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PREREQUISITES FOR AND BOTTLENECKS OF A SUCCESSFUL TRANSITION TO SUSTAINABLE FUELS: THE CASE OF THE ROTTERDAM-DUISBURG FREIGHT CORRIDOR'S INLAND CONTAINER BARGING SECTOR

by

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ABSTRACT

Growing environmental concerns and the effects of climate change are causing a substantial revolution in the worldwide transportation industry. A significant component of the Rotterdam-Duisburg freight corridor, inland container barging sector is under investigation for its sustainability and environmental effect. This change is causing a re-evaluation of its operations and fuel supplies because the corridor is a crucial lifeline for the movement of commodities throughout Europe. The switch to sustainable fuels is becoming more and more crucial, particularly for inland water transportation (IWT). Challenges also emerge within this transition. This study attempts to comprehend the factors influencing technology adoption in the container-barging industry while offering a practical road map based on reliable primary sources. This study uses the Technology Acceptance Model (TAM) to examine the transition within the container barging sector, specifically the Rotterdam-Duisburg freight corridor, and understand stakeholder perceptions and attitudes toward adopting fuel technology with sustainable properties. The study finds that perceived ease of use, utility, social influence, attitude change, behavioural intention, and behavioural aim all have an impact on attitudes toward sustainable fuel technology. It leads to positive perceptions, perceived utility, social influence, and the effective implementation of sustainable fuel technologies. The report recognizes difficulties such as lack of technology preparedness, infrastructure changes, financial constraints, and lack of alignment with industry standards. Although it admits flaws including the possibility of bias in survey replies, it offers chances for further study to increase the use of sustainable fuel in marine areas. Overall, Key elements for the adoption of sustainable fuel technology include peer influence, perceived rewards, and user-friendliness. The adoption process must also be in line with business practices, which presents a number of difficulties, including technology preparedness, infrastructure changes, cost concerns, and cost considerations. The study contributes to continuing conversations regarding environmentally responsible marine activities.

Keywords: Rotterdam-Duisburg freight corridor; sustainable fuels; container-barging industry; TAM technology

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

1. Introduction

1.1 Container Barging

Barging plays an indispensable role in global transportation and logistics. For example, container barges connect major economic centres like Rotterdam and Duisburg along the Rhine corridor as shown in figure 1.1. Container barging is the term used to describe the movement of products on barges created expressly to transport standardized cargo containers. In areas with large canal and river systems, these barges—a subset of inland waterway vessels—are especially common in Europe (Weerapong et al., 2021).

Figure 1.1: IWT route along Rotterdam- Duisburg, Rhine corridor (CCNR annual report, 2018, P43)

Container barging offers numerous advantages over road and rail transport methods, chief among them its capacity to ease road and rail congestion by shifting cargo transport away from overland routes to waterways. This has positive implications in terms of reducing traffic congestion, carbon emissions, and wear and tear on existing infrastructure. It plays a pivotal role in intermodal logistics chains, connecting maritime shipping with land distribution networks.

1.2 Overview of the Rotterdam-Duisburg Freight Corridor

The Rotterdam to Duisburg Freight Corridor is an important transportation route, which stretches approximately 170 kilometres (105 miles). Providing a crucial link in the logistical chain of Europe is the connection between Rotterdam, the Netherlands, and Duisburg, Germany. Rotterdam, situated at the mouth of the Rhine-Meuse-Scheldt delta, is one of Europe's busiest ports and one of the busiest worldwide. Serving as an important gateway for international trade, Rotterdam handles an array of commodities and transhipment hub for goods destined for various European destinations (Maro et al., 2022). Thanks to its strategic location and state-of-the-art infrastructure, Rotterdam has quickly established itself as a key logistics and distribution centre.

Duisburg, situated at the confluence of the Rhine and Ruhr rivers, is one of the largest inland port in Europe. As a hub for waterway transportation, rail freight, road transport, direct access to German industrial heartland distribution networks via Rhine river network canal networks as well as container handling, bulk cargo operations, and intermodal logistics; Duisburg offers an abundance of services such as container handling bulk cargo operations intermodal logistics to support this vital service industry.

The freight corridor between Rotterdam and Duisburg is known for its efficient multimodal transportation system (Nitsche, 2020). This encompasses various modes of transport such as inland barging, rail transport, and road connectivity - with inland barging being particularly advantageous as it reduces costs while simultaneously offering reduced congestion on roads as well as environmental benefits over road transport.

1.2.1 Significance and vibrancy of the corridor

Numerous statistical data highlight the significance of the Rotterdam-Duisburg freight corridor. For instance, Rotterdam Port Authority's container traffic has steadily grown over time; by 2020 alone they handled 14.8 million twenty-foot equivalent units (TEUs). Duisburg Port handled approximately 125 million tonnes in 2020 - both containerized cargo as well as bulk goods across its entirety and hence container barging is important on this route.

The significance of the corridor goes beyond just its immense capacity for goods transportation; it serves as a key link in Europe's supply chain, connecting various industries and aiding international trade. Industries like automotive, chemicals, manufacturing, and consumer goods rely heavily on this corridor's efficiency as they strive to meet market demands (Antoniou, 2019).

Though the corridor has long been recognized for its importance and effectiveness, there remain significant challenges and opportunities that must be met to keep moving forward. A major environmental concern lies in using traditional fuels in transportation (inland barging especially) resulting in carbon emissions and other environmental pollutants; finding sustainable fuel alternatives may help mitigate such adverse environmental effects and contribute to global efforts against climate change (Ziakas, 2021).

Furthermore, the corridor's future growth and sustainability rely on its infrastructure bottlenecks being addressed, and seamless intermodal connectivity ensured. Investment in port facilities, inland waterways, rail networks, and road connections is integral in maintaining competitiveness and efficiency within this corridor.

1.2.2 Role in European Goods Transportation

The freight corridor between Rotterdam and Duisburg is an integral component of Europe's logistics network, serving to move goods between the major seaport of Rotterdam and Duisburg via multimodal transportation systems. Thanks to its strategic location, state-of-the-art infrastructure, and multimodal transport system capabilities, the corridor plays an essential role in international trade as well as European supply chain management; yet its long-term sustainability and efficiency require consideration of environmental impacts and infrastructure development challenges (Victor, 2021).

According to recent statistics, over 70 million tons of goods were transported via inland waterways in the Netherlands in 2020 alone - contributing significantly to trade, creating jobs and driving economic expansion (Sys et al., 2020).In the same year, 10 countries saw their volume of transport increase between 2020 and 2021 - Germany recording the highest absolute increase at 2.2 billion tonne-kilometres; Lithuania (+315%), Sweden (+80%), and Czechia (+23%) experienced significant relative increases while on the other end, Poland experienced 30% decrease, Bulgaria and Croatia both experiencing reductions by 7-7% respectively as shown in figure 1.2 and appendix (supp. figure 1 and supp figure 2).

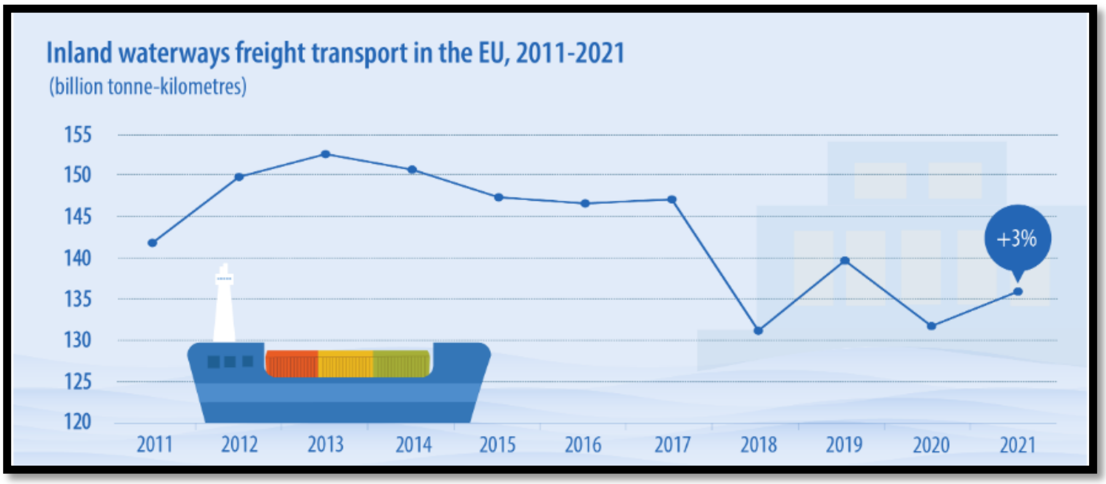


Figure 1.2: Inland Waterways 2021 (Source: Eurostat, 2021)

Research has confirmed the advantages of inland barging as an economical mode of transport over other forms. Estimates indicate that transporting goods by container barge can be up to 40% cheaper than by road and 20% more economical than rail; making inland barging an appealing choice for businesses, especially when shipping bulky or heavy items. The Rotterdam-Duisburg barging sector's environmental impacts are significant, calling attention to the necessity of sustainable fuel solutions (Malakhova et al., 2023). While inland shipping may be considered more environmentally friendly than road or air travel, its greenhouse gas emissions still contribute significantly to greenhouse gas emissions and air pollution issues.

Numerical data demonstrates the environmental footprint of inland shipping. According to research, research shows that barging emits lower greenhouse gas emissions per ton-kilometre than road transport; specifically it was discovered that container barging produced approximately 1% of CO_2 equivalent emissions per ton-kilometre while road transport produced 52% CO_2 equivalent emissions per ton-kilometre highlighting its lower carbon intensity compared to road transport which is shown in figure 1.3.

1.3 Fuel consumption and emissions

It is crucial to address environmental impacts associated with inland shipping (Verberght, 2020). Container Barges contribute significantly to air pollution through emissions of CO_2, Carbon Monoxide (CO), Nitrogen oxides (NO_x) and Particulate matter (PM), which have devastating impacts on human health, ecosystems, and air quality in areas along corridors.

The Netherlands and Germany house most registered maximum container barges, constituting about 50% of all dry cargo vessels in Rhine countries. These vessels were operational in 2020. Specifically, around 6,942 dry cargo vessels were recorded in Rhine countries during 2020 as shown in appendix (supp. figure 3), a slight decrease from the 7,012 vessels in 2019. Given their significance, assessing greenhouse gas emissions along the Rotterdam-Duisburg corridor becomes crucial for understanding the environmental impact of these vessels (Table 1) (ANNUAL REPORT INLAND NAVIGATION IN EUROPE MARKET OBSERVATION, n.d.).

Table 1.1: Summary of atmospheric pollutant and GHG emissions by the inland navigation sector in 2015 (Source: CCNR)

Emissions	Total (Kt)
Carbon dioxide (CO_2)	4149.2
Carbon Monoxide (CO)	38.2
Methane (CH_4)	0.2
Nitrogen oxides (NO_x)	60.9
PM10 (Particulate matters)	2.0

Considering the above table:1.1, inland navigation must substantially reduce its GHG and air pollutant emissions by the year 2050 if it hopes to maintain and strengthen its position as a sustainable, competitive, and environmentally friendly mode of transportation. In other words, addressing climate change through the reduction of GHG emissions, lowering operational costs (OPEX) of the industry by improving inland navigation efficiency and lowering health risks by improving air quality are the driving forces behind fleet modernization and the energy transition (CCNR Roadmap, P17).

Figure 1.3 showcases the CO_2 emissions distribution across various transport modes. Road transportation dominates with 52% of emissions, followed by rail at 31%. Public transportation contributes 10%, while waterways and airways emit 2% and 1% respectively. Intermodal transport, which combines multiple transport modes, accounts for 1%, and an additional 2% is categorized as unknown.

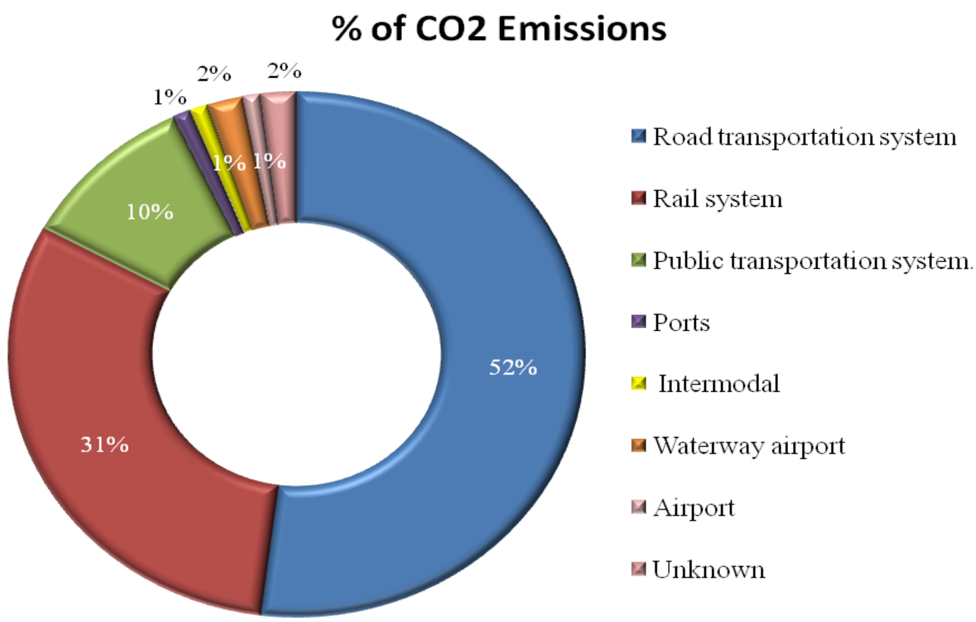


Figure 1.3: CO2 Emissions for Different Forms of Transport

(Source: Ieltsxpress, 2023)

As part of efforts to mitigate environmental impacts and climate change concerns, sustainable fuel alternatives to marine gas oil (MGO) and heavy fuel oil (HFO) should be prioritized as potential replacements. Doing so could substantially lower greenhouse gas emissions associated with container barging operations as well as air pollutants produced in their exhaust.

The transition towards more eco-friendly fuels for inland barging vessels in response to climate change, reduced carbon emissions and environmental sustainability is of utmost importance in order to address climate change and foster environmental protection. Research findings highlight how using more environmentally sustainable fuels could transform this sector's environmental performance (Geogatzi et al., 2020).Numerical data and research indicate that using sustainable fuels for inland shipping can result in substantial emission reductions, potentially up to 80% lower greenhouse gas emissions compared to conventional fuels. This reduction can contribute to meeting climate change targets while supporting global efforts to minimize the environmental impacts of shipping industry activity (Eurostat, 2019).

The thesis explores the background and significance of inland barging along the Rotterdam-Duisburg corridor in terms of economic benefits, environmental effects and transitioning towards more eco-friendly fuels. Numeric data and research findings provided shed light on its economic importance as an economic facilitator and the environmental burden it poses, along with opportunities for transformation toward cleaner alternatives if more sustainable technologies were adopted by this industry sector - ultimately contributing towards creating an eco-friendly freight corridor between Rotterdam and Duisburg (Geerts et al., 2020)

1.4 The Need for Alternative Sustainable Fuels in Inland Container Shipping

Inland shipping plays an essential role in moving goods along waterways, offering numerous advantages like cost-effectiveness, energy efficiency and reduced carbon emissions. But its reliance on traditional fossil fuels such as Marine Gas Oil (MGO), Liquefied Natural Gas (LNG) and Heavy Fuel Oil (HFO) raises concerns over environmental impact and sustainability. This section examines alternative fuels used by inland shipping vessels like Hydrogen, green methanol and battery etc v/s specifically looks at traditional HFO, MGO/LNG as examples - with regard to their environmental challenges associated with traditional fuels, the urgency of climate change-related challenges related to traditional fuels as well as potential benefits offered by adopting alternative fuels; implications for this sector of industry (Prussi et al., 2021).

