF is related to the organizational learning theory as explained in Section 3.4.1 and implies that the PAs should be focused on the discovery of relevant new information regarding alternative fuels and the distribution of this new knowledge to individuals in the organisation who need it. Furthermore, they should consider the use of the knowledge to enhance internal operations and external adaption. In practice, this also implies that the PAs work together with research institutes, universities, innovation centres etc. to make sure that research regarding alternative fuels is conducted.

Lastly, the CSFs of adequate and coordinated policies and regulations and government support conclude the top eight CSFs of the content analysis. Since these two factors stem from the macro-level analysis, the PAs might have less of a direct influence on them. However, they should work together with their governments to secure their support and to make sure that their governments establish adequate and coordinated policies and regulations together with the PAs and the industry as a whole. By developing a strong relationship with government entities, the PAs can jointly influence the regulatory environment and guarantee the required policies and regulations are in place to support the successful establishment of the Rotterdam-Singapore green shipping corridor. With government support, the PAs could overcome the obstacles and exploit the possibilities provided by the shift to alternative fuel usage in shipping.

Note that several CSFs are interdependent. For example, strategic alignment between PAs and their governments may result in adequate and coordinated policies and regulations which in turn can result in safety (e.g. safe handling of alternative fuels). It is therefore important to note that the PAs must focus on the CSFs as a whole to establish the Rotterdam-Singapore green shipping corridor.

Furthermore, as mentioned in Section 5.1, the shift towards alternative fuels could lead to different bunker strategies of shipping lines. This potential change in bunkering strategies could have large implications for the bunker ports, especially for the largest bunker ports that have massive investments tied to these operations. When sailing between Rotterdam and Singapore, a ship passes three of the twelve main large bunker ports as lined out in Section 4.2.1. Namely, Fujairah, Gibraltar, and Antwerp. For Singapore and Rotterdam to remain in their positions as the largest bunker ports in their regions, they must focus on still being able to offer competitive prices, few legal restrictions, and quick bunkering. This concurs with the contribution made by Coeck et al. (1996). In port competition, namely, the authors suggest focusing on competencies that are inimitable by process.

The differences between Rotterdam and Singapore in terms of establishing a green shipping corridor between the two could imply different stages of alternative fuel handling in the port. As lined out in the literature, port networks have a great influence on port competition and ports' competitiveness (Parola et al., 2017). If Rotterdam and Singapore share information, they can increase the competitiveness of the green shipping corridor between the two and accelerate the establishment of it. Rotterdam could, for example, share information on the safe handling of alternative fuels, which turned out to be the most important CSF in Singapore. This is also underlined by Notteboom et al. (2020) who explain that ports may gain a competitive advantage by learning cutting-edge technologies or acquiring superior knowledge in the context of port cooperation.

Rotterdam and Singapore take on a relatively proactive role in infrastructure regarding methanol, hydrogen and biofuels. However, given the uncertainty in the fuel pathway (Hervas, 2023; IRENA, 2021), both Rotterdam and Singapore should be aware of all new developments regarding alternative fuels and take a proactive approach to securing supply.

6.3 Research limitations and suggestions

This section lines out several noteworthy research limitations and consequently suggestions for further research that could tackle the limitations. Firstly, this thesis has performed a single-case study. This results in limited generalizability of the findings (Gomm et al., 2011). This research focused on identifying the CSFs of establishing the Rotterdam-Singapore green shipping corridor and analysed data regarding this case. Therefore, outcomes are perhaps not representative of other green shipping corridor initiatives across the globe.

Moreover, this thesis uses a specific frame of three alternative fuels. Namely, methanol, hydrogen, and biofuels. As mentioned, the alternative fuel pathway is uncertain (Hervas, 2023; IRENA, 2021). If in the future it turns out a different alternative fuel becomes most dominant, the outcomes of this thesis cannot necessarily be interpreted in the same way, hence, this frame also limits the generalizability of the outcomes.

Furthermore, as can be seen in Figure 4: Ranking of CSFs resulting from content analysis, several predetermined codes were not used to code any quotations. This could imply either of two things. Firstly, the CSFs linked to the codes are not relevant for establishing the Rotterdam-Singapore green shipping corridors, or secondly, there is a risk that the data analysed did not completely suit the objective to determine the CSFs of establishing the Rotterdam-Singapore green shipping corridor and these codes and their related factors are in fact relevant to establishing the Rotterdam-Singapore green shipping corridor. The former would be a reasonable conclusion from the content analysis, but the latter could imply that the results from the content analysis are biased. In addition, Eriksson and Lindström (1997) explain that with a deductive approach in content analysis, there is a risk of formulating categories based exclusively on an established theory or model (i.e. predefined categories). This is especially relevant for this thesis because of the lack of literature regarding CSFs in green shipping corridors. Another limitation of content analysis lies in one of its benefits. Vaismoradi et al. (2013) explain that the benefits of content analysis lie in the opportunity for the quantification of data. This, however, also poses a drawback in how to interpret the quantifications. In this research, for example, the category of organizational commitment is mentioned more than twice as frequently as the category of clean energy infrastructure. This does not imply that this CSFs is therefore twice as important. In future research, more efforts could be made to calculate the relative importance of CSFs of establishing the Rotterdam-Singapore green shipping corridor. For example, an analytical hierarchy process could be used for this. To this end, a survey containing the CSFs should be composed and presented to a substantial group of industry experts. This survey should include the evaluation of CSFs using a five-point Likert scale, as has been done by B. Hwang et al. (2013) in their research regarding CSFs in PPPs.