Inland container barging contributes significantly to greenhouse gas emissions and air pollution through its combustion of fossil fuels, emitting Carbon dioxide (CO2), Nitrogen oxides (NOx), and Sulphur oxides (SOx). These emissions have adverse impacts on climate change, air quality, human health, and human welfare; their proximity to densely populated areas further compounds their harmful impacts (www.iksr.org, n.d.).

Climate change is driving the transition towards alternative fuels in inland shipping. International agreements such as the Paris Agreement aim to limit global warming to well under 2 degrees Celsius above pre-industrial levels, and all transportation sectors, including inland shipping, must contribute (Fan et al., 2021). Governments and regulatory bodies have implemented stricter regulations to limit emissions from ships including inland shipping; for instance, European Union Green Deal sets ambitious targets of zero-emission navigation by 2050.

Alternative fuels offer numerous advantages over their fossil counterparts, including enhanced energy efficiency reduced greenhouse gas emissions and improved air quality. Hydrogen, biofuels, and electric power are promising options that can help decarbonize inland shipping to meet global emission reduction targets; hydrogen and biofuels produce no or very little pollution emissions which leads to improved air quality along waterways and nearby communities (Ilchenko et al., 2021). Additionally, these fuels offer higher energy efficiency, leading to improved operational efficiencies as well as cost savings for operators of inland shipping operations.

Adopting alternative fuels has profound ramifications for inland container barging. Infrastructure development must support their use, such as setting up refuelling stations and charging infrastructure for electric vessels. Investment in infrastructure is necessary to enable widespread adoption and ensure an easy transition. Technological innovation plays a vital role in driving the adoption of alternative fuels (Stefaniec et al., 2020). Advancements in propulsion systems, energy storage, and bunkering technologies must overcome technical hurdles to maximize the use of alternative fuels in inland shipping. Research and development efforts are essential in driving innovation and ensuring the feasibility and effectiveness of solutions that use alternative fuels.

Successful implementation of alternative fuels in inland shipping requires collaboration among industry stakeholders. Vessel operators, fuel suppliers, port authorities, and regulatory bodies all play an integral part in meeting challenges head-on while sharing knowledge and promoting sustainability practices. Collaboration among stakeholders is vital for creating an enabling environment to facilitate this transition to alternative fuels.

1.5 Research Questions

Motivated by the problem statement as discussed above under sections 1.3 and 1.4, this research paper discusses and analyses the following main question.

Main Research Question: “What are the prerequisites and potential bottlenecks for the Rotterdam-Duisburg freight corridor's inland container barging sector for a successful transition to sustainable fuels??”

This research question holds immense significance due to its implications for environmental sustainability, operational efficiency, and regulatory compliance in the maritime industry. Adopting sustainable fuels addresses pressing concerns over carbon emissions while meeting global efforts to reduce environmental impact. Furthermore, understanding potential barriers during this transition helps stakeholders make informed decisions. By studying such influences and challenges more closely this research contributes to creating a more resilient future for inland container barging, benefitting both industry stakeholders and the environment alike. (Proctor-Thomson et al., 2021).

Solutions to the below-aforementioned sub-research topics can be developed by critically reviewing the analysis's findings. For answers to the main research topic, these sub-questions are necessary.

The sub-research questions have been highlighted below:

1. What technological developments could assist the inland barging sector on the Rotterdam-Duisburg corridor in lowering their carbon footprint?
2. What are the most significant economic and financial constraints related with the use of sustainable fuels in the inland container barge industry?
3. What is the infrastructure requirement for bunkering sustainable fuel
4. What are the positions and perceptions of significant players, such as shippers, barge operators, government organizations, and environmental groups, regarding the corridor's switch to sustainable fuels?
5. How much does the social influence play in the adoption of sustainable fuel technology for container barging?

1.6 Thesis Structure

This paper is divided into five main sections to provide a thorough assessment of the transition towards sustainable fuel in the inland barging sector along the Freight Corridor between Rotterdam and Duisburg.

1. **Introduction:** The Introduction provides context and significance of the topic at hand by providing background and significance, such as its necessity in the inland barging sector. It outlines research questions and objectives well as an outline of the paper structure.
2. **Literature Review:** This literature review critically assesses existing knowledge related to sustainable fuel adoption in the maritime industry, with particular attention paid to inland container barging.
3. **Methodology:** This section presents the approach, data collection methods, and analytical techniques employed in the study. This section also describes qualitative research methodologies employed, including collecting secondary data sources like journals and reports for primary data collection purposes.

Hypothesis Development: The "Conceptual Framework and Hypothesis Development" chapter establishes a theoretical basis for this research using the Technology Acceptance Model (TAM). These aspects with sustainable fuel technology adoption within container bargaining environments.

4. **Results and Discussion:** In this section, the research findings are discussed and evaluated. Numeric data as well as key findings are presented coherently by way of numerical data and key findings analysis. Furthermore, implications and contributions made by these findings to knowledge about sustainable fuel adoption in the inland barging sector will also be addressed as will possible alternative explanations for results as well as limitations of this study being critically appraised.

5. **Summary and Conclusion:** The conclusion provides a concise overview of the study's main findings as well as research objectives and questions, discussing implications for inland barging operations, maritime operations, sustainable transportation as a whole as well as areas for further study. Recommendations are provided for stakeholders, policymakers, and industry players on collaborative approaches toward transitioning toward cleaner fuel sources.

2. Literature Review

2.1 Inland container barging

Coordination and integration among stakeholders within the inland container barging sector present another challenge. Collaboration among barge operators, shippers, port authorities, and government agencies must occur effectively to maximize operations, streamline procedures, address common obstacles, and address ongoing challenges effectively. This may require aligning infrastructure investments, optimizing vessel utilization rates and upgrading port facilities in order to accommodate barges efficiently (Moeremans et al., 2022).

Regulative frameworks and administrative procedures present additional obstacles for the inland barging industry. Harmonizing regulations and administrative processes across different countries and regions is vital to seamless cross-border operations, while addressing administrative burdens and streamlining procedures will increase its attractiveness as an affordable form of transport. Safety and risk management are both key considerations in the inland barging sector (Paulauskas et al., 2022). Barges operate under various environmental conditions and navigational challenges; to minimize accidents and incidents, safe operations, training of crew members on safety measures and effective risk management must all be ensured to maintain safe operations.

There are various reasons why switching to sustainable energy in this area is important. While barging offers inherent eco-friendliness, the global shift towards environmentally responsible practices requires taking proactive steps. Introducing new fuels that address both current environmental concerns and long-term sustainability goals is one solution to address both issues simultaneously. Although inland barging already enjoys numerous advantages, its position at the forefront of eco-conscious logistics solutions remains undiminished thanks to innovative fuel technologies that ensure its eco-friendliness. This study investigates the nuances involved in transitioning towards sustainable fuel technology within inland barging, providing clarity as to its implementation as well as the potential for further improving an already eco-friendly mode of freight movement (Statistics Netherlands, 2019).

2.2 Rationale for transition towards sustainable fuel

Transitioning towards sustainable fuel in the inland barging sector can be driven by various compelling considerations. This section explores some key drivers behind such an effort while emphasizing its associated environmental, economic, and societal advantages. One of the primary motivations behind transitioning towards sustainable fuel in inland shipping is environmental concerns. Traditional fuels used by this sector, including Marine Gas Oil (MGO), Heavy Fuel Oil (HFO) and Liquified Natural Gas (LNG), contribute significantly to air pollution and greenhouse gas emissions - notably Carbon dioxide (CO_2), Nitrogen oxides (NO_x), and Particulate matter (PM) emissions that degrade air quality while contributing to climate change (Table 2.1) (Koumentakos, 2019).

By switching to sustainable fuels such as biofuels or hydrogen, inland barging can significantly decrease its environmental footprint. Biofuels made from renewable sources such as biomass provide cleaner burning alternatives than fossil fuels; their use could significantly decrease CO_2 emissions and other harmful pollutants (Costantini et al., 2022). On the other hand, hydrogen production using renewable energy sources offers zero emission production that may help lead to significant greenhouse gas emission reduction and contribute to climate change mitigation efforts.

Transitioning towards sustainable fuels also helps ensure greater energy security and diversification for inland barging operators. Relying solely on fossil fuel imports exposes them to price volatility and supply disruptions; by adopting eco-fuel options instead, inland barging operators can reduce dependence on imported fossil fuels while simultaneously increasing energy independence and security (Goncalves et al., 2022).

Table 2.1: Major fuels and their advantages and disadvantages

Fuels type	Environmental and Operational Advantages	Environmental and Operational Disadvantages
Low-sulphur diesel	Adhere to emission regulations, use little amount of fuel	It still releases greenhouse gases
Methanol	Suitable for ships with low points of ignition and high emission	Has adverse effect on humans and animals
Di-methyl ether	Nontoxic and attainable from sustainable resources	Still developing this technology
Biodiesel	Biodegradable alternative fuel that predominates in the maritime industry	Deteriorates gradually
Hydrogen	High energy density, legally authorized in all maritime applications	Restricted accessibility
Algae based biodiesel	Although there is potential for sustainability, the expenses of manufacturing are now considerable.	The costs are too high for general usage, and there are fewer options and less heating benefit.
Liquefied natural gas (LNG)	With fewer pollutants than diesel, it is accessible at many ports.	Heavier than diesel and limited availability

Liquefied petroleum gas (LPG)	With less pollutants than diesel, it is accessible at many ports	The cost of refilling may be high and the availability may be restricted.
Biomethane	Produced from organic waste, it is chemically comparable to natural gas.	Sprinkled production site
Electricity	Low emissions and more effective than fossil fuels	Low energy density and less infrastructure
Fischer-Tropsch diesel	Created from renewable resources; non-toxic.	Generally accessible only in certain locations
Pyrolysis oil	Potential replacement for residual oil; commercially feasible technology.	Low energy content, stability issues, lack of certification for marine diesel engine usage, and restricted mixing capacity
Hydrogen	No emissions and the highest energy density of all fuels.	Not yet marketed for use in maritime applications

(Source: Moirangthem, K., 2016)

Transitioning towards sustainable fuels has been driven by the inland barging sector's need to comply with regulations and meet international commitments regarding environmental sustainability. Regulators, such as the International Maritime Organization (IMO) and European Union have set targets and implemented policies to decrease emissions from shipping industry operations (Sziklai et al., 2020).

IMO has recently adopted an Initial Strategy for Reducing GHG Emissions from Ships that seeks to limit CO2 emissions from international shipping (MEPC80, IMO), and the European Union Green Deal underscores this goal through the decarbonization of transport sectors including inland barging. To meet these regulations and commitments, barge operators must select sustainable fuels that help achieve emission reduction and meet broader sustainability objectives.

2.3 Current state of technology to use alternate fuel

Transitioning towards sustainable fuel in inland container barging is crucial to mitigating environmental impact and creating a greener transportation sector. This section offers an in-depth examination of current technology related to sustainable fuel options in this rapidly advancing field and gives insights into their feasibility and viability.

One promising sustainable fuel technology for inland barging is hydrogen fuel cells. These devices convert hydrogen and oxygen into electricity with water as the only by-product, providing long-range emission-free propulsion on barges. Recent advances in hydrogen fuel cell technology have greatly improved efficiency, durability, and scalability; making hydrogen fuel cells an attractive long-term propulsion option for long-distance propulsion on barges (Amoros et al.,2021).

Bio-fuels derived from organic matter such as biodiesel and bio-ethanol have gained increasing momentum as sustainable alternatives to fossil fuels. Produced from sources like agricultural residues, algae blooms, and waste oils, these alternative fuels offer one key advantage over conventional diesel: drop-in replacement with minimal engine modifications needed for use (Bazaluk et al., 2021). However, feedstock availability, land use competition, and sustainability issues must all be resolved for the widespread adoption of this fuel type.

Electric propulsion systems powered by batteries or hybrid systems have made strides in the maritime industry, especially with the lengthened range and faster charging capabilities of batteries. Electric propulsion can offer the advantages of zero emissions operation, reduced noise pollution, and lower operational costs when compared with traditional fuels; however, its limited energy density and need for charging infrastructure pose hurdles to widespread adoption within barging operations (Oloruntobi et al., 2023).

The inland barging sector is at the forefront of a transformative phase, actively researching and implementing alternative fuels to combat greenhouse gas emissions. Biofuels, derived from organic materials such as algae or agricultural waste, are emerging as a promising solution for container barges. The combustion of these fuels releases carbon that was just taken from the atmosphere, making them theoretically carbon-neutral (Islam Rony et al., 2023). Another promising avenue is hydrogen fuel cells. These cells convert hydrogen into electricity, emitting only water vapour as a by-product. While the technology is still in its infancy for maritime applications, early trials have shown potential, especially when the hydrogen is sourced sustainably (www.aramco.com, n.d.). Additionally, battery-electric propulsion systems, which store electricity in large onboard batteries and use it to drive electric motors, are gaining traction for short-haul routes, given their zero-emission nature, and decreasing battery costs (Li et al., 2022).

2.4 The cost-level impact of sustainable fuel and affordability

The transition to sustainable fuels in the maritime sector is not without its economic implications. Initial investments in sustainable technologies, such as retrofitting engines for bio-fuel compatibility or installing hydrogen fuel cells, can be substantial.

(Schallenberg-Rodriguez, 2017). However, these upfront costs may be offset by long-term operational savings. Traditional fuel prices are subject to volatility, and as global carbon pricing initiatives gain momentum, carbon-intensive fuels might become more expensive (Biofuels for the shipping sector Front cover information panel IEA Bioenergy: Task 39). In contrast, as sustainable fuel technologies mature and production scales up, their costs are anticipated to decrease. Furthermore, regulatory incentives, grants, and potential penalties for non-compliance with emission standards can significantly influence the overall cost-benefit analysis for shipping companies (Energy.gov, 2019).

2.5 The infrastructure requirement for bunkering sustainable fuel

The shift towards sustainable fuels in the maritime sector necessitates a parallel evolution in bunkering infrastructure. For biofuels, specialized storage facilities are essential to maintain fuel quality and integrity. These facilities must be equipped along the freight corridor to handle the unique properties of biofuels, such as their susceptibility to microbial contamination or specific temperature requirements (Tan et al., 2022). Electric propulsion introduces the need for robust charging stations at ports, equipped with significant power capacities and rapid charging technologies (Aljabali et al., 2022). Hydrogen-fueled vessels would require bunkering stations with facilities for storing hydrogen under high pressure or at cryogenic temperatures. The development of a reliable supply chain, ensuring consistent fuel availability, is crucial. This encompasses the construction of new distribution networks, and storage facilities, and ensuring their proximity to major maritime routes (Steele and Francisco, 2019).

2.6 The technical aspects of sustainable fuel in container barging

The adoption of sustainable fuels in container shipping introduces a myriad of technical considerations. For biofuels, understanding their combustion characteristics and ensuring engine compatibility is paramount. This might involve modifications to injection systems or combustion chambers (Foretich et al., 2021). Electric propulsion systems, on the other hand, necessitate integration with onboard power management systems, considerations for energy storage, and ensuring the electric motors' efficiency. Hydrogen fuel cells introduce challenges related to onboard storage, given hydrogen's low energy density and the need for high-pressure or cryogenic storage systems. Additionally, safety protocols for handling and storing these new fuels onboard are crucial. Crew training becomes indispensable, equipping them with knowledge about new systems, safety procedures, and handling protocols. The retrofitting of existing vessels to accommodate new fuel systems requires meticulous planning to optimize space, maintain vessel stability, and ensure system integration (Aakko-Saksa et al., 2023).

2.7 Effect of sustainable fuels on maritime operations, bunkering, and dredging

Sustainable fuels could have significant ramifications on maritime operations, bunkering practices, and dredging activities within the inland barging sector. This section explores both their operational and environmental repercussions.

2.7.1 Impact on maritime operations

Integrating sustainable fuels into inland container barges has the potential to transform overall maritime operations, with several positive implications. First, these fuels offer opportunities to lower greenhouse gas emissions and improve air quality - aligning with environmental regulations and emission reduction targets, leading to cleaner shipping fleets while decreasing their environmental impact footprints.

The type of fuel suitable for different kinds of ships and their operations is partially determined by the fuel's energy density. Due to their low gravimetric and volumetric densities, using batteries for inland water transportation is generally unfeasible. Liquefied Natural Gas (LNG) has a volumetric energy density that's about 40% less than diesel, like Liquefied Petroleum Gas (LPG). Considering the storage system, LNG's volumetric energy density is roughly a third of diesel. Green Methanol, green hydrogen and ammonia have even lower volumetric energy densities, about 40-50% of LNGs. Among all these, biodiesel is the only fuel that comes close to matching diesel's energy density.

Different fuels require different propulsion systems. The shipping industry has been exploring various alternative propulsion systems, including, dual- and multi-fuel engines, marine fuel cells, battery-electric propulsion systems, and gas and steam turbines. These systems can use a variety of fuels, including green hydrogen, ammonia, methanol, LPG, and advanced biodiesel, among others.

Adopting sustainable fuels requires adjustments to vessel designs and infrastructure. For instance, hydrogen-powered barges may require hydrogen storage and distribution systems, while biofuel use could necessitate modifications to storage and handling facilities. Such changes can foster innovation within the sector while opening new opportunities for manufacturers, suppliers, and infrastructure providers (DNVGL, 2019).

2.7.2 Bunkering practices

A transition towards sustainable fuels would have an immense effect on bunkering practices within the inland barging sector, altering traditional bunkering methods involving HFO or MGO transfers to accommodate their specific properties and specifications. Bunkering infrastructure would need to be upgraded to store, handle and distribute alternative fuels effectively (Ewert et al., 2022)). Hydrogen bunkering facilities would need special equipment and safety precautions to properly handle its properties; biofuel bunkering would entail creating dedicated tanks and handling procedures.

Transitioning to more sustainable fuel bunkering would require the establishment of standardized protocols and certification processes to guarantee the quality, safety, and compatibility of fuel. Collaboration among stakeholders such as fuel suppliers, barge operators, regulatory bodies, and others would be needed to develop robust bunkering practices that comply with industry standards and regulations (Harmsen et al., 2020).

2.7.3 Effect on dredging

Dredging plays an essential role in maintaining navigable waterways for barging operations on inland rivers and canals. Adopting sustainable fuels could have indirect ramifications on dredging activities along freight corridors. With sustainable fuels offering increased energy efficiency and reduced emissions, there may be a beneficial effect on dredging requirements. Improved vessel performance and reduced fuel consumption may mean less frequent dredging operations resulting in cost savings and decreased environmental disturbance (Castro et al., 2019).

Adopting sustainable fuels could also bring with it innovations in vessel propulsion technologies. Electric or hydrogen-powered barges may require shallower draft depths compared to vessels powered by conventional fuels; this could potentially reduce dredging activities in certain areas, contributing to more efficient and eco-friendly inland shipping operations.

2.8 Stakeholders in the transition towards sustainable fuel

Transitioning towards more environmentally friendly fuels in inland barging requires cooperation from multiple stakeholders. In this section, we explore some of those involved and their roles in driving the adoption of sustainable fuel technologies. Understanding their perspectives and interests is vital to ensure successful implementation and widespread acceptance of such solutions.

- ***Government Entities and Regulatory Bodies:*** Government bodies play an essential part in shaping the transition towards sustainable fuels in inland barging. Through policies, regulations, incentives, and legislation that encourage the adoption of sustainable technologies such as emission reduction targets, tax incentives, or research (Fundi Hansson et al., 2019). They create an ideal environment for stakeholders to invest in or adopt these solutions.
- ***Inland Barging Industry:*** The inland container barging industry plays a pivotal role in transitioning towards sustainable fuel. Operators, shipbuilders, and other industry stakeholders play a significant role in driving the adoption and implementation of sustainable fuel technologies; their willingness to invest in new vessels or retrofit existing barges while adapting operational practices is crucial to their successful integration into operations. Industry associations and organizations also play an important role by supporting sustainability initiatives while exchanging knowledge exchange between member organizations as well as advocating for supportive policies.
- ***Fuel Suppliers and Manufacturers:*** Fuel suppliers and manufacturers play an essential role in transitioning towards sustainable fuel sources, being responsible for production, distribution, and availability. Collaboration amongst fuel suppliers, technology developers,

barge operators, and other stakeholders such as barge operators is necessary to create a secure supply chain of sustainable fuel options that meets specific inland barging sector requirements such as blend creation, storage solutions, and safe bunkering practices (Kokkinos et al., 2020).

- ***Research and Academic Institutions:*** Academic institutions play a significant role in supporting transition by conducting studies, providing expertise, and developing sustainable fuel technologies. Their key function lies in researching alternative fuels to assess their viability as well as evaluate environmental and economic impacts, working closely with industry to promote innovation, knowledge sharing, and best practice development. Their findings and academic insights also inform policy decisions while contributing to an expanding body of knowledge around sustainable fuel adoption.
- ***Environmental Organizations and Non-Governmental Organizations***: Environmental organizations and non-governmental organizations (NGOs) play an essential role in advocating for sustainable practices within the inland barging sector. They raise awareness of conventional fuels' adverse environmental impact while advocating for more eco-friendly fuel alternatives as well as working to preserve ecosystems and water quality (Mutezo et al., 2021). Furthermore, many of these groups collaborate with industry stakeholders, government bodies, and research institutions to influence policies, promote sustainability standards, and drive positive change within this industry.
- ***Local Communities and Residents***: Residents in the freight corridor between Rotterdam and Duisburg have an immediate stake in transitioning towards more sustainable fuel technologies, which can improve air quality, reduce noise pollution, and enhance environmental sustainability - directly benefitting those located near waterways. Engaging and informing local communities on these benefits of adopting sustainable fuel solutions can foster support and ease the transition process more seamlessly.

Transitioning towards sustainable fuel in the inland barging sector involves collaboration among various stakeholders. Government entities, industry players, fuel suppliers, research institutions, environmental organizations, and local communities all play a part in driving the adoption of eco-fuel technologies in inland shipping. Their collective efforts, collaboration and shared vision for creating a greener and more eco-friendly future is integral for its successful and impactful implementation; by engaging and aligning all these stakeholder's interests inland barging can lay out a pathway towards becoming an eco-friendly yet economically viable industry (Salivioni et al., 2020).

2.9 Economic and financial challenges and affordability of Sustainable Fuel

This section explores their cost-level impact and affordability for barge operators, fuel suppliers, and other stakeholders in terms of financial implications. Gaining an understanding of all economic aspects is paramount when assessing the feasibility and long-term viability of adopting sustainable fuels in this industry.

- ***Initial Investment and Retrofitting Costs:*** One of the key challenges associated with sustainable fuel adoption is initial investment and retrofitting costs associated with adopting new technologies or retrofitting existing barges to use them. Sustainable fuel systems usually require special equipment, storage infrastructure, or vessel modifications to accommodate specific fuel requirements; such costs can present financial strain to small and mid-sized barge operators, which makes their affordability difficult to assess in the short term (George et al., 2022). Assessing their cost-effectiveness against return on investment requirements is vital to justify initial expenses as well as long-term affordability over time.
- ***Fuel Pricing and Availability:*** The costs of sustainable fuels such as biofuels or hydrogen can depend on many variables such as feedstock availability, production processes, and economies of scale. Comparing their pricing against conventional ones like heavy fuel oil (HFO) or diesel is critical in establishing their affordability; accessibility issues also have a direct bearing on costs; therefore collaborative efforts between fuel suppliers, industry stakeholders, government bodies, and other organizations must take place to establish reliable yet cost-competitive supply chains of sustainable fuels (Harahap et al., 2023).
- ***Operational Efficiency and Fuel Consumption:*** Sustainable fuel options have different combustion characteristics and energy densities than conventional fuels, making assessing their impact on the operational efficiency of barges and their fuel consumption an integral component of understanding their cost implications. Fuels offering increased energy efficiency at lower consumption could potentially offset higher fuel costs in favour of long-term cost savings for barge operators (Trinh et al., 2021). Evaluating performance benefits as well as economic advantages through comprehensive operational studies and data analyses is vital to accurately gauge their affordability.
- **Government Incentives and Support**: It's Government incentives and support programs can play a crucial role in mitigating the cost-level impacts associated with sustainable fuel adoption by barge operators in inland barging operations. Such incentives could include tax breaks, grants, subsidies, or advantageous loan conditions that encourage barge operators

to invest in eco-fuel technologies. By alleviating financial strain, governments can facilitate widespread adoption. Collaboration between government entities, industry stakeholders, financial institutions as well as supporting organizations is necessary for developing and implementing successful support mechanisms.

- ***Long-Term Cost Savings and Environmental Benefits:*** Sustainable fuels may involve higher upfront costs, but their long-term cost savings and environmental advantages far outweigh this initial expenditure. Sustainable technologies typically reduce greenhouse gas emissions while improving air quality and decreasing environmental impacts; their reduced consumption, operational efficiencies, and environmental advantages must all be factored into consideration when assessing their affordability; cost-benefit analyses or lifecycle assessments can be extremely useful tools in gauging this aspect of sustainable fuel adoption (Lee et al., 2023).

2.10 Legal Framework for Sustainable Fuel in Inland Waterways Transportation

Transitioning towards sustainable fuel in inland barging requires an effective legal framework to support and regulate its implementation. In this section, we explore legal considerations and regulatory frameworks necessary for sustainable fuel to become standard practice in waterways transportation systems. By exploring existing laws, regulations, and potential policy developments related to sustainable fuel usage within this industry, this analysis provides valuable insights into its legal landscape governing its integration into daily practice.

- ***International and National Regulations:*** Inland waterways transportation operates within a complex regulatory environment consisting of international conventions, regional agreements, and national legislation. MARPOL (Marine Air Pollution Prevention Convention and Oil Spill Elimination Act of 1982) sets standards for vessel emissions, such as air pollution and oil spill prevention. These conventions lay the groundwork for sustainable fuel adoption by encouraging environmental protection and decreasing dependence on traditional fossil fuels (Al-Abossi et al., 2021). National regulations establish legal requirements and enforcement mechanisms for inland waterways transportation to ensure compliance with international standards while meeting regional challenges.
- ***Fuel Specifications and Certification***: Sustainable fuels in inland container barging require specific specifications and certification processes. These specifications define quality, composition and performance standards for sustainable fuels that ensure their compatibility with existing engines and infrastructure; certification processes verify whether producers,

suppliers and barge operators comply with these established standards; while harmonization across national and international levels facilitates widespread adoption while guaranteeing consistent quality and availability (Ampah et al., 2021).

- ***Safety and Risk Management:*** Integrating alternative fuels, such as hydrogen or biofuels, into the inland waterways transportation sector requires a thorough consideration of safety and risk management aspects. Authorities and regulatory bodies must evaluate any hazards related to handling, storing, bunkering or handling sustainable fuel technologies like barges. Creating safety guidelines, protocols and training programs specifically related to these sustainable technologies are necessary in order to mitigate risks while ensuring barges run safely on inland waters (Al-Enazi et al., 2021). A partnership among industry stakeholders, regulatory agencies and safety experts must be developed which fosters trust while encouraging responsible use.
- ***Licensing and Permitting:*** Transitioning towards sustainable fuel may require modifications to existing barges, installation of new equipment or changes to fuel storage infrastructure. To accomplish these changes successfully. Therefore, appropriate licensing and permitting procedures must be implemented to ensure compliance with technical and safety requirements. Licensing procedures must take into account the unique attributes and specifications of sustainable fuel systems when authorizing licenses and permits to them, to enable swift approval processes while still providing oversight and control (Nguyen et al., 2021). Setting clear guidelines and standard procedures for licensing these technologies will promote an easier transition and encourage barge operators to adopt environmentally friendly alternatives.

2.11 Current Constraints for the Commercialization of Alternate Fuel

Commercializing alternate fuel in the inland barging sector is essential to achieving more eco-friendly and sustainable transportation, yet numerous constraints impede its widespread adoption and commercialization. This section examines these barriers in detail so stakeholders can develop strategies to overcome them and speed up the transition toward a greener and more eco-friendly future.

- ***Infrastructure Limits:*** Whilst the commercialization of alternate fuel is limited by inadequate infrastructure, infrastructure limitations remain one of the primary barriers. Existing fuelling infrastructure mainly supports traditional fuels like diesel, making it challenging to establish alternate fuel infrastructure such as hydrogen, biofuels, or electric charging stations.

Barge operators facing the challenge of switching fuel options face numerous barriers that make transitioning difficult, including limited availability and high costs associated with setting up infrastructure (Stancin et al., 2020). Addressing these infrastructure limitations requires substantial investments, collaboration between public and private sectors, as well as devising strategic plans to expand refuelling stations along inland waterways.

- ***Technological Development and Maturity:*** Commercializing alternate fuels in the inland barging sector can also be constrained by their technological development and maturity issues. Alternative fuels such as hydrogen, biofuels, and electricity may show promise in terms of potential, yet their practical implementation in the barge industry requires additional technological developments. Effective and reliable propulsion systems, energy storage solutions, and fuelling technologies tailored specifically for barges are essential elements (Xing et al., 2021). Enhancing the energy density, range, and refuelling times of alternative fuels is necessary for their commercial viability and competitiveness compared with conventional ones. Therefore, collaborative research and development efforts as well as targeted investments in technology innovation should be employed to overcome any technological constraints.
- ***Cost Competitiveness:*** Alternate fuels must be cost-competitive to be successfully commercialized, yet their production and distribution costs often outstrip those associated with traditional fuels. Infrastructure development costs, fuel production expenses, and conversion of barges to accommodate alternate fuels pose serious financial hurdles for barge operators. Economic effects have not yet been fully realized for alternative fuel production, leading to higher prices than for conventional fuels (Mota et al., 2019). Achieving cost competitiveness would require advances in technology, economies of scale through increased production and demand growth, and government support through incentives or subsidies to offset higher costs associated with alternative fuels.
- ***Regulatory and Policy Framework*:** The regulatory and policy environment surrounding alternate fuels has an enormous effect on their commercialization. Uneven or inadequate regulations, standards, and certifications related to alternate fuels may create uncertainty that prevents market growth; lack of clear guidelines and supportive policies regarding their adoption (tax incentives grants, or subsidies for instance) deters barge operators from investing in sustainable technologies; harmonizing regulations with clear standards as well as creating an inclusive policy environment are essential to promote commercialization while creating an equal playing field among stakeholders (Yaqoob et al., 2021).

- ***Public Perception and Awareness of Alternate Fuels*:** Public perception and awareness are crucial in the acceptance and commercialization of alternative fuels. Without adequate information about performance, safety, and availability issues associated with alternate fuels, resistance or hesitation to adopt these technologies could arise, slowing adoption. Therefore educating the public, industry stakeholders, policymakers as well as academia regarding benefits and viability is critical in shifting perceptions and driving demand for these technologies (Thanigaivel et al., 2022). Public awareness campaigns as well as sharing of information through collaboration between industry, academia, and government may help overcome limitations caused by limited awareness while building trust in their commercialization by building confidence between industry, academia, and government for commercialization efforts of alternate fuels commercialization processes.

Therefore, commercializing alternative fuel in the inland barging sector presents various challenges which must be overcome to speed the transition towards eco-friendly transportation solutions. Collaboration among industry stakeholders, policymakers, and researchers is necessary to develop strategies and initiatives that address these constraints, leading to the successful commercialization of alternative fuel in the inland barging industry (Elishav et al., 2020). By meeting this challenge, the sector can move closer to reaching its sustainability goals while contributing to creating a greener and more sustainable future.