To overcome the risk that the data analysed did not completely suit the objective to determine the CSFs of establishing the Rotterdam-Singapore green shipping corridor, data validation with industry experts was performed. However, the four industry experts consulted are all based in the Netherlands. Moreover, although the four respondents all stem from different stakeholder groups, not all stakeholder groups are represented. Due to limited access to relevant contacts, consulting industry experts on the Singapore side, unfortunately, posed significant challenges, whereas industry experts on the Rotterdam side were easier to approach and were more open to responding and helping. Furthermore, speaking to more industry experts proved to be difficult because of the sensitive nature of the information, which is deeply connected with the strategic choices of the organisations. Within the context of green shipping corridors, where strategic decisions are competitively sensitive because of the novelty of the concept and all its innovations, securing industry experts' willingness to talk about specific factors deemed important within their respective organizations (i.e. CSFs) proved to be challenging. A more even distribution per port and a larger pool of industry experts would perhaps provide a more diverse perspective and more comprehensive insights resulting in potentially reduced bias.

In addition, Burnard (1991) and Graneheim and Lundman (2004) explain that to increase the validity of content analysis, it should be performed by at least two researchers independently. Thereafter, these researchers should discuss their outcomes and obtain consensus. This is not possible in the frame of an individual master's thesis, but if used in further studies on this topic, would increase the validity of the content analysis.

Furthermore, the risk of formulating categories based exclusively on an established theory or model also has been tried to be countered by validating the results with industry experts. Nevertheless, the same limitations of the external validation in this thesis aforementioned, also apply to this risk. All in all, a more extensive validation process would enhance the findings of this research regarding identifying the CSFs for establishing the Rotterdam-Singapore green shipping corridor.

Additionally, since the concept of green shipping corridors and its related transition towards alternative fuels is heavily intertwined with innovation, in further research it is crucial to use the most recent data and methodologies. For example, members of the IAPH Clean Marine Fuels Working Group and the World Ports Climate Action Program, are working together on defining port readiness levels to accommodate alternative fuels for ships (International Association of Ports and Harbours, 2022). Such information could provide relevant insights in a competition assessment and would provide a more comprehensive overview. Such information would make the competition analysis more comprehensive.

Of the data used for the content analysis, 42 per cent was related to hydrogen. Although this concurs with the finding of Fahnestock & Bingham (2021) that the majority of alternative fuel projects in shipping focused on hydrogen as a fuel, it could lead to biased results in the presentation of the overall CSFs stemming from the content analysis. The results segregated per alternative fuel type show an overlap of CSFs between the fuels. However, it is important to note the relatively low sample size analysed related to both methanol and biofuels, compared to the more substantial sample size related to hydrogen. This discrepancy in the data might result in bias in the results upon segregating these per alternative fuel type, potentially affecting the generalizability and robustness of these findings.

Another discrepancy in the data that could result in biased outcomes is that a substantial part of the data analysed in the content analysis stems from neither the port of Rotterdam nor Singapore, namely 29 per cent. These data comprise more general documents not pertaining to specific projects in either of the two ports. It includes, for example, data regarding shipping lines, environmental groups and the IMO. Although these are all relevant stakeholders in the greening of ports (Notteboom et al., 2020), and are therefore indirectly linked to the establishment of the Rotterdam-Singapore green shipping corridor in this research, their direct influence on this corridor could be limited. Therefore, including these data in the content analysis could lead to biased outcomes of the analysis.

Appendix A

Appendix A1: Overview of all CSFs that emerged from the literature

CSF	Overarching theme	Source
Appropriate risk allocation and risk sharing	PPPs	(Aerts et al., 2014)
Appropriate risk allocation and sharing	PPPs	(B. Hwang et al., 2013)
Attractive financial package and acceptable tariff levels	PPPs	(Aerts et al., 2014)
Available financial market	PPPs	(Aerts et al., 2014)
Backward economic development	Energy transition	(Bai et al., 2023)
Biological diversity	Energy transition	(Bai et al., 2023)
Clarification of contract documents	PPPs	(B. Hwang et al., 2013)
Clear defined responsibilities and roles	PPPs	(B. Hwang et al., 2013)
Clear definition of responsibilities	PPPs	(Aerts et al., 2014)
Commitment of partners	PPPs	(Aerts et al., 2014)
Community support	PPPs	(Aerts et al., 2014)
Competitive tendering system	PPPs	(Aerts et al., 2014)
Concrete and precise concession agreement	PPPs	(Aerts et al., 2014)
Difficulties in communication with local communities	Energy transition	(Bai et al., 2023)
Difficulty in technological standardization	Energy transition	(Bai et al., 2023)
Disunity and concern for national interests	Energy transition	(Bai et al., 2023)
Favorable legal framework	PPPs	(B. Hwang et al., 2013)
Government support	SSM	(Chua et al., 2023)
High upfront costs	Energy transition	(Bai et al., 2023)
Inadequate and uncoordinated policies and regulations	Energy transition	(Bai et al., 2023)
Incomplete industrial foundation	Energy transition	(Bai et al., 2023)
Increased military tensions	Energy transition	(Bai et al., 2023)
Insufficiency of qualified employees	Energy transition	(Bai et al., 2023)
Insufficient clean energy infrastructure	Energy transition	(Bai et al., 2023)
Knowledge management	SSM	(Chua et al., 2023)
Knowledge transfer	PPPs	(Aerts et al., 2014)
Lack of capital investment	Energy transition	(Bai et al., 2023)