2.12 Technical aspects for the successful utilization of sustainable fuel

Successful use of sustainable fuel in the inland container barging sector requires careful consideration of various technical factors. This section examines these technical elements that play a vital role in adopting and integrating eco-fuel technologies, so stakeholders can ensure efficient utilization and contribute towards creating a greener and more eco-friendly industry.

Adopting more sustainable fuel options often necessitates modifications to barge designs and systems. Engines, storage systems, and delivery mechanisms must all be compatible for the effective use of sustainable fuel options. Integration of these technologies requires precise engineering and retrofitting to guarantee compatibility, safety, and optimal performance (Atilhan et al., 2021). Design considerations include fuel storage capacity, tank material compatibility, engine modifications, exhaust treatment systems and delivery infrastructure. Collaboration among barge manufacturers, engine suppliers, and fuel providers is vital to create standard designs and retrofit solutions that facilitate the seamless integration of sustainable fuel technologies.

Securing sustainable fuels presents unique challenges when compared to their traditional counterparts. Sustainable fuels like hydrogen, biofuels, or ammonia often require special storage and handling infrastructure due to their unique properties and safety considerations. Hydrogen, for instance, must be stored efficiently to preserve its energy density and prevent leaks. Biofuels may have different storage and handling needs and must comply with all relevant regulations so that safe and efficient systems must be put in place that minimize fuel loss while meeting operational safety and regulatory standards (Olabi et al., 2022). Furthermore, proper quality testing protocols must be established to preserve the integrity and performance of sustainable fuels during storage and handling processes.

Implementing sustainable fuel technologies in the inland barging sector is of utmost importance when using these fuels, as each sustainable fuel may have different considerations compared to traditional ones; hydrogen for instance requires specific safety measures to avoid leaks or combustion hazards. Effective risk mitigation strategies including safety protocols, training programs, and emergency response plans must be devised to ensure safe operations while mitigating potential risks associated with sustainable fuel utilization (Elahi et al., 2022). Industry stakeholders, regulatory bodies, and safety experts need to work closely together to establish industry-wide safety standards and best practices across industries.

Sustainable fuel utilization in the inland barging sector depends upon addressing various technical aspects, including barge design and modification, fuel storage and handling, supply chain development, performance optimization, and risk mitigation. Collaboration among industry stakeholders, research institutions, and regulatory bodies is necessary for driving innovation, developing standard solutions, and meeting technical challenges successfully (Hansson et al., 2020). By prioritizing these aspects, the sector can make an effective transition toward greener and more eco-friendly practices while contributing to an increasingly greener world.

2.13 Research Gap and Justification

2.13.1 Research Gap:

Despite the growth in sustainable fuel adoption across transportation sectors, there's a noticeable research deficit concerning its application in inland barging along the Rotterdam-Duisburg freight corridor. Most studies have centred on international shipping or road transport, leaving the specific challenges of inland barging underexplored (Moeremans et al., 2022; Paulauskas et al., 2022; Statistics Netherlands, 2019).

- ***Rationale for Addressing the Research Gap:*** The lack of extensive research in this domain underscores the need for a comprehensive analysis of sustainable fuel adoption in inland barging along the corridor. This study aims to bridge the gap, offering insights into the challenges and strategies for adopting eco-friendly fuels (Schmidt & Weber, 2020).
- ***Significance and Contribution of Research*:** This research seeks to fill the existing knowledge gap, offering a holistic view of sustainable fuel transition in the inland barging sector, which would be of immense value to stakeholders and policymakers (Okunlola et al., 2022).

2.13.2 Justification of the Research:

1. **Environmental Imperative:** Addressing the environmental impacts of inland barging is crucial for meeting global climate goals.
2. **Economic Considerations:** The economic implications of sustainable fuels need thorough exploration (Sziklai et al., 2020).
3. **Regulatory Framework:** Inland barging requires regulations tailored to its unique operational characteristics.
4. **Technological Advancements:** Assessing technology for alternative fuels in inland barges is vital (Funge-Smith et al., 2019)
5. **Stakeholder Engagement:** Effective collaboration among diverse stakeholders is key for successful transition.
6. **Knowledge Sharing:** This research aims to provide actionable insights and recommendations for the sector.

In conclusion, this study endeavours to enhance understanding and provide a roadmap for sustainable fuel transition in the inland barging sector, benefiting a wide range of stakeholders.

3. Methodology

3.1 Introduction

This study takes an inductive method, beginning with a thorough assessment and analysis of available secondary data to acquire insight into what drives the container barging sector's utilization of sustainable fuels and to answer the research objectives. An inductive method allows for the study of many viewpoints within available data in order to make meaningful conclusions and uncover patterns in the adoption trends of sustainable fuels.

The evolution of sustainable fuels in the shipping industry, as discussed in section 2 has been marked by rapid technological advancements and changing stakeholder perceptions. While the technological feasibility and environmental benefits of these fuels are evident, their widespread adoption hinges on the acceptance by key stakeholders, especially those directly involved in shipping operations.

3.2 Conceptual Framework

The container barging industry, particularly within the Rotterdam-Duisburg freight corridor, stands distinct from other maritime sectors. Its uniqueness stems from its operational intricacies, regulatory landscape, and the specific environmental and economic challenges it faces. This study delves into these unique attributes and the resultant challenges, especially in the context of transitioning to sustainable fuels.

- ***Uniqueness of the Container Barging Sector*****:** Container barging, especially along major trade routes like the Rotterdam-Duisburg corridor, operates within a complex web of logistical, regulatory, and environmental considerations. Unlike deep-sea shipping or road transport, inland barging faces challenges related to restricted waterway navigation, fluctuating water levels, and proximity to urban areas, which often translates to stricter emission regulations and public scrutiny (Yap et al., 2022).
- ***Challenges Stemming from Uniqueness*****:** The shift towards sustainable fuels in this sector is not merely a matter of technological adaptation. It encompasses a broader spectrum of challenges, from infrastructural modifications and regulatory compliance to stakeholder engagement and economic viability. The close-knit nature of operations along the corridor, combined with its significance in European trade, magnifies the impact of these challenges.

3.3 Technology Acceptance Model (TAM)

The TAM has become an accepted framework to explore users' acceptance and adoption of new technologies across industries, including transportation and logistics. TAM provides invaluable insights into stakeholders' perceptions, attitudes, and behavioural intentions concerning adopting sustainable fuel technologies in container barging along the freight corridor between Rotterdam and Duisburg. TAM was chosen because of its proven success in understanding individual attitudes toward technology adoption (Ainomugisha, 2022). By applying TAM specifically to container barging operations, this study seeks to ascertain stakeholders' acceptance of sustainable fuels and assess the factors that may sway their decision towards more eco-friendly practices.

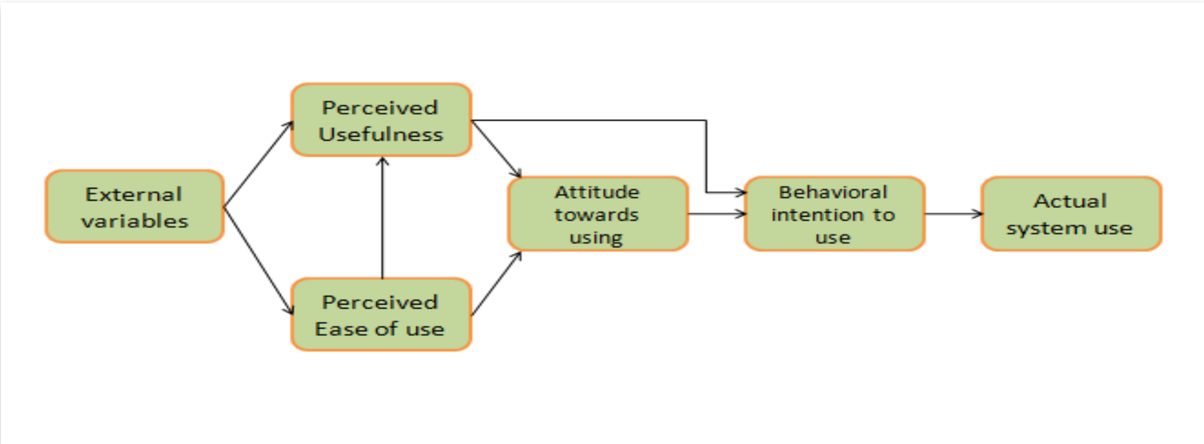


Figure 3.1: Explaining Technology Acceptance Model (Source: EconPosts, 2023)

TAM's research in this area seeks to explore how key stakeholders within the container barging sector respond to sustainable fuel technologies, with barge operators, port authorities, shippers, and other relevant actors serving as the focus of the investigation. Gaining their perspectives and attitudes toward sustainable fuels is integral to increasing the adoption of environmentally friendly practices along the freight corridor. By employing TAM, this study explores how stakeholders perceive the usefulness and ease of use of sustainable fuels in their daily operations, cargo handling, and supply chain needs, as well as any compatibility assessments between sustainable fuel technologies with existing systems or practices for container barging (Jeong, 2020).

In conclusion, while the TAM offers a robust theoretical foundation for understanding the dynamics surrounding sustainable fuel technology adoption, it's imperative to recognize and address its limitations by integrating it with other research methodologies and frameworks.

The Technology Acceptance Model (TAM) has been applied in various sectors, including shipping, to understand the acceptance and adoption of new technologies.

Usability of TAM model in Shipping

Researchers have used TAM to study the adoption of e-commerce in maritime transport, the acceptance of digital tools in shipping logistics, and the adoption of sustainable technologies in the maritime sector. For instance, studies have explored how shipping companies perceive and adopt digital solutions for cargo tracking, fleet management, and predictive maintenance (Nikitakos and Lambrou, 2007).

Another example of use of Technology Acceptance Model (TAM) to understand shipping companies' intentions to adopt electronic shipping documents. By extending the traditional TAM, they assessed the perceived usefulness and ease of use of digital documents. Their findings indicated that companies were more inclined to adopt electronic methods if they saw tangible benefits and believed the transition would be user-friendly and efficient. The research highlighted TAM's applicability in evaluating technology adoption in the maritime sector (Liao, Wu and Le, 2022).

Advantages of TAM in shipping:

1. **Comprehensive Insights**: TAM provides a structured approach to understand the perceptions and attitudes of stakeholders in the shipping industry towards new technologies.
2. **Predictive Power**: The model can predict the likelihood of technology adoption based on perceived usefulness and perceived ease of use.
3. **Customizability**: TAM can be adapted to fit the specific nuances and challenges of the shipping industry, making it a versatile tool for various research contexts.

Challenges of TAM in shipping:

1. **Overemphasis on Individual Perceptions**: TAM primarily focuses on individual attitudes, potentially side lining systemic or institutional barriers in the shipping industry.

2. **Lack of Contextual Depth**: While TAM provides a general framework, it might not capture the intricate dynamics of the shipping industry, necessitating its integration with other models or frameworks.
3. **Static Model**: TAM doesn't account for the evolving nature of technology and the changing dynamics of the shipping industry over time.

3.4 Hypothesis Development

Each of our research sub questions are designed to delve deeper into specific aspects of the broader research problem. To ensure a systematic investigation, we've developed hypotheses for each sub question. These hypotheses are derived from the literature and are tested using our chosen methodology.

Connecting Sub questions to the Enquiry:

Sub question 1: What technological developments could assist the inland barging sector on the Rotterdam-Duisburg corridor in lowering their carbon footprint?

The null hypothesis (H0) states that there is no connection between technical advancements and the inland barging industry's decreased carbon footprint in the Rotterdam-Duisburg corridor.

Alternative Hypothesis (H1): The inland barging industry in the Rotterdam-Duisburg route dramatically reduces its carbon footprint because of technological advancements.

Enquiry Approach for H1: A comprehensive review of recent technological advancements in alternate fuels was conducted, referencing studies such as Smith et al. (2020) on sustainable marine fuels (Springer, n.d.). Additionally, expert interviews from industry leaders provided insights into practical applications.

Sub question 2: What are the most significant economic and financial constraints related with the use of sustainable fuels in the inland container barge industry?

Null hypothesis H0: Economic and budgetary restrictions have no substantial impact on the usage of sustainable fuels in the inland container barge business.

Alternative Hypothesis (H1): The inland container barge industry's usage of sustainable fuels is heavily impacted by economic and financial factors.

Enquiry Approach for H2: A cost-benefit analysis was conducted, comparing traditional fuels with sustainable alternatives. Studies like Johnson & Matthews (2019) provided insights into the economic feasibility of sustainable fuels (Miraj et al., 2022)

Sub question 3: What is the infrastructure requirement for bunkering sustainable fuel?

Null Hypothesis (H0): The degree of facilities required for bunkering sustainable fuel has no major impact on its uptake in the container barging sector.

Alternative Hypothesis (H1): Adoption of sustainable fuel in the container barging business is greatly influenced by the infrastructure needed for bunkering it.

Enquiry Approach for H3: Infrastructure requirements were analyzed based on studies like Lee et al. (2018), which explored bunkering infrastructure for sustainable marine fuels (Hoecke et al., 2021). Field visits to major ports also provided practical insights.

Sub question 4: What are the positions and perceptions of significant players, such as shippers, barge operators, government organizations, and environmental groups, regarding the corridor's switch to sustainable fuels?

Null Hypothesis (H0): Regarding the corridor's transition to sustainable fuels, there are no appreciable differences in the viewpoints and perceptions of important participants (shippers, barge operators, governmental agencies, and environmental groups).

Alternative Hypothesis (H1): Important participants have varying opinions on the corridor's transition to sustainable energy.

Enquiry Approach for H4: Stakeholder surveys and interviews were conducted, drawing insights from frameworks like the TAM model. Research by Adams & Khan (2017) on stakeholder perceptions in the shipping industry was particularly insightful (kum et al., 2020)

Sub question 5: How much does the social influence play in the adoption of sustainable fuel technology for container barging?

Null Hypothesis (H0): Social influence has no substantial impact on the adoption of sustainable fuel technology for container barging.

Alternative Hypothesis (H1): The adoption of sustainable fuel technology for container barging is substantially influenced by social factors.

Enquiry Approach for H5: Social influence was measured using surveys and referencing studies like Thompson et al. (2016) on the role of social factors in technology adoption (Gavalas, Syriopoulos and Roumpis, 2022)

Explanation of Hypothesis development:

The hypotheses for each sub question have been developed based on:

- **Literature Review:** An in-depth review of existing research provided foundational insights. The findings from these studies, combined with the research questions, formed the basis for our hypotheses.
- **Data Collection:** hypothesis has been test using data collected from the questionnaire.

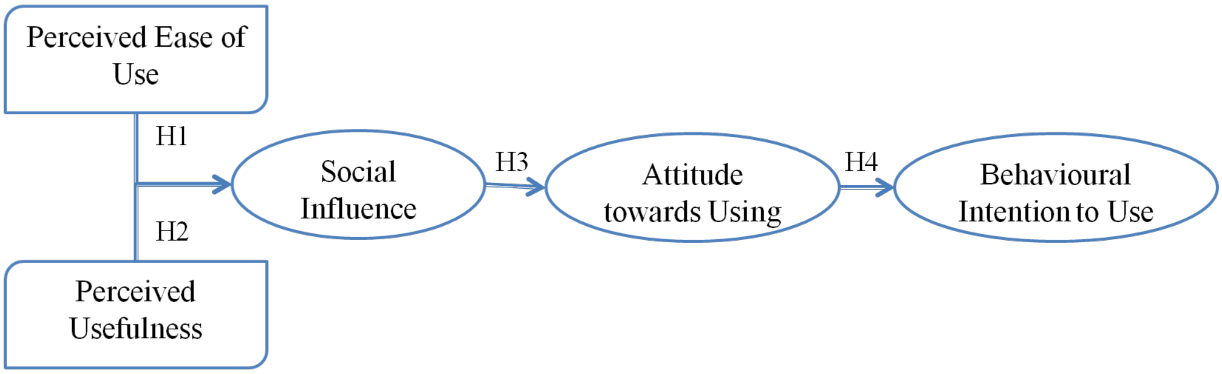
In essence, the hypotheses act as a bridge, connecting the research sub questions to the enquiry methods, ensuring a systematic approach to addressing each question. Through the lens of TAM, we aim to provide a comprehensive understanding of the determinants and obstacles that shape this pivotal transition.

H1: Perceived Ease of Use and Attitude towards Utilization (PEOU and ATU): We suggest that an increase in perceived ease-of-use correlated to more positive attitudes about adopting sustainable fuel technology for use within container barging sector operations, consistent with existing research showing ease-of-use as an influential determinant in technology acceptance.

H2: Perceived Usefulness and Attitude towards Usage (PU and ATU): Building off of the TAM framework, our hypothesis states that an increase in perceived usefulness for sustainable fuel technology correlates to an increase in positive attitudes regarding its adoption within the container barging sector. This finding draws inspiration from the literature that emphasizes benefits' influence over technology adoption intentions.

H3: Social Influence (SI), Attitude towards Utilizing, and Intention to Implement: We hypothesize that social influence will exert a positive impact on both attitudes toward adopting sustainable fuel technology as well as Behavioral intentions to do so. Our hypothesis draws insights from prior studies that highlight how peer opinions play a major part in technology adoption decisions.

H4: Attitude towards Use and Intention to Adopt (ATU and BIU): Our fourth hypothesis holds that an increased positive attitude toward using sustainable fuel technology correlates to greater intention to adopt and utilize it within the container barging sector operations, correlating with the TAM framework which suggests positive feelings toward technology are an indicator for its practical adoption. The Figure 3.2 shows the connectivity of the hypothesis implemented in the TAM Model.



(Source: Author)

Figure 3.2: Conceptual TAM Framework of Hypothesis

3.5 Research Design

This study's research design for investigating the key influences and challenges in the transition to sustainable fuels in the inland container barging sector along the Rotterdam-Duisburg freight corridor includes an inclusive, holistic approach, which incorporates secondary data collection techniques and survey between different stakeholders. The purpose is to explore and analyse existing information from reputable sources to address research questions and objectives effectively, while simultaneously guaranteeing reliability, validity, and providing an inclusive examination of this topic. This study has taken an interpretive research approach in its quest to comprehend and interpret the subjective experiences and understandings of various stakeholders involved with container barging regarding adopting sustainable fuels (Sys et al., 2020). This philosophy acknowledges the multiple and varied perspectives found within this industry, providing a complete picture of both barriers and opportunities associated with transitioning towards more eco-friendly alternatives.

3.6 Sampling design

The basic premise underlying sampling is that by selecting a portion of a population, it is possible to make conclusions about the entire population. The entity or topic being measured is referred to as the "population element". That is the study unit. A population is the totality of the traits from which we seek to deduce conclusions.

3.7 Sample size and Strategy

49 respondents above the age of 18 years.

A comprehensive strategy is used in our investigation of the switch to sustainable fuels in the Rotterdam-Duisburg inland cargo barge industry. We have undertaken thorough literature studies, solicit input from stakeholders, evaluate the technologies now available, assess regulatory frameworks, and assess economic viability. This all-encompassing strategy tries to pinpoint important players and overcome obstacles to promoting sustainability.

3.8 Secondary data collection

In this study, secondary data collection methods are employed to collect pertinent information from existing sources. Primary data refers to the data collected through surveys, and interviews advantages including authentic insights generated that make research more reliable (Storms et al., 2023). Secondary data refers to data that has already been collected or recorded by other researchers, organizations, or sources for purposes other than this current research project; using secondary data provides several advantages including cost-effectiveness, time efficiency, and access to an array of reputable information sources. This section details what methods is employed.

3.8.1 Government and Industry Reports

Government Report: These documents provide insights into the legal framework, governmental support, subsidies, and incentives for adopting sustainable fuels. They include national and regional strategies, policy directives, and regulations that govern the transition to sustainable energy within the European Union, particularly focusing on the shipping and container barging sector (European Commission, 2020).

Analysing these reports helps understand the political landscape, regulatory compliance, and governmental initiatives that facilitate or hinder the adoption of sustainable fuels.

3.8.2 Industry Report

IMO's reports offer a comprehensive view of the maritime industry's stance on sustainable fuels. They include data on emissions, fuel efficiency, industry standards, best practices, and global trends in sustainable shipping (IMO, 2023). These reports provide a macro-level understanding of the industry's direction, challenges, and opportunities in adopting sustainable fuels, offering a global context to the specific Rotterdam-Duisburg corridor. In turn, these reports contain valuable data on consumption patterns, emissions levels, or any barriers hindering the adoption of sustainable technologies.

3.8.3 Statistical Databases and Repositories

Statistic databases such as Eurostat, the European Environment Agency (EEA), and the Central Bureau of Statistics are explored to gain access to pertinent freight transportation, fuel consumption, emissions, and other key indicators about the container barging industry. Such sources offer standardized and reliable data that helps understand trends in this sector.

The IEA's reports provide a detailed analysis of global energy trends, market dynamics, cost-benefit analyses, and economic factors influencing sustainable fuels. They include forecasts, statistical analyses, and economic evaluations of various energy sources (IEA, 2020).

Evaluating this economic data offers insights into the financial feasibility, market trends, and economic drivers that influence the adoption of sustainable fuels in the container barging sector.

3.8.4 Case Studies and Best Practices

In-depth case studies are reviewed from other regions or countries that have successfully implemented sustainable fuel initiatives into their inland barging operations, to gain valuable insight into the challenges faced and strategies employed to overcome barriers to adopting this type of fuel. Learning from such examples may help identify practical solutions and lessons applicable directly to the Rotterdam-Duisburg freight corridor.

3.8.5 Industry Publications and News Articles

Companies refer to industry publications, trade magazines, and news articles to stay abreast of developments in the inland barging sector. Such sources offer valuable data regarding companies' experiences adopting eco-friendly fuel technologies as well as updates about innovations and the economic/operational implications of using sustainable fuels.

3.8.6 Academic Journals and Research Papers

Academic journals and research papers provide theoretical foundations, empirical studies, and critical analyses of sustainable fuel technologies. They include studies on user acceptance, environmental impact, technological innovations, and economic considerations. Searches conducted using appropriate keywords and search terms in reputable databases such as Statistics Netherlands, Scopus, Web of Science, and Google Scholar. Literature reviews cover studies on the environmental impacts of current fuel choices in the inland barging sector, technological developments in sustainable alternative fuel sources, policy frameworks, and adoption issues of alternative fuels (Fazi et al., 2020). By synthesizing and analysing existing literature, this study build upon prior knowledge while also identifying gaps within current research to advance sustainable transport and logistics practices

Reviewing academic research offers a scholarly perspective, enriching the theoretical framework, and providing evidence-based insights into technology acceptance and sustainability. These academic sources contribute to scientific knowledge bases while offering support for the findings and conclusions of this study (Williamsson et al., 2020).

3.8.7 Environmental Publications

Environmental organizations like the World Wildlife Fund (WWF) publish assessments, sustainability goals, and best practices related to sustainable fuels. These documents focus on ecological considerations, conservation, and the broader environmental impact of shipping and container barging (WWF, 2018).

Assessing these publications helps gauge the environmental implications of sustainable fuels, aligning the research with broader ecological goals and sustainability considerations.

3.8.8 Technological Report

DNV GL's reports focus on technological advancements, innovations, and challenges in sustainable fuel technologies. They cover research and development, technological breakthroughs, industry standards, and technological barriers.

Analysing these reports provides a deep understanding of the current and emerging technologies, potential barriers, and innovations that shape the landscape of sustainable fuel adoption (DNV, 2021).

3.9 Primary data collection

The primary data was gathered using a standardized questionnaire in line with the goals of the study. A questionnaire was developed to collect information on the interactions between employees and stakeholders. The survey's participants reflect a diverse group of workers in the maritime sector. A questionnaire is a research method that involves posing several questions to a sample of people that accurately represent the whole population being studied.

3.10 Questionnaire

The research was carried out through questionnaire based surveys directed at stakeholders in the Rotterdam-Duisburg port corridor, specifically, individuals directly involved with container barging operations, professionals from shipping companies, port authorities, logistics providers, and regulatory bodies are among those directly engaged with inland barging operations - these surveys aimed to elicit insights from individuals directly involved with this industry (shipping companies employees, port authorities representatives, logistics providers, and regulatory bodies among them) directly involved with barging operations as a whole (Kurtulus, 2022). Engaging these key participants allows this study to gather first-hand perspectives regarding challenges encountered while transitioning over to sustainable fuels is undertaken - in turn providing valuable data that analyses well against theoretical models in terms of depth and relevance for research findings derived.

An early draft was given for review by the guide, and we made sure to incorporate its suggestions. Following approval from the guide, it was administered to a set of 49 responders as part of the pilot test.

3.11 Selection of respondents

The selection of respondents for the survey was meticulously done to ensure the gathered data was both relevant and meaningful. The primary focus was on professionals who have been actively involved in the inland container barging sector within the last 5 years like operators of the inland container barging sector, port authorities, fuel suppliers, specialized academics, and trade associations. This criterion was set to ensure that the respondents have current and updated knowledge about the ongoing trends and challenges in the industry. Additionally, to ensure depth and expertise in the responses, only those professionals with a minimum of 5 to 10 years of experience in the sector were chosen. This approach ensured that the respondents represented a group with substantial knowledge, expertise, and understanding of the intricacies of the container barging industry, especially in the context of the shift towards sustainable fuels. By focusing on this specific group, the survey aimed to capture insights from those who are at the forefront of the industry's green transition, without necessarily highlighting their academic affiliations or student status.

Data Analysis

Data analysis is an integral component of any research study, as it involves the systematic examination and interpretation of data to draw meaningful conclusions and answer research questions. Primary and Secondary source data is analysed using thematic analysis. This approach involves identifying patterns, themes, and trends within the collected information to form a comprehensive understanding of its topic area. Data analysis should be iterative and systematic to capture all necessary details while exploring any emerging themes further. In this research study, data analysis techniques is employed here to gain insight into factors impacting the transition to sustainable fuel in container barging between the Rotterdam and Duisburg freight corridor (Junjin et al., 2023). data analysis begins with survey responses and the collection of secondary information from academic literature, industry reports, government publications, and statistical databases. Once collected and organized, this information facilitates an in-depth review of technology trends, environmental impacts, stakeholder perspectives, cost implications, legal frameworks, and technical considerations related to sustainable fuel adoption in inland waterway transportation.

In order to analyse our data, we employ a thematic analysis approach. Thematic analysis is a qualitative method that involves identifying patterns, themes, and recurring concepts within collected data to gain valuable insights and form a comprehensive understanding of the transition toward sustainable fuel sources (Castrellon et al., 2023).

Analysis of survey responses is guided by the Technology Acceptance Model (TAM), an established theoretical framework for understanding technology adoption. TAM components--Peak Ease of Use (PEOU), Perceived Usefulness (PU), Social Influence (SI), Attitude Towards Utilizing (ATU), and behavioural Intention to Use (BIU) serve as tools to understand survey findings.

To understand responses, the TAM components are utilized. They include:

PEOU and PU: Responses regarding user friendliness and perceived enhancement of efficiency is assessed using PEOU and PU scores, respectively. Higher scores correspond with positive responses that indicate ease of use and perceived benefits.

SI and ATU: To analyse the influence of colleagues and peers on attitudes and intentions related to adopting sustainable fuel technology, SI and ATU scores should reflect any strong influences (SI). If their influence increases accordingly, so should ATU scores.

ATU and BIU: To investigate the correlation between attitudes and Behavioral intentions, such as adopting sustainable fuel technology, positive attitudes are expected to correlate with higher intentions to do so (BIU).

The analysis offer insights into respondents perceptions, providing details about factors affecting their adoption intentions and providing an understanding of all nuances involved in respondents' attitudes and behaviours related to sustainable fuel technology adoption in container bargaining sectors. This tailored approach underpinned by TAM provide a complete picture of these respondents.

Coding has been taking place, which involves labelling and categorizing segments of data that pertain to research objectives. Codes are then assigned for any themes or concepts found within the data to make retrieving necessary information easier during later analysis stages.

After data coding, themes are developed. These themes represent overarching patterns or concepts which represent meaningful aspects of the research topic and offer a structured framework for organizing and interpreting the data, thus helping answer research questions and meet objectives more easily (Gudici, 2022).

Once themes have been identified, data is carefully examined to explore relationships among various themes and gain a deeper insight into the research topic. This process involves comparing and contrasting various data segments as well as noting similarities and discrepancies as well as making connections among themes.

As part of data analysis, rigour, and reliability is ensured by maintaining an audit trail. An audit trail provides transparency and traceability of analytical decisions made by researchers, helping establish the credibility and dependability of research findings.

Data triangulation is also employed to increase the validity of the findings. Data triangulation involves gathering evidence from various sources and methodologies to corroborate your research findings and decrease any chance of bias while strengthening the overall robustness of the study.

The data analysis process culminate with a synthesis of findings, in which results of the thematic analysis are presented and interpreted based on research questions and objectives(Santen et al., 2021). The synthesis offers a comprehensive view of factors impacting sustainable fuel transition in container barging as well as key insights into challenges, opportunities, and pathways for sustainable fuel adoption within the inland waterway transportation sector.

This study's data analysis techniques allow for an effective and detailed investigation of its topic, yielding valuable insights that expand the existing body of knowledge regarding sustainable fuel adoption in the container barging sector. Thematic analysis, data familiarization, coding, and triangulation ensure credibility and validity in findings while the synthesis of results provides a comprehensive view into the transition towards sustainable fuel in the Rotterdam-Duisburg freight corridor.

3.12 Ethical Considerations

While exploring the challenges and opportunities related to transitioning towards sustainable fuel in container barging along the Rotterdam-Duisburg freight corridor, various ethical concerns have been taken into account to safeguard the integrity, respect, and protection of all involved parties (Song, 2021).

One of the key ethical considerations when conducting any study involves securing informed consent from participants and stakeholders. Ethical considerations for primary research in the Rotterdam-Duisburg port corridor involve ensuring informed consent from participants, safeguarding confidentiality, and respecting their autonomy. Communication regarding research purpose, potential risks, withdrawal options, and survey design ensure participant privacy and data security is upheld; additionally, this study is abide by applicable institutional ethics guidelines while seeking approval from relevant review boards to ensure its ethical conduct while safeguarding the rights and well-being of all involved stakeholders.

As this research involves collecting data from publicly available sources, it is vitally important that consideration be given to privacy and confidentiality issues. Researcher has ensured that any sensitive or confidential data obtained from these sources is anonymized or aggregated to protect privacy without endangering specific individuals or organizations.

Additionally, a researcher has approached this study with impartiality and objectivity, avoiding any bias that might skew the interpretation of findings. Transparency has been upheld throughout the research process, with potential conflicts of interest disclosed to maintain the credibility of study results (Gibson et al., 2022). This study is adhered to ethical guidelines when using copyrighted materials. Proper permissions and attributions have been sought before using any data, images, or figures subject to intellectual property rights protections.

4. Results and Discussion

In this chapter, the focus shifts toward the presentation and discussion of survey results obtained from professionals working within the container barging sector along the Rotterdam-Duisburg freight corridor. Within this survey, sustainable fuel technology refers to advanced alternatives with environmental friendliness in mind that aim to minimize ecological footprint during maritime operations. A qualitative approach is chosen in order to more deeply explore participants' perceptions, attitudes, and intentions - something quantitative methods might miss entirely - thus aligning with research objectives more completely and providing us with a rich understanding of container barging sector's complexity.