CSF	Overarching theme	Source
Lack of concrete action plans	Energy transition	(Bai et al., 2023)
Lack of efficient administrative procedures	Energy transition	(Bai et al., 2023)
Lack of technical information and assistance	Energy transition	(Bai et al., 2023)
Large-scale traditional energy facilities	Energy transition	(Bai et al., 2023)
Life cycle environmental impact	Energy transition	(Bai et al., 2023)
Limited government efforts	Energy transition	(Bai et al., 2023)
Limited role of ASEAN	Energy transition	(Bai et al., 2023)
Limited technological capacity	Energy transition	(Bai et al., 2023)
Low competition in the energy sector	Energy transition	(Bai et al., 2023)
Low energy prices	Energy transition	(Bai et al., 2023)
New technology acceptance	SSM	(Chua et al., 2023)
Open communication	PPPs	(Aerts et al., 2014)
Organizational commitment	SSM	(Chua et al., 2023)
Performance management	SSM	(Chua et al., 2023)
Policy uncertainties and inconsistencies	Energy transition	(Bai et al., 2023)
Political instability	Energy transition	(Bai et al., 2023)
Political Support	PPPs	(Aerts et al., 2014)
Potential job loss	Energy transition	(Bai et al., 2023)
Project technical feasibility	PPPs	(Aerts et al., 2014)
Proper stakeholder management	PPPs	(Aerts et al., 2014)
Realistic cost/benefit assessment	PPPs	(Aerts et al., 2014)
Reasonable debt/equity ratio	PPPs	(Aerts et al., 2014)
Relationship management	SSM	(Chua et al., 2023)
Rely on imported technologies	Energy transition	(Bai et al., 2023)
Restrictions from geographical conditions	Energy transition	(Bai et al., 2023)
Shared authority between public and private sectors	PPPs	(Aerts et al., 2014)
Sound economic policy	PPPs	(Aerts et al., 2014)
Special guarantee by the government	PPPs	(Aerts et al., 2014)

CSF	Overarching theme	Source
Stable economic situation	PPPs	(Aerts et al., 2014)
Stable political situation	PPPs	(Aerts et al., 2014)
Strategic alignment	SSM	(Chua et al., 2023)
Strong private consortium (organizationally and financially)	PPPs	(Aerts et al., 2014)
Strong private consortium	PPPs	(B. Hwang et al., 2013)
Supply uncertainties	Energy transition	(Bai et al., 2023)
Threat of terrorism	Energy transition	(Bai et al., 2023)
Transparency in procurement process	PPPs	(B. Hwang et al., 2013)
Unbalanced access to technology	Energy transition	(Bai et al., 2023)
Uncertain social acceptance	Energy transition	(Bai et al., 2023)
Unpredictable market	Energy transition	(Bai et al., 2023)
Volatility of exchange and interest rate	Energy transition	(Bai et al., 2023)
Well-organized public agency	PPPs	(B. Hwang et al., 2013)

Appendix B

Appendix B1: Overview of data used in content analysis

Number	Stakeholder	Port	Link	Source
		Hydrogen		
#1	Port authority	Rotterdam	Import	https://www.portofrotterdam.com/en/news-and-press-releases/renewable-liquid-hydrogen-supply-chain-between-portugal-and-netherlands-on
#2	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Import	https://www.vopak.com/newsroom/news/gasunie-hes-international-and-vopak-join-forces-develop-import-terminal-hydrogen
#3	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Import	https://www.portofrotterdam.com/nl/nieuws-en-persberichten/air-products-en-gunvor-werken-aan-groene-waterstof-importterminal-in
#4	Associations, government agencies, and non-governmental organizations (NGOs)	Rotterdam	Import	https://www.cepsa.com/en/press/spain-and-the-netherlands-promote-the-green-hydrogen-maritime-corridor
#5	Port authority Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.portofrotterdam.com/en/news-and-press-releases/uniper-and-port-rotterdam-authority-start-feasibility-study-green-hydrogen
#6	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://nl.airliquide.com/energietransitie-de-benelux/waterstof-voor-industrie-en-transport/curthyl
#7	Port authority Companies involved in (semi-) industrial activities in the port area	Rotterdam	Transport	https://www.hynetwork.nl/voor-de-omgeving/rotterdam/de-realisatie-van-het-waterstofnetwerk-rotterdam
#8	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.h2-fifty.com/latest/2022-12-23-green-hydrogen-project-h2-fifty-selected-for-ipcei-grant-funding/
#9	Companies involved in (semi-) industrial activities in the port area	Rotterdam	production	https://www.neste.nl/releases-and-news/innovation/neste-gaat-over-tot-uitvoeringsfase-met-partners-het-multiplhy-