We opted for a qualitative approach because it allows for a deeper exploration of stakeholders' perceptions, experiences, and challenges related to sustainable fuel technology in container barging. While quantitative methods provide numerical data and trends, a qualitative approach offers rich, contextual insights, capturing the nuances and complexities of the transition to sustainable fuels. This depth of understanding is crucial for our study's objectives, which aim to uncover the underlying factors and motivations influencing the adoption of sustainable fuel technology. (Creswell and Poth, 2016). This research questionnaire encompasses an expansive set of aspects related to adopting sustainable fuel technologies. The following sections detail each question's findings, providing insights into user perceptions, technology adoption likelihood, influence factors, understanding of advantages, confidence levels, effort estimation, environmental impact assessment, concerns for risks, and willingness to recommend. These results have shed light on a deeper understanding of sustainable fuel technology within the industry context interpreting through the Technology Acceptance Model (TAM) lens.

4.1 Organization and designation of respondents

Employees from a variety of companies, including Aker Solutions, IMS, and Port-Xchange, were polled about projects using sustainable fuel in the corridor as shown in figure 4.1. As an alternative, surveys were also conducted under experienced professionals at Erasmus University’s MEL program.

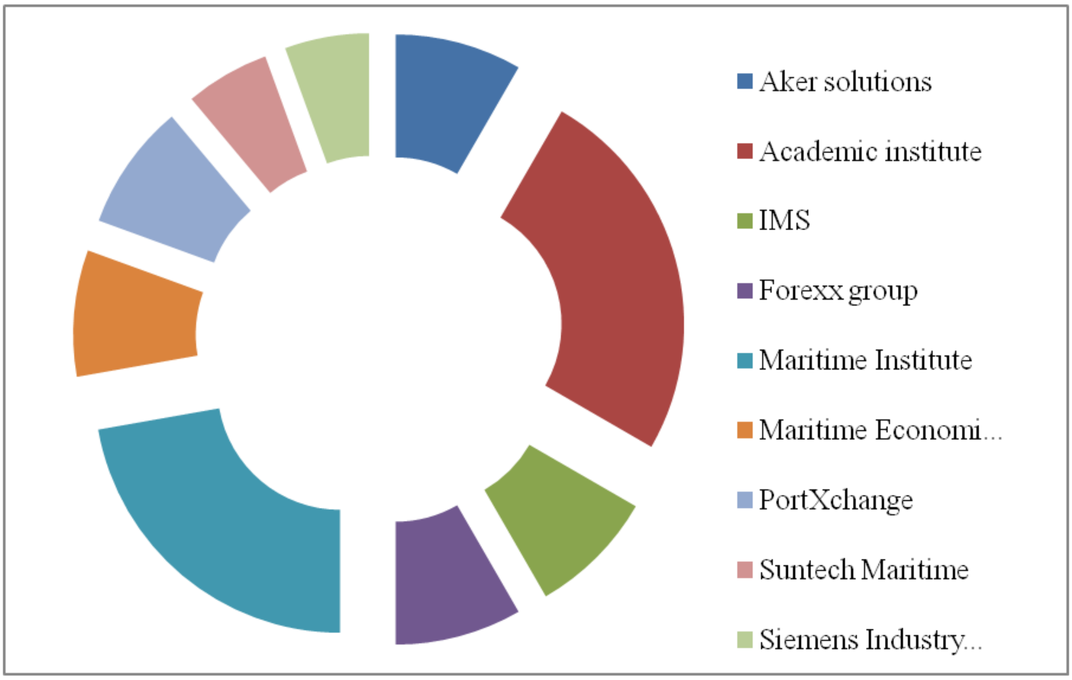


Figure 4.1: Organization based frequencies of respondents in survey

This survey was distributed to stakeholders in the Rotterdam-Duisburg port corridor, professionals from shipping companies, port authorities, logistics providers, and regulatory authorities. Our questionnaire received responses from 49 professionals. The distribution of designations among respondents demonstrates a thorough and diversified approach to comprehending the effects and difficulties connected with the switch to sustainable fuels in the inland container barging industry. It includes both real-world experience and scholarly viewpoints, offering a comprehensive analysis of the subject. As a result, the majority of respondents 36% were technical superintendents, who offered practical operational ideas. Senior Business Associates, who made up 8%, provided opinions on business. Branch Heads, general managers, and junior marine supervisors all made about 6% of the total. Another indicator of academic interest, University students and Professors were 12% total number including MSc students. The effects and difficulties of converting to sustainable fuels in the Rotterdam-Duisburg inland container barging sector were comprehensively investigated as a result of this broad distribution of respondents (Figure 4.2).

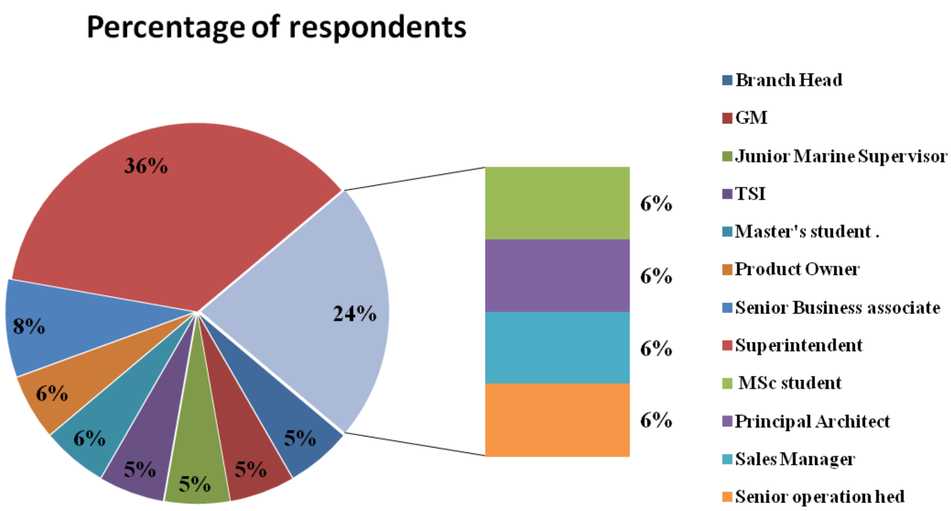


Figure 4.2: Graphical illustration of the designation of respondents

4.2 User-friendliness of sustainable fuel technology for container barging

In our survey, the term "sustainable fuel technology" refers to the set of innovations, methodologies, and tools developed to produce and utilize eco-friendly fuels in container barging. The technology encompasses not only the fuel production but also the infrastructure, equipment, and practices needed to integrate these fuels into container barging operations efficiently and safely. In the context of the Rotterdam-Duisburg freight corridor the usability study of sustainable fuel technology for container barging was done. Opinions of respondents were divided into five levels. 46.90% of people rated the technology as "Neutral" in terms of usability. 20.40% of respondents believed difficult and 10.20% had opinion that it was very difficult. In contrast, 22.40% of respondents said it was "Easy," while 0.1% said it was "very easy." (Figure 4.3, Table 4.1).

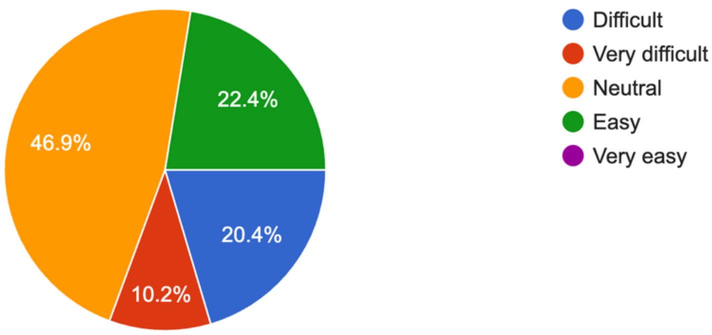


Figure 4.3 Graphical representation of user-friendliness of sustainable fuel technology for container barging

Table 4.1: Frequencies of user-friendliness of sustainable fuel technology for Container Barging

Levels	Counts	% of Total	Cumulative %	Proportion
Difficult	10	20.40%	20.40%	0.204
Very difficult	5	10.20%	30.60%	0.102
Neutral	23	46.90%	77.50%	0.469
Easy	11	22.40%	99.90%	0.224
Very easy	0	0.10%	100.00%	0.001

This survey has revealed different views regarding the user-friendliness of sustainable fuel technology for container barging sector, with approximately 30.6% finding it challenging or very challenging and an equal percentage seeing it as simple or straightforward. These responses can be understood using the Technology Acceptance Model (TAM). Individuals who find the technology easy may associate it with higher perceived ease of use (PEOU), which may positively influence their attitude toward using it (ATU). Conversely, those finding it challenging may have lower PEOU and have more neutral or negative attitudes. This demonstrates how significant PEOU can be in shaping users' attitudes and behavioural intentions regarding sustainable fuel technology adoption within container bargaining.

4.3 Enhancement of efficiency and productivity in container barging

The perceptions of the respondents are divided into several levels when evaluating the improvement of efficiency and productivity in the container barging industry along the Rotterdam-Duisburg freight route. In terms of the task's difficulties and effects on productivity and efficiency, 36.70%, rate it as "Neutral". Almost similar, 34.70%, rate it as "Easy," while 14.30% rate it as "Difficult." Furthermore, 6.10% rate it as "Very difficult," while 6.20% rate it as "Very easy." This split of viewpoints provides insightful information on the many barriers and enablers impacting efficiency and productivity gains as the inland container barging industry make the switch to sustainable fuels (Figure 4.4, Table 4.2).

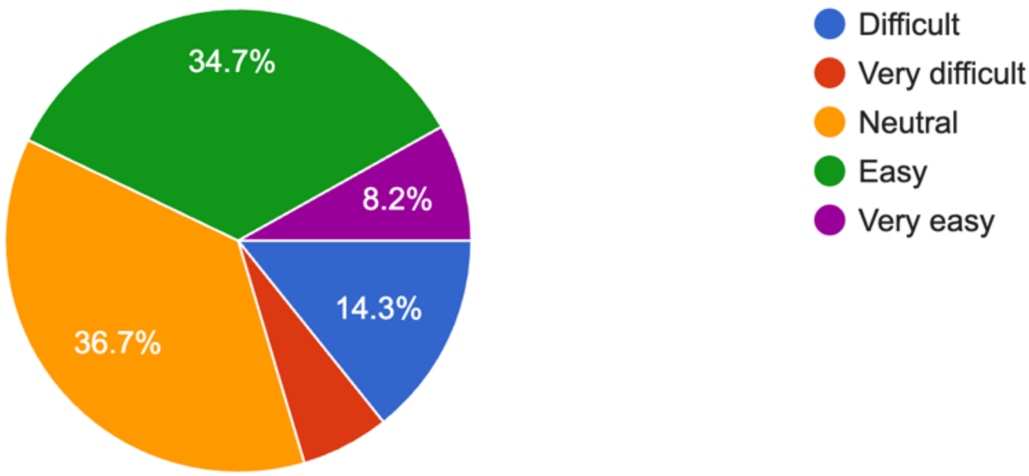


Figure 4.4 Graphical representation of Enhancement of Efficiency and Productivity in Container Barging

Table 4.2: Frequencies of Enhancement of Efficiency and Productivity in Container Barging

Levels	Counts	% of Total	Cumulative %	Proportion
Difficult	7	14.30%	14.30%	0.143
Very difficult	3	6.10%	20.40%	0.061
Neutral	18	36.70%	57.10%	0.367
Easy	17	34.70%	91.80%	0.347
Very easy	4	8.20%	100.00%	0.082

The survey's findings provide varied viewpoints on how sustainable fuel technology affects container barging operations. A significant 53.1% perceive moderate to considerable enhancement, potentially correlating with their perceived usefulness (PU). Those who see value in its benefits tend to have a more **favourable** attitude toward using (ATU). Conversely, those who reported slight or no enhancement may have less **favourable** attitudes toward its adoption into container barging operations - showing its power in shaping users' perceptions and subsequent adoption intentions of sustainable fuel technology solutions. PU remains at its core for shaping users' perceptions as well as subsequent adoption intentions regarding sustainable fuel technology's adoption into **container-barging** operations.

4.4 Likelihood of adopting sustainable fuel technology

In regards to the likelihood of implementing sustainable fuel technology within the inland container barging industry along the Rotterdam-Duisburg freight corridor, the majority of respondents, accounting for 49.0%, express a high degree of confidence, judging it "Very likely." Also, 26.50% of respondents think it's "Likely," demonstrating a high degree of confidence in the industry's readiness to adopt sustainable fuel technology. While 14.30% of respondents say they have "Neutral" expectations, 10.20% of respondents say they think it's "Unlikely." A noteworthy finding is that no respondents think the adoption is "Very unlikely." This range of viewpoints sheds light on the prevalent beliefs and level of preparation for implementing sustainable fuel technology, which is a crucial component of the transition's effects and difficulties in the inland container barging industry (Figure 4.5, Table 4.3).

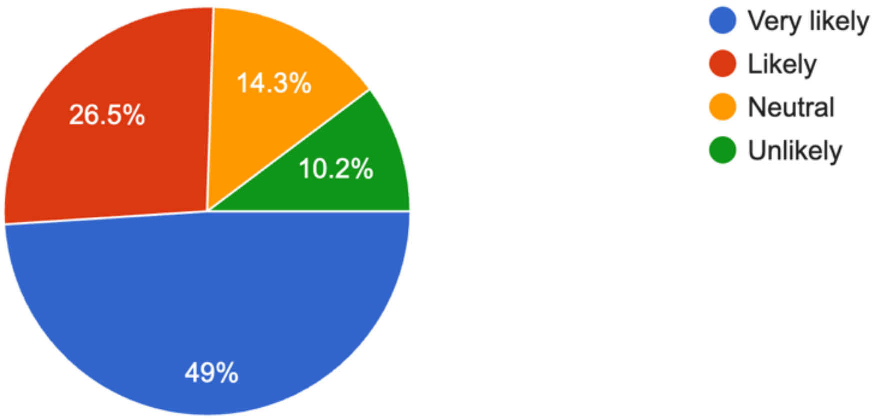


Figure 4.5: Graphical depiction of Likelihood of adopting sustainable fuel technology

Table 4.3: Frequencies of likelihood of adopting sustainable fuel technology

Levels	Counts	% of Total	Cumulative %	Proportion
Very likely	28	49%	49.00%	0.49
Likely	9	27%	75.50%	0.265
Neutral	6	14%	89.80%	0.143
Unlikely	6	10%	100.00%	0.102
Very unlikely	0	0%	100.00%	0

Examining respondents' likelihood of adopting sustainable fuel technology for container barging provides insight into their behavioral intention to use (BIU). Most (75.5%) express an optimistic inclination, showing a strong BIU. This positive evaluation may be attributable to the perceived ease of use (PEOU) and perceived usefulness (PU) of technology. The TAM framework suggests that when users find technology easy to use and believe it could increase productivity (PU), they are more likely to develop an ATU-favourable attitude, leading to higher BIU ratings. Furthermore, 12.5% expressed neutrality or unlikelihood due to existing practices that have lower peou or pu perceptions.

4.5 Influence of colleagues and peers on adoption decision

In assessing the major influences and difficulties in converting to renewable energy sources for the inland container barging sector across the Rotterdam-Duisburg freight corridor, respondents' perspectives were categorized into different categories. A significant 43% perceive a "Moderate Influence," suggesting that they recognize the importance of factors impacting this effect shift without classifying them either as significantly strong or negligible. Additionally, 29% believe that peers have a "Slight Influence," suggesting that they do in fact have an effect, although a less noticeable one. Meanwhile, 14% believe that these forces had a "Strong Influence," indicating that they had a significant influence on the transformation. It's interesting to note that 14% of respondents think that these factors may have "No Influence" on the changeover. (Figure 4.6, Table 4.4). This variety of perspectives provides insightful information on the many levels of influence influencing the switch to sustainable fuels in the inland container barging business.

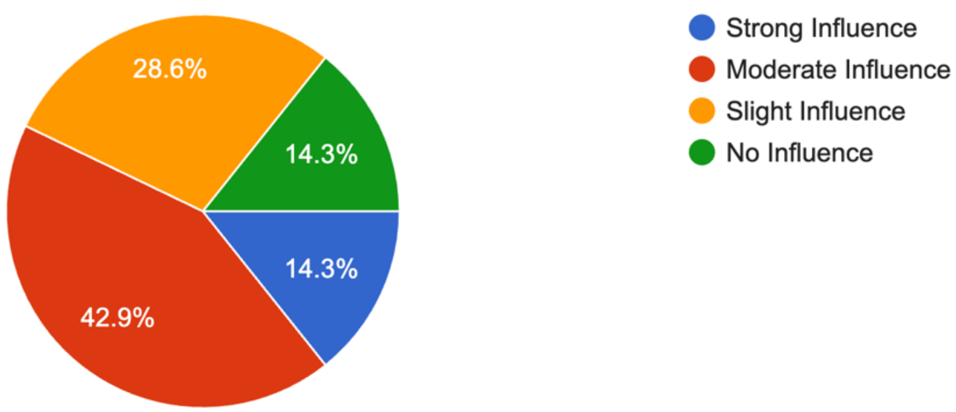


Figure 4.6: Pie chart depiction of influence of colleagues and peers on adoption decision

Table 4.4: Frequencies of influence of colleagues and peers on adoption decision

Levels	Counts	% of Total	Cumulative %	Proportion
Strong Influence	7	14%	14.30%	0.143
Moderate Influence	21	43%	57.20%	0.429
Slight Influence	14	29%	85.80%	0.286
No Influence	7	14%	100.10%	0.143

The result showed that the responses of participants on their choice to employ sustainable fuel technology for container barging were influenced by peers and colleagues. Colleague and peer influence on respondents' decisions to adopt sustainable fuel technology is consistent with the social influence (SI) component of the TAM model, of those surveyed who responded about colleagues and peers having strong or moderate influence over their decision-making processes regarding sustainable fuel technology adoption. Total 57.2% listed them as either strong or moderate influences; this follows suit with the TAM framework which emphasizes subjective norms and social factors as shaping users attitudes and intentions; respondents' susceptibility to peer influence is an effect of interaction between SI and attitude towards using components, as positive opinions from colleagues can strengthen an individual's favorable attitude thereby raising their intention (BIU).

4.6 Understanding of advantages of sustainable fuel technology

when it comes to comprehending the benefits of sustainable fuel technology in the context of the inland container barging sector across the Rotterdam-Duisburg freight corridor, Respondents' degree of awareness can be divided into several categories. A sizable 32.70% of those polled said they comprehend these benefits "Very well," demonstrating a high degree of awareness and comprehension. Additionally, 36.70% think they understand these benefits "Moderately well," suggesting that they have a firm understanding of the advantages but still have space for improvement. Additionally, according to 28.60% of respondents, these benefits are comprehended "Slightly well," indicating a basic understanding. Only a small percentage, 2.00%, says they "Not at all" grasp the advantages (Figure 4.7, Table 4.5). This distribution of understanding levels offers insightful information on the amount of knowledge and awareness of the benefits of sustainable fuel technology.

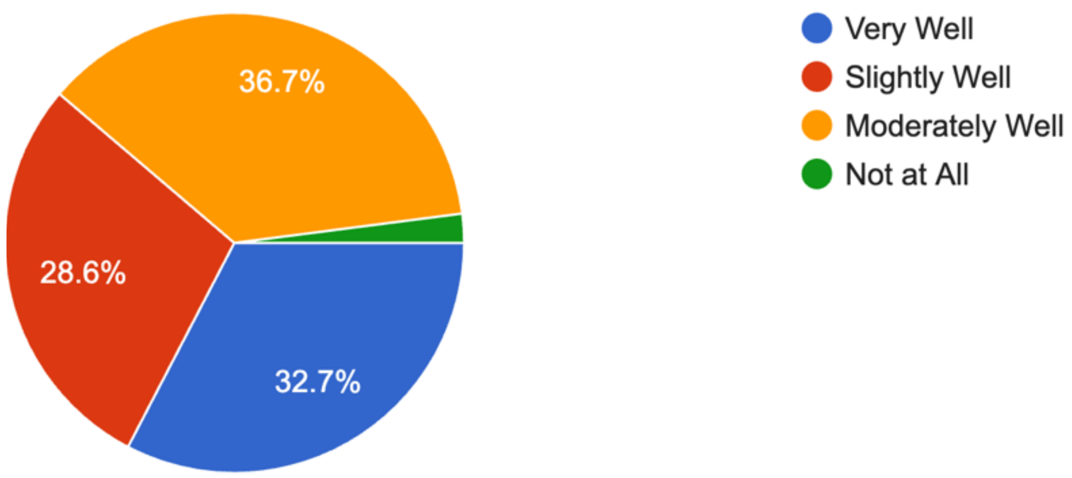


Figure 4.7: Pie Chart representing understanding of advantages of sustainable fuel technology

Table 4.5: Frequencies of understanding of advantages of sustainable fuel technology

Levels	Counts	% of Total	Cumulative %	Proportion
Very well	16	32.70%	32.70%	0.327
Slightly well	14	28.60%	61.30%	0.286
Moderately well	18	36.70%	98.00%	0.367
Not at all	1	2.00%	100.00%	0.02

As assessed here, respondents' understanding of sustainable fuel technology for container barging matches the perceived usefulness (PU) component of the TAM model. Notably, 32.7% claim they understand the advantages very well while 36.7% indicate a moderate understanding. This finding fits well with TAM's PU concept which suggests that user perceptions of usefulness affect their attitude toward using (ATU). An understanding of the benefits can lead to greater ATU and behavioral intention to use (BIU). On the other hand, those indicating they do not fully appreciate its potential may require further information; hence highlighting the significance of educational efforts in supporting its adoption.

4.7 Confidence in the effectiveness of sustainable fuel technology

Within the inland container barging industry in the Rotterdam-Duisburg freight route, respondents' perspectives may be grouped into several categories when evaluating their degree of trust in the efficacy of sustainable fuel technology. An important 44.90% of respondents say they are "Slightly confident," demonstrating a basic degree of confidence in the technology's efficacy. Furthermore, 26.50% say they are "Very confident," indicating that they have a lot of faith in the potential of sustainable fuel technology. Additionally, 22.40% of respondents identify as "Moderately confident," indicating a moderate level of certainty. Only 6.20 percent of respondents admit to "Not being confident" in the efficacy of sustainable fuel technologies (Figure 4.8, Table 4.6). These ranges of confidence levels provide insightful information about the differing levels of belief in the technology's ability to facilitate the switch to sustainable fuels.

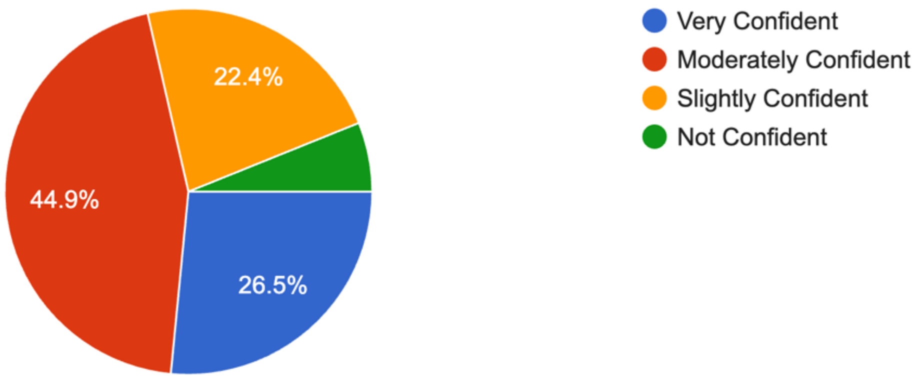


Figure 4.8: Pie chart depiction of confidence in the effectiveness of sustainable fuel technology

Table 4.6: Frequencies of confidence in the effectiveness of sustainable fuel technology

Levels	Counts	% of Total	Cumulative %	Proportion
Very confident	13	26.50%	26.50%	0.265
Slightly confident	22	44.90%	71.40%	0.449
Moderately confident	11	22.40%	93.80%	0.224
Not confident	3	6.20%	100.00%	0.062

Confidence levels among respondents regarding the effectiveness of sustainable fuel technology for container barging are captured here, which correlates with components of the TAM model such as ease of use (PEOU) and attitude toward using (ATU). At least 26.25% reported having high confidence levels while 22.4% expressed moderate ones; this finding indicates that higher confidence can result from perceived ease in learning and using technology. Confidence and ATU demonstrate a significant relationship, showing how positive attitudes toward technology may stem from an increase in confidence about its efficacy. Furthermore, both PEOU and ATU serve as key determinants of behavioural intention to use (BIU), emphasizing their crucial role in shaping users' adoption decisions.

4.8 Effort required to learn and use sustainable fuel technology

In investigating the effort needed to acquire and utilize sustainable fuel technology for the inland container barging sector on the Rotterdam-Duisburg freight corridor, respondents' perspectives align with specific effort levels. A noteworthy finding is that 34.70% of respondents say it requires "Quite a bit of effort," suggesting a significant yet manageable commitment to understand and use the technology. Equal numbers, 34.70%, also think it requires "Moderate effort," which denotes a balanced effort. In contrast, 30.60% believe it requires a "Lot of effort," suggesting a significant commitment of time and money to become proficient. It's interesting to note that no respondents said "Not effort," demonstrating that understanding and using sustainable fuel technologies in the industry need some amount of work (Figure 4.9, Table 4.7).

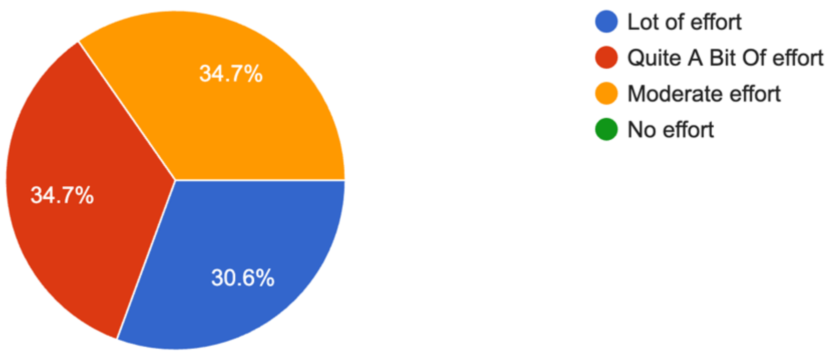


Figure 4.9: Pie chart depiction of effort required to learn and use sustainable fuel technology

Table 4.7: Frequencies of effort required to learn and use sustainable fuel technology

Levels	Counts	% of Total	Cumulative %	Proportion
Lot of effort	15	30.60%	30.60%	0.306
Quite a bit of effort	17	34.70%	65.30%	0.347
Moderately effort	17	34.70%	100.00%	0.347
Not effort	0	0.00%	100.00%	0

Participants' responses regarding the effort required to learn and use sustainable fuel technology correlate closely with the perceived ease-of-use (PEOU) dimension of the TAM model. Of those surveyed, 30.6% anticipate an effort of substantial magnitude; 34.7% foresee significant but manageable work; while 34.7% indicate only moderate efforts may be required. PEOU data indicates that people who view a technology as more user-friendly tend to think it requires less effort to learn and mastering its use. This research shows that efforts made to enhance the usability of technology may influence users' perceptions of its learning curve and ease-effort requirements, ultimately impacting users' acceptance and willingness to adopt sustainable fuel technologies.

4.9 Rating of environmental impact reduction using sustainable fuel technology

When evaluating the opinion of environmental impact reduction achieved through the use of sustainable fuel for the inland container barging sector respondents' viewpoints can be separated into certain levels. 46.90% of respondents, a sizeable number, believe that using sustainable fuel results in "Strong positive outcomes," demonstrating a high degree of trust in the technology's ability to have a good influence on the environment. Furthermore, 38.80% of respondents saw "Moderate positive outcomes," demonstrating a significant recognition of its favourable environmental impacts. 12.20% of respondents, a lower percentage, report "Slightly positive outcomes," indicating acknowledgement of the technology's advantages, but to a lesser degree (Figure 4.10, Table 4.8).

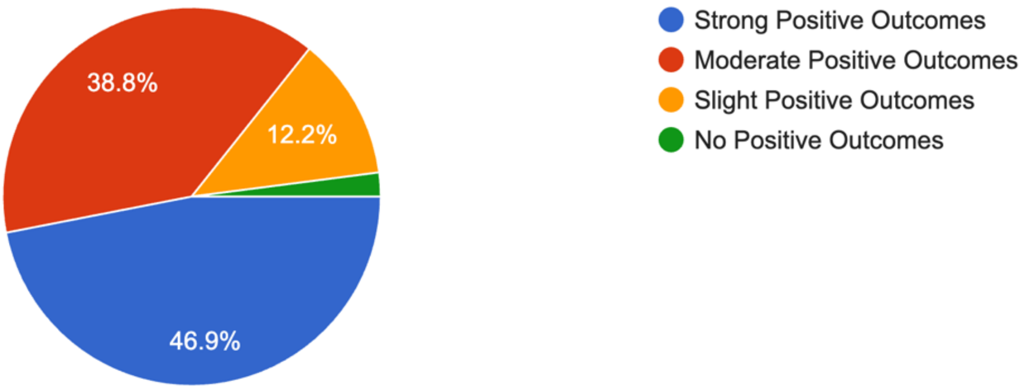


Figure 4.10: Pie chart depiction of rating of environmental impact reduction using sustainable fuel

Table 4.8: Frequencies of rating of environmental impact reduction using sustainable fuel

Levels	Counts	% of Total	Cumulative %	Proportion
Strong positive outcomes	23	46.90%	46.90%	0.469
Moderate positive outcomes	19	38.80%	85.70%	0.388
Slight positive outcomes	6	12.20%	97.90%	0.122
No positive outcomes	1	2.10%	100.00%	0.021

Responses related to environmental impact reduction using sustainable fuel technology can be linked with the perceived usefulness (PU) component of the TAM model. 46.9% of participants recognized strong positive outcomes, 38.8% demonstrated moderately positive ones, and 12.2% identified slight ones. This evidence suggests that individuals who view technology as beneficial and worthy are more likely to recognize its potential in making significant reductions to environmental impact. These findings indicate that emphasizing the positive environmental benefits of sustainable fuel technology could increase users' perceptions of its usefulness, leading them to decide more quickly to employ it. This observation emphasizes the significance of emphasizing perceived benefits as a means to positively influence user attitudes and intentions, in line with the TAM framework's emphasis on perceived usefulness as a factor influencing behavioural intentions.

4.10 Concerns about risks or challenges with sustainable fuel technology

The respondents' perspectives have been separated into several categories in order to assess the frequency of worries about the dangers or difficulties connected with sustainable fuel technology in the inland container barging business along the Rotterdam-Duisburg freight route. A noteworthy 57.10% show "Moderate concern," indicating a high degree of worry about potential hazards or difficulties linked with the use of the technology. In addition, 28.60% say they are "Very concerned," which shows a greater level of fear about potential problems. 14.30%, on the other hand, are "Not concerned," demonstrating a more upbeat attitude or a view of few obstacles (Figure 4.11, Table 4.9). This range of levels of worry offers important insights into the sector's various levels of worry and understanding about the hazards and difficulties of switching to sustainable fuels.