Number	Stakeholder	Port	Link	Source
				project-met-als-doel-de-productie-van
#10	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.shell.nl/media/nieuwsberichten/2022/holland-hydrogen-1.html
#11	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production, import	https://www.uniper.energy/projects-and-cases/hydrogen-maasvlakte
#12	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Storage, production	https://www.gesgroup.global/green-fuel-terminals/ges-rotterdam/
#13	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.onyx-power.com/nl/nieuwtjes-en-pers/voorbereiding-waterstofproductieproject-in-rotterdam/
#14	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Import, supply	https://www.portofrotterdam.com/en/news-and-press-releases/oci-expands-import-terminal-for-green-ammonia
#15	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://smartport.nl/project/e-thor-ketens-sluiten-met-een-elektrolyser/
#16	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Import, storage	https://www.mitsubishicorp.com/jp/en/pr/archive/2021/html/0000047567.html
#17	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Storage, transport, supply	https://www.portofrotterdam.com/en/news-and-press-releases/vopak-focuses-on-hydrogen-imports-in-rotterdam-with-german-company
#18	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Storage	https://koole.com/horisont-energi-signs-mou-with-koole-terminals-on-development-of-ammonia-terminal-and-storage-facility-at-port/
#19	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.portofrotterdam.com/en/news-and-press-releases/battolyser-systems-builds-1-gigawatt-plant-in-rotterdam?utm_source=linkedin&utm_medium=social&utm_campaign=hbrkanalen
#20	Supply chain and transport organizers	N/A	Customer	https://www.maersk.com/news/articles/2022/11/03/maersk-and-the-spanish-government-to-explore-large-scale-green-fuels-production

Number	Stakeholder	Port	Link	Source
#21	Port authority	Singapore	Supply	https://www.mpa.gov.sg/media-centre/details/singapore-hosted-the-world-s-first-bulk-liquefied-hydrogen-carrier-suiso-frontier-to-the-port-of-singapore
#22	Port authority	Singapore	Other	https://www.jp.com.sg/companies-collaborate-to-explore-hydrogen-as-a-low-carbon-alternative-for-singapore/
#23	Port and terminal operating companies Research institutes, universities, and innovation centres.	Singapore	Production, transport	https://www.singaporepsa.com/2022/03/29/ntu-singapore-to-develop-technologies-to-extract-hydrogen-from-liquid-organic-hydrogen-carriers-supported-by-industry-collaborators/
#29	Port authority	Rotterdam	Import	https://www.portofrotterdam.com/sites/default/files/2021-11/202111ID-230_ST_IMP_TERM_WSTOF_PP_NL.pdf
#30	Port authority	Singapore	Other	https://www.mpa.gov.sg/docs/mpalibraries/media-releases/older/expression-of-interest-for-ammonia-project-(final)
#62	Research institutes, universities, and innovation centres.	Singapore	Transport, customer	https://surbanajurong.com/perspective/transporting-and-distributing-green-fuel-hydrogen-a-case-study-on-singapore/
#63	Associations, government agencies, and non-governmental organizations (NGOs) Service providers (banks, insurance companies, classification and certification societies, rating agencies, IT companies etc.)	Singapore	Other	https://go.gov.sg/studyofhydrogenimportsanddownstreamapplicationsforsingapore
		Methanol		
#24	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.gidara-energy.com/advanced-methanol-rotterdam
#25	Supply chain and transport organizers Companies involved in (semi-) industrial activities in the port area	Rotterdam & Singapore	Production, Customer	https://www.x-pressfeeders.com/news/x-press-feeders-and-oci-global-sign-green-methanol-offtake-agreement

Number	Stakeholder	Port	Link	Source
#26	Port authority	Rotterdam	Supply, storage	https://www.portofrotterdam.com/en/news-and-press-releases/waterfront-shipping-takes-leadership-role-demonstrating-simplicity-methanol
#27	Port authority Companies involved in (semi-) industrial activities in the port area Port authority Companies involved in (semi-) industrial activities in the port area	Singapore Singapore	Storage, supply, Customer Other	https://www.mpa.gov.sg/media-centre/details/successful-first-methanol-bunkering-operation-in-the-port-of-singapore https://www.mpa.gov.sg/docs/mpalibraries/media-releases/2023/international-chemical-and-oil-pollution-conference-and-exhibition-2023
#48	Port authority	Singapore	Other	https://www.mpa.gov.sg/docs/mpalibraries/media-releases/2023/international-chemical-and-oil-pollution-conference-and-exhibition-2023
#60	Supply chain and transport organizers	N/A	Customer	https://www.maersk.com/news/articles/2023/06/13/maersk-secures-green-methanol
#65	Industry and branch organizations Port community associations, branch organizations	N/A	Other	https://www.ocimf.org/document-libary/carriage-of-methanol-in-bulk-onboard-offshore-vessels
		Biofuels		
#28	Companies involved in (semi-) industrial activities in the port area	Singapore	Production	https://www.neste.com/about-neste/who-we-are/production/singapore
#31	Companies involved in (semi-) industrial activities in the port area	Singapore	Production	https://www.shell.com.sg/media/2022-media-releases/Shell-acquires-EcoOils-drive-Shells-low-carbon-fuels-ambition.html#
#32	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.shell.com/media/news-and-media-releases/2021/shell-to-build-one-of-europes-biggest-biofuels-facilities.html
#33	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Supply	https://www.varoenergy.com/en/news/varo-s-subsidiary-reinplus-fiwado-goodfuels-and-nederlands-loodswezen-develop-partnership-to-

Number	Stakeholder	Port	Link	Source
				supply-more-sustainable-biofuels/\
#34	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Storage	https://www.vopak.com/newsroom/news/news-vopak-invests-storage-capacity-waste-based-feedstocks-port-rotterdam?language_content_entity=en
#35	Companies involved in (semi-) industrial activities in the port area	Rotterdam	Production	https://www.upm.com/articles/biofuels/23/europe-needs-more-advanced-biofuels-to-rapidly-reduce-transport-emissions/
#49	Port community associations, branch organizations	N/A	Other	https://www.zerocarbonshipping.com/publications/using-bio-diesel-onboard-vessels/
#50	Supply chain and transport organizers	N/A	Customer	https://www.maersk.com/~/media_sc9/maersk/solutions/transportation-services/eco-delivery/info-sheet-about-bio-fuels-maersk.pdf
Specific Fuel Not Applicable				
#36	Supply chain and transport organizers	Rotterdam	Other	https://www.rwg.nl/nl/news/603
#37	Port and terminal operating companies	Singapore	Other	https://www.singaporepsa.com/our-commitment/sustainability/
#38	Environmental groups	N/A	Other	https://www.greenpeace.org/eu-unit/issues/climate-energy/46371/how-europes-transport-system-can-tackle-the-energy-and-climate-crises/
#39	Associations, government agencies, and non-governmental organizations (NGOs)	N/A	Other	https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx
#40	Industry and branch organizations	Singapore	Other	https://www.kongsberg.com/maritime/about-us/news-and-media/blog-stories/sustainable-oceans-in-singapore/
#41	Environmental groups	N/A	Other	https://europe.oceana.org/shipping-pollution-1/
#42	Associations, government agencies, and non-governmental organizations (NGOs)	Singapore	Other	https://www.mot.gov.sg/what-we-do/green-transport/maritime-environment-responsibility

Number	Stakeholder	Port	Link	Source
#43	Associations, government agencies, and non-governmental organizations (NGOs)	Rotterdam	Other	https://www.rijksoverheid.nl/onderwerpen/scheepvaart-en-havens/innovatie-in-de-scheepvaart
#44	Environmental groups	N/A	Other	https://wwf.panda.org/wwf_news/?9272466/Shipping-industry-15C-pathway-IMO-meeting
#45	Service providers (banks, insurance companies, classification and certification societies, rating agencies, IT companies etc.)	N/A	Other	https://www.londonpandi.com/about-us/sustainability/
#46	Service providers (banks, insurance companies, classification and certification societies, rating agencies, IT companies etc.)	N/A	Other	https://www.dnv.com/expert-story/maritime-impact/alternative-fuels.html
#47	Research institutes, universities, and innovation centres.	N/A	Other	https://www.emsa.europa.eu/we-do/sustainability/environment/sustainable-shipping.html
#52	Port and terminal operating companies	Rotterdam	Other	https://hutchisonports.com/sustainability/HutchisonPorts_SR2022.pdf
#53	Industry and branch organizations	N/A	Other	https://www.intercargo.org/wp-content/annual-report/2021-2022/
#55	Associations, government agencies, and non-governmental organizations (NGOs)	Rotterdam	Other	https://www.greendeals.nl/sites/default/files/2019-11/GD230%20Green%20Deal%20on%20Maritime%20and%20Inland%20shipping%20and%20Ports.pdf
#56	Port community associations, branch organizations	N/A	Other	https://cms.zerocarbonshipping.com/media/uploads/documents/Green-Corridors-Pre-Feasibility-Blueprint.pdf
#57	Research institutes, universities, and innovation centres.	N/A	Other	https://www.marin.nl/en/publications/are-we-ready-for-the-energy-transition
#58	Supply chain and transport organizers	N/A	Customer	https://www.one-line.com/sites/g/files/lnzjqr776/files/2022-08/ONE_Sustainability%20Report%202022_290722_0.pdf
#59	Port and terminal operating companies	Rotterdam	Other	https://www.apmterminals.com/-/media/corporate/sustainability-reports/maersk-apm-terminals-sustainability-

Number	Stakeholder	Port	Link	Source
				report-2022.pdf?rev=d794dfc8c8b241f4b5ac1bb493c9ea0a
#61	Research institutes, universities, and innovation centres.	N/A	Other	https://www.ocimf.org/document-libary/carriage-of-methanol-in-bulk-onboard-offshore-vessels
#64	Supply chain and transport organizers	N/A	Other	https://www.msc.com/-/media/files/sustainability/reports/2022_msc_sustainability_report.pdf

Appendix B2: Overview of predetermined codes that stem from the literature

Predefined categories	Source
Capital investment	(Bai et al., 2023)
Clean energy infrastructure	(Bai et al., 2023)
Clear definition of responsibilities	(Aerts et al., 2014; B. Hwang et al., 2013)
Community support	(Aerts et al., 2014; Bai et al., 2023)
Concrete and precise concession agreement	(Aerts et al., 2014)
Government support	(Aerts et al., 2014; Bai et al., 2023; Chua et al., 2023; B. Hwang et al., 2013)
Increased military tensions	(Bai et al., 2023)
Knowledge transfer	(Aerts et al., 2014; Chua et al., 2023)
New technology acceptance	(Chua et al., 2023)
Organizational commitment	(Aerts et al., 2014; Chua et al., 2023)
Performance management	(Chua et al., 2023)
Adequate and coordinated policies and regulations	(Aerts et al., 2014; Bai et al., 2023)
Political stability	(Aerts et al., 2014; Bai et al., 2023)
Realistic cost/benefit analysis	(Aerts et al., 2014)
Reasonable debt/equity ratio	(Aerts et al., 2014)
Relationship coordination	(Aerts et al., 2014; Chua et al., 2023)
Renewable energy supply	(Bai et al., 2023)
Risk allocation and risk sharing	(Aerts et al., 2014; S. Hwang, 2007)
Stable economic situation	(Aerts et al., 2014)
Strategic alignment	(Chua et al., 2023)
Technological feasibility	(Aerts et al., 2014)
Threat of terrorism	(Bai et al., 2023)
Transparency in procurement process	(B. Hwang et al., 2013)

Appendix B3: Predetermined codes used in Atlas.ti

Predefined categories	Description	Source
Anti-corruption*	Activities intended to prevent or reduce corruption (= illegal, bad, or dishonest behaviour, especially by people in positions of power (Cambridge Dictionary, n.d.-a)	(B. Hwang et al., 2013; S. Lucassen, personal communication, 24 October 2023)
Capital investment	Money that is spent on buildings and equipment to increase the effectiveness of a business (Cambridge Dictionary, n.d.-b)	(Bai et al., 2023)
Clean energy infrastructure	The need for sufficient infrastructure to support clean energy usage (Bai et al., 2023)	(Bai et al., 2023)
Clear definition of responsibilities	Clear definition of what one's job or duty is to deal with (Cambridge Dictionary, n.d.-f)	(Aerts et al., 2014; B. Hwang et al., 2013)
Community support	The support of people living in one particular area or people who are considered as a unit because of their common interests (Cambridge Dictionary, n.d.-c)	(Aerts et al., 2014; Bai et al., 2023)
Concrete and precise concession agreement	Concrete and precise contract that grants an organisation the right to do a certain business under the jurisdiction of a government or on the property of another organisation, subject to certain conditions (Kenton, 2020)	(Aerts et al., 2014)
Customer demand*	Conditions need to be in place to mobilise demand for green shipping and to scale zero-emission shipping on the corridor (Getting to Zero Coalition et al., 2021)	(M. Stoelinga, personal communication, 6 October 2023; P. Walison, personal communication, 20 October 2023)
Government support	Government involvement, help, or endorsement to encourage and facilitate the adoption and implementation of sustainable practises within the shipping sector (Lister, 2015)	(Aerts et al., 2014; Bai et al., 2023; Chua et al., 2023; B. Hwang et al., 2013)
Increased military tensions	A feeling of fear or anger between two groups of people who do not trust each other (Cambridge Dictionary, n.d.-g)	(Bai et al., 2023)
Infrastructural resilience*	The resilience of the infrastructure to external shocks (e.g., climate events, geopolitical tensions etc.) (Y. Baay, personal communication, 16 October 2023)	(Y. Baay, personal communication, 16 October 2023)
Knowledge transfer	Range of activities to support mutually beneficial collaborations between universities, businesses and the public sector (University of Cambridge, 2009)	(Aerts et al., 2014; Chua et al., 2023)
New technology acceptance	Positive decision to use a technology (Taherdoost, 2018)	(Chua et al., 2023)
Organizational commitment	Firm's dedication to implement a project. This is related to inter-firm management and the organizational culture (Chua et al., 2023)	(Aerts et al., 2014; Chua et al., 2023)
Performance management	Performance indicators to measure performance and collaboration (internal and external) (Chua et al., 2023). It serves as a tool to drive continuous improvement.	(Chua et al., 2023)

Predefined categories	Description	Source
Adequate and coordinated policies and regulations	Official rules governing a particular domain and the agreed-upon plans or strategies developed by a group of people or entities to control and manage specific situations within that domain (Cambridge Dictionary, n.d.-e, n.d.-d)	(Aerts et al., 2014; Bai et al., 2023)
Political stability	The ability of the political system to manage internal conflicts within the framework of state institutions (Margolis, 2010)	(Aerts et al., 2014; Bai et al., 2023)
Realistic cost/benefit analysis	Realistic analysis and comparison of the projected or estimated costs and benefits associated with a project (Stobierski, 2019).	(Aerts et al., 2014)
Reasonable debt/equity ratio	Reasonable financial ratio showing the share of debt and shareholders' equity used to fund an organization's assets (Peterson & Fabozzi, 1999)	(Aerts et al., 2014)
Relationship coordination	Strengthen mutual dependence, trust and commitment (Chua et al., 2023). Focus on stakeholders.	(Aerts et al., 2014; Chua et al., 2023)
Renewable energy supply	Supply of energy that is derived from natural sources that are replenished at a higher rate than they are consumed (United Nations, 2022b)	(Bai et al., 2023)
Risk allocation and risk sharing	Clear determination which party to the PPP contract will bear the cost (or reap the benefit) of a change in project outcomes arising from each risk factor (The World Bank, n.d.)	(Aerts et al., 2014)
Safety*	Fire, explosion and ignition hazards that fuel usages pose (Astbury, 2008)	(M. Stoelinga, personal communication, October 6, 2023)
Stable economic situation	Financial system of a nation that displays only minor fluctuations in output growth and exhibits a consistently low inflation rate (UNESCAWA, n.d.)	(Aerts et al., 2014)
Strategic alignment	Goals that align within the organization (internal) and among partners (external) (Chua et al., 2023)	(Chua et al., 2023)
Technological feasibility	Evaluation of the technical complexity of the expert system and often involves determining whether the expert system can be implemented with state-of-the-art techniques and tools (Yoon & Adya, 2003)	(Aerts et al., 2014)
Threat of terrorism	Threat of calculated use of violence to create a general climate of fear in a population and thereby to bring about a particular political objective (Britannica, 2023)	(Bai et al., 2023)

Note: Several descriptions of CSFs were missing in the papers they were published in. Therefore, these descriptions stem from external sources.

*These factors do not stem from the literature, but from the external validation.

Appendix C

Appendix C1: Overview of all green shipping corridor initiatives

#	Port	Name	Type	Alternative fuel bunker readiness
1	Los Angeles	N/A	Network	Hydrogen (American Bureau of Shipping, 2022)
	Long Beach			N/A
	Shanghai			N/A
2	Vancouver	Pacific Northwest to Alaska Green Corridor	Network	N/A
	Seattle			N/A
	Juneau			N/A
3	N/A	Chilean Green Corridor Network	Network	N/A
4	N/A	Great Lakes - St. Lawrence	Network	N/A
5	Antwerp	N/A	Point-to-point	Biofuels and Hydrogen (American Bureau of Shipping, 2022), Methanol (Habicic, 2023)
	Montreal			N/A
6	Halifax	N/A	Point-to-point	N/A
	Hamburg			N/A
7	Newcastle	Clean Tyne Corridor	Single point	N/A
8	Dover	N/A	Network	N/A
	Calais			N/A
	Dunkirk			N/A
9	Gothenborg		Point-to-point	Methanol (Port of Gothenburg, 2023)
	North Sea Port			N/A
10	N/A	H2 powered North Sea Crossing	Network	N/A
11	Gothenburg	N/A	Point-to-point	Methanol (Port of Gothenburg, 2023)
	Rotterdam			Biofuels, Hydrogen and Methanol (American Bureau of Shipping, 2022)

#	Port	Name	Type	Alternative fuel bunker readiness
12	Rotterdam	European Green Corridor Network	Network	Biofuels, Hydrogen and Methanol (American Bureau of Shipping, 2022)
	Tallinn			N/A
	Hamburg			N/A
	Gdynia			N/A
	Rønne			N/A
13	N/A	Nordic Regional Corridors	Network	N/A
14	Turku	Decatrip	Point-to-point	N/A
	Stockholm			N/A
15	N/A	Green Corridors Spain	Network	N/A
16	Rotterdam	N/A	Point-to-point	Biofuels, Hydrogen and Methanol (American Bureau of Shipping, 2022)
	Singapore			Biofuels, Hydrogen and Methanol (American Bureau of Shipping, 2022)
17	Singapore	SILK Alliance	Network	Biofuels, Hydrogen and Methanol (American Bureau of Shipping, 2022)
18	N/A	Aus-Asia Iron Ore	Network	N/A
19	N/A	QUAD Shipping Taskforce	Network	N/A
20	New Orleans	Gulf of Mexico Green Shipping Corridor	Point-to-point	N/A
	Houston			Methanol (Maritime Executive, 2023a)
21	Los Angeles	N/A	Network	Hydrogen (American Bureau of Shipping, 2022)
	Long Beach			N/A
	Singapore			Biofuels, Hydrogen and Methanol (American Bureau of Shipping, 2022)
22	Los Angeles	N/A	Point-to-point	Hydrogen (American Bureau of Shipping, 2022)
	Nagoya			Biofuels (Bahtić, 2023)

#	Port	Name	Type	Alternative fuel bunker readiness
23	Helsinki	Estonia-Finland Green Corridor	Network	N/A
	Tallinn			N/A
	Vuosaari			N/A
	Muuga			N/A
24	N/A	South Africa Europe Iron Ore	Network	N/A

Appendix C2: Descriptive overview of data used in content analysis

		Number	Share
Port	Rotterdam	32	48.5%
	Singapore	15	22.7%
	N/A	19	28.8%
Value chain*	Import	8	10.5%
	Production	17	22.4%
	Transport	4	5.3%
	Storage	7	9.2%
	Supply	7	9.2%
	Consumption	5	6.6%
	Other	28	36.8%
Alternative fuel	Hydrogen	27	41.5%
	Methanol	8	12.3%
	Biofuels	9	13.8%
	N/A	21	32.3%
Stakeholder*	Port authority	14	18.4%
	Port and terminal operator	5	6.6%
	Supply chain and transport organizers	10	13.2%
	Companies involved in (semi-) industrial activities in port area	27	35.5%
	Associations, government agencies, and non-governmental organizations	4	5.3%
	Industry and branch organizations	4	5.3%
	Environmental groups	3	3.9%
	Service providers (banks, insurance companies, IT companies, rating agencies etc.)	3	3.9%
	Research institutes, universities, and innovation centres	6	7.9%

Note: The totals per category differ, since some texts used are relevant for more than one subgroup per category e.g. several projects encompass more than one link in the value chain or more than one alternative fuel.
*Stakeholder categories emerged from Notteboom et al. (2020)

Appendix C3: Overview of results from content analysis ranked by frequency

Critical Success Factor	Frequencies	Level of analysis
Organizational commitment	102	Micro
Relationship coordination	74	Meso
Strategic alignment	68	Meso
Safety	61	Meso
Knowledge transfer	60	Micro
Adequate and coordinated policies and regulations	56	Macro
Government support	47	Macro
Clean energy infrastructure	37	Meso
Technological feasibility	34	Macro
Customer demand	28	Macro
Clear definition of responsibilities	27	Meso
Renewable energy supply	24	Meso
Realistic cost/benefit analysis	24	Micro
Capital investment	23	Meso
Concrete and precise concession agreement	13	Meso
New technology acceptance	7	Micro
Community support	6	Meso
Stable economic situation	3	Macro
Anti-corruption	0	Macro
Increased military tensions	0	Macro
Political stability	0	Macro
Reasonable debt/equity ratio	0	Macro
Threat of terrorism	0	Macro
Infrastructural resilience	0	Meso
Risk allocation and risk sharing	0	Meso
Performance management	0	Micro
Total	**694**	

Appendix C4: Overview of CSFs grouped per level of analysis and supporting theories including frequencies

CSF	Supporting theory	Level of Analysis	Frequency
Anti-corruption	PESTLE: Political	Macro	0
Community support	PESTLE: Sociocultural	Meso	6
Customer demand	PESTLE: Economic	Macro	28
Government support	PESTLE: Political	Macro	47
Increased military tensions	PESTLE: Political	Macro	0
Adequate and coordinated policies and regulations	PESTLE: Political/legal	Macro	56
Political stability	PESTLE: Political	Macro	0
Reasonable debt/equity ratio	PESTLE: Economic	Macro	0
Stable economic situation	PESTLE: Economic	Macro	3
Technological feasibility	PESTLE: Technological	Macro	34
Threat of terrorism	PESTLE: Political	Macro	0
Subtotal			**174**
Capital investment	Real options theory	Meso	23
Clean energy infrastructure	N/A	Meso	37
Clear definition of responsibilities	N/A	Meso	27
Concrete and precise concession agreement	Contract theory	Meso	13
Infrastructural resilience	Dynamic Capabilities Theory	Meso	0
Relationship coordination	Relational view Stakeholder theory	Meso	74
Renewable energy supply	Resource Dependence Theory	Meso	24
Risk allocation and risk sharing	Enterprise Risk Management	Meso	0
Safety	Normal accident theory	Meso	61
Strategic alignment	Contingency (fit) theory	Meso	68
Subtotal			**327**
Knowledge transfer	Organizational learning	Micro	60
New technology acceptance	Organizational learning	Micro	7
Organizational commitment	Resource-based view theory	Micro	102
Performance management	N/A	Micro	0
Realistic cost/benefit analysis	N/A	Micro	24
Subtotal			**193**

Appendix C5: Overview of CSF ranking resulting from content analysis segregated per port

Rotterdam			Singapore		
Ranking	CSF	Frequency	Ranking	CSF	Frequency
#1	Organizational commitment	50	#1	Safety	39
#2	Strategic alignment	35	#2	Relationship coordination	32
#3	Relationship coordination	29	#3	Knowledge transfer	30
#4	Clean energy infrastructure	23	#4	Organizational commitment	25
#5	Adequate and coordinated policies and regulations	21	#5	Government support	21
#6	Renewable energy supply	20	#6	Adequate and coordinated policies and regulations	17
#7	Customer demand	17	#7	Strategic alignment	16
#8	Government support	15	#7	Technological feasibility	16
#9	Knowledge transfer	13	#9	Realistic cost/benefit analysis	12
#9	Technological feasibility	13	#10	Clean energy infrastructure	10
#11	Capital investment	12	#11	Clear definition of responsibilities	8
#12	Clear definition of responsibilities	11	#12	Customer demand	6
#12	Safety	11	#13	Capital investment	5
#14	Concrete and precise concession agreement	8	#13	Renewable energy supply	5
#15	Community support	5	#15	Community support	1
#15	New technology acceptance	5	#15	Concrete and precise concession agreement	1
#15	Realistic cost/benefit analysis	5	#17	Increased military tensions	0
#18	Stable economic situation	2	#17	New technology acceptance	0
#19	Increased military tensions	0	#17	Performance management	0

Rotterdam			Singapore		
Ranking	CSF	Frequency	Ranking	CSF	Frequency
#19	Performance management	0	#17	Political stability	0
#19	Political stability	0	#17	Reasonable debt/equity ratio	0
#19	Reasonable debt/equity ratio	0	#17	Risk allocation and risk sharing	0
#19	Risk allocation and risk sharing	0	#17	Stable economic situation	0
#19	Threat of terrorism	0	#17	Threat of terrorism	0

Note: All CSFs with the same frequency were given the same ranking.

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