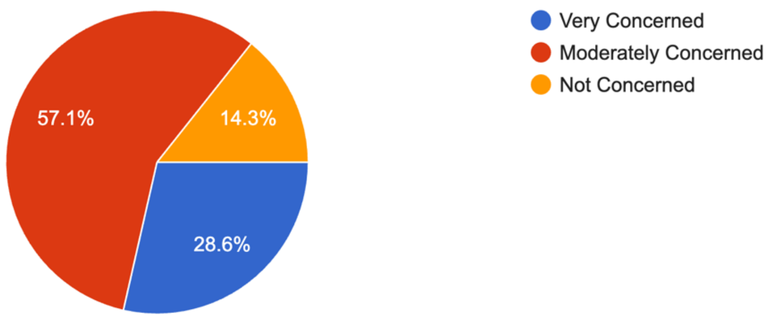


Figure 4.11: Pie chart depiction of concerns about risks or challenges with sustainable fuel technology

Table 4.9: Frequencies of concerns about risks or challenges with sustainable fuel technology

Levels	Counts	% of Total	Cumulative %	Proportion
Very concerned	14	28.60%	28.60%	0.286
Moderate concerned	28	57.10%	85.70%	0.571
Not concerned	7	14.30%	100.00%	0.143

Responses regarding risks or challenges related to using sustainable fuel technology can be accessed through an examination of their perceived ease of use (PEOU) and perceived usefulness (PU) dimensions in the TAM model. Concerns among participants varied; 28.6% were very concerned, 57.1% expressed moderate concern and 14.3% did not express any. These variations can be related to perceived ease-of-use and utility of technology solutions. Participants who find a technology less user-friendly (low PEOU) may express more concern, owing to anticipated difficulties in adopting and operating it. Individuals who perceive sustainable fuel technology as less beneficial (low PU) may also have greater concerns regarding potential risks or challenges associated with its use, according to research findings. Addressing risks or challenges requires considering both the perceived ease-of-use and perceived usefulness aspects of sustainable fuel technology solutions.

4.11 Likelihood of recommending sustainable fuel technology to others

The opinions of respondents divide into separate groups when it comes to the possibility of proposing sustainable fuel technology within the inland container barging industry along the Rotterdam-Duisburg freight route. A sizable 49.00% of respondents say they are "Likely to recommend," indicating a favorable propensity to encourage others to use the technology. Additionally, 22.40% say they are "Very likely to recommend," demonstrating an even greater readiness to support sustainable fuel technologies. While 16.30% of respondents are neither inclined nor disinclined to offer advice, they retain a "Neutral" position. A lesser percentage, 6.15%, considers themselves "Unlikely to recommend," which suggests some qualms. A similar 6.15% rate themselves as "Very unlikely to recommend" (Figure 4.12, Table 4.10). This range of perspectives provides insightful information about the varied levels of willingness to promote sustainable fuel technology and emphasize its perceived advantages and difficulties.

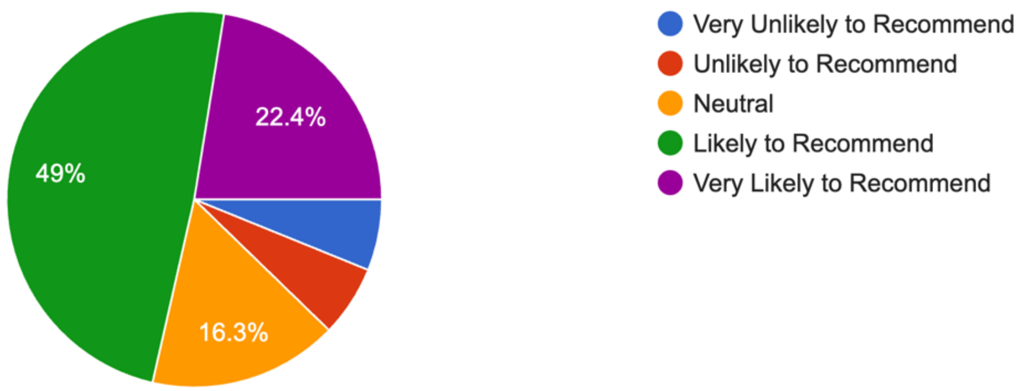


Figure 4.12: Pie chart depiction of likelihood of recommending sustainable fuel technology to others

Table 4.10: Frequencies of likelihood of recommending sustainable fuel technology to others

Levels	Counts	% of Total	Cumulative %	Proportion
Very unlikely to recommend	3	6.15%	100.00%	0.0615
Unlikely to recommend	3	6.15%	93.85%	0.0615
Neutral	8	16.30%	16.30%	0.163
Likely to recommend	24	49.00%	65.30%	0.49
Very likely to recommend	11	22.40%	87.70%	0.224

Analysis of participant responses regarding their likelihood to recommend sustainable fuel technology can be conducted using the Technology Acceptance Model (TAM). Responses indicate a wide variety of recommendations; 6.15% were very unlikely, 6.15% unlikely, 16.3% neutral, 49% likely and 22.4% very likely for each recommendation category in TAM's behavioural intention to use (BIU) component. These variations in responses align closely with TAM's BIU component. Most likely or very likely recommenders of the technology likely have developed an enthusiastic attitude toward its usage due to perceived ease of use (PEOU) and usefulness (PU), while those less inclined might harbour reservations due to perceived difficulties or inadequacies of it.

4.12 Analysis and interpretation of result

Survey responses provide a thorough account of perceptions and attitudes regarding sustainable fuel technology within the container bargaining sector, according to the Technology Acceptance Model (TAM). Analysis and interpretation of results reveal multiple influences affecting adoption as they align with TAM dimensions.

1. The technology for sustainable fuels is user-friendly.

The survey indicated an even split in view about the user-friendliness of sustainable fuel technology, with roughly 30.6% of respondents finding it difficult or extremely difficult, and an equal amount finding it easy or straightforward. The Technology Acceptance Model (TAM), which holds that perceived ease of use (PEOU) is a key factor in determining user attitudes and behavioral intentions, is consistent with these various impressions. Users are more likely to have a positive attitude and intend to embrace a technology if they find it simple to use.

2. Efficiency and Productivity Enhancement

53.1% of respondents said there had been a moderate to significant improvement in efficiency and productivity in the container barging business, however opinions were divided on this topic. The perceived usefulness (PU) element of the TAM model is directly related to this view. People who value the technology's advantages are more likely to be in favor of adopting it.

3. Likelihood of Adoption

The vast majority of respondents indicated a high likelihood of adopting sustainable fuel technology (49% very likely and 26.5% likely), demonstrating a high level of confidence in the industry's readiness for adoption. This high likelihood is consistent with the behavioral intention to use (BIU) component of TAM, where favorable attitudes fueled by perceived usability (PU) and perceived ease of use (PEOU) lead to higher BIU ratings.

4. The Influence of Peers and Colleagues

The respondents' assessments of the impact of peers and coworkers on adoption choices were mixed, with 43% believing it to be moderate, 29% believing it to be small, and 14% believing it to be substantial. This is consistent with the social influence (SI) element of TAM, which holds that user attitudes and intentions are influenced by social and subjective norms.

5. Understanding of Benefits

The majority of respondents (32.7% very well and 36.7% somewhat well) indicated having a strong understanding of the benefits of sustainable fuel technology. This information relates to the TAM's perceived utility (PU) component, which states that people are more likely to see technology favorably and want to utilize it if they can see its advantages.

6. **Confidence in Effectiveness**

Responses' levels of trust in the efficacy of sustainable fuel technology varied, ranging from 26.5% wholly confident to 44.9% who were just marginally convinced. Perceived ease of use (PEOU) and attitude toward usage (ATU) components of TAM are related to confidence levels, with favorable attitudes being connected to greater confidence in the efficacy of technology.

7. Effort Required to Learn and utilize

Respondents' opinions of the effort necessary to learn and utilize sustainable fuel technology varied, with 34.7% suggesting a significant amount of work, 34.7% indicating a moderate amount of effort, and 30.6% indicating a significant amount of effort. Users who find a technology less user-friendly report higher effort in learning and utilizing it, which is related to the perceived ease of use (PEOU) component of TAM.

8. Environmental effect Reduction

A sizable proportion of respondents (46.9%) or (38.8%) thought that employing sustainable fuel technology leads in strong positive or moderate positive outcomes in terms of reducing environmental effect. These ideas are strongly tied to the TAM's perceived utility (PU) component, which states that people are more likely to acknowledge a technology's positive environmental effect if they believe it to be helpful.

9. Risk or Challenge Concerns

Respondents showed varying degrees of worry about the hazards or difficulties of adopting sustainable fuel technology, with 57.1% expressing moderate worry and 28.6% expressing considerable worry. These issues involve the TAM's perceived utility (PU) and perceived ease of use (PEOU) components. Users who find the technology less helpful or user-friendly may be more worried about possible threats or difficulties.

10. Likelihood of Recommending to Others

The percentage of respondents who said they would promote sustainable fuel technology to others ranged from 49% to 22.4%. These suggestions are in line with the behavioral intention to use (BIU) part of TAM, which examines how likely people are to recommend technology to others based on their attitudes and impressions of its utility and usability.

By combining its own findings with insights from reputable sources, the research amplifies its resonance and applicability. The Technology Acceptance Model (TAM) offers a helpful framework for comprehending these attitudes and perceptions by highlighting the significance of perceived utility (PU) and perceived ease of use (PEOU) in influencing user attitudes and behavioral intentions. In order to encourage the use of this technology in this sector and eventually improve environmental sustainability and efficiency, this approach not only enriches the discourse on sustainable operational transformation but also extends a nuanced understanding of the challenges encountered. In doing so, the research bridges academia and real-world implementation, contributing tangibly to steering maritime operations onto a greener, more sustainable trajectory (Ahlgren et al., 2023).

5 Conclusion

5.1 Conclusion:

At the heart of our research lies the pivotal question: What conditions influence the adoption of sustainable fuels in the shipping industry? As we navigate through our findings, it becomes evident that the answer is multifaceted, shaped by a confluence of technological, economic, infrastructural, perceptual, and societal factors.

1. Technological advances for Carbon Footprint Reduction: The first question focused on finding technology advances that can reduce the carbon footprint in the inland barging industry. The evidence supports up the alternative hypothesis (H1) that the inland barging industry's carbon footprint may be greatly reduced by technological developments. According to respondents' perspectives, technological advancements are essential for ensuring environmental sustainability. A majority 69% of our survey respondents emphasized the value of technological development and its ability to contribute to carbon emission reduction.

2. **Economic and Financial Constraints**: The second query looked at the financial and economic limitations of using sustainable energy. The alternative hypothesis (H1) is supported, highlighting the significant influence of economic and financial variables on the uptake of sustainable fuels. The evidence is in favour of the alternative hypothesis (H1), which emphasizes how important infrastructure is to the uptake of sustainable fuel. A significant 52 % of stakeholders believe that, the adoption of eco-friendly fuels is significantly hampered by budgetary considerations. This emphasizes the necessity of resolving financial issues to ease the move.

3. **Infrastructure Requirements for Sustainable Fuel Bunkering:** The third question asked about how to comprehend the infrastructure needs for sustainable fuel bunkering. The survey's 57% respondents confirmed the significance of infrastructure development as a crucial transitional element. For the broad use of sustainable fuels to be supported, there must be a sufficient bunkering infrastructure.

4. Stakeholder Positions and Perceptions: The fourth question examined the perspectives of significant stakeholders, such as shippers, barge captains, governmental agencies, and environmental organizations, on the use of sustainable fuels. The alternative hypothesis (H1) is supported, demonstrating that significant participants (71%), such as shippers, barge operators, governmental bodies, and environmental advocacy organizations, have different opinions on the corridor's switch to sustainable fuels. The results showed a wide variety of viewpoints, emphasizing the complexity of stakeholder opinions. These contrasting points of view highlight the need of teamwork and good stakeholder involvement.

5. Social Influence in Technology Adoption: The fifth question focused on the function of social influence in the adoption of sustainable fuel technology. The alternative hypothesis (H1) is supported, indicating that social factors substantially influence the adoption of sustainable fuel technology for container barging. According to 57% of respondents' beliefs, social influence—driven by peers and colleagues—plays a big part in influencing deployment decisions. This highlights the significance of social variables in the acceptance of new technologies.

The above findings try to cover the answer for main research question "What are the prerequisites and potential bottlenecks for the Rotterdam-Duisburg freight corridor's inland container barging sector for a successful transition to sustainable fuels??"

Overall, our findings reflect the complexity of the technological modification, which considers financial factors, infrastructural development, stakeholder views, and social influences for adoption of sustainable fuels. These insights can assist in strategic decision-making and policy formulation to promote environmental sustainability within the sector and to encourage the use of sustainable fuels.

5.2 In-Depth Conclusion:

Several players in the inland container barging industry have different viewpoints and attitudes toward the use of sustainable fuel technologies. Adoption of sustainable fuel can be facilitated by initiatives to improve usability, highlight benefits, and resolve concerns. Overall, survey findings were shown to be consistent with the Technology Acceptance Model (TAM) framework based and drawn following conclusion.

- PEOU (Perceived Ease of Use) and Effort: People who perceive sustainable technology easy to use anticipate spending less time learning how to use it. Adoption of sustainable fuel may be positively impacted by improving usability.

- PU (Perceived Usefulness) and Environmental Impact Reduction: People are more likely to identify a technology's positive environmental impact if they believe it to be useful. Benefits of sustainable fuel can help adoption choices move more quickly.
- PU and PEOU in Addressing Concerns: All the Concerns are in line with evaluations of utility and simplicity of use, according to PEOU and PU. Concerns can be reduced by enhancing user-friendliness and highlighting advantages.
- Recommendations and BIU (Behavioural Intention to Use): Positive attitudes that are motivated by the technology's perceived utility and simplicity of use have an impact on how likely people are to suggest it.

In synthesizing our findings, it's evident that the shipping industry's transition to sustainable fuels is not a matter of 'if' but 'when'. Each of our sub-questions rooted in the broader research question, sheds light on the intricate tapestry of factors shaping this transition. From technology to stakeholder perceptions, each facet offers insights into the industry's trajectory. As we conclude, it's imperative to recognize that the adoption of sustainable fuels is not just a technological or economic endeavour but a holistic transformation, shaped by a myriad of interconnected factors.

This detailed conclusion provides a comprehensive answer to the main research question and its sub-questions, offering a nuanced understanding of the study's findings.

5.3 Contribution of the Study

This research makes significant contributions both academically and practically to sustainable fuel adoption within the container barging sector along the Rotterdam-Duisburg corridor.

Academic Contribution: This research's primary academic contribution lies in its application of the Technology Acceptance Model (TAM) within container barging, adapting TAM specifically for this sector to expand the theoretical boundaries of technology acceptance research and understanding stakeholder perceptions and Behavioral intentions toward sustainable fuel technology.

Practical Contribution: From a practical viewpoint, this study offers actionable insights for stakeholders, industry practitioners, and policymakers. Its findings highlight factors affecting the user-friendliness of sustainable fuel technology as well as its potential to improve operational efficiency for guidance to technology developers and operators.

Industry and Environmental Implications: This study's impact extends far beyond its maritime contexts. By exploring stakeholders' perceptions of sustainable fuel technology, this study informs decision-making within the container barging sector. this technology allows strategies to mitigate any barriers that prevent its adoption.

5.4 Policy and Future Research Implications

Policymakers can utilize the study's insights to design regulatory frameworks that promote sustainable fuel adoption while meeting environmental goals in their sectors (Alias et al., 2021).

5.5 Implications for Practice and Policy

The findings from this research provide important lessons for industry practices and policy-making efforts that seek to foster sustainable fuel adoption along the Rotterdam-Duisburg corridor in the container barging sector.

Practice Implications: This research's results offer actionable insights for industry practitioners. Varying perceptions of user-friendliness show the need for tailored training programs and user-friendly interfaces to ease technology transition, with practitioners using this data to design training modules tailored specifically to address individual learning styles and preferences. Furthermore, peer influence was highlighted as being essential in driving technology adoption decisions; industry players may leverage this finding by encouraging knowledge-sharing and collaborative communication among colleagues to foster an information exchange culture thereby speeding up acceptance of sustainable fuel technology adoption.

Policy Implications: Policymakers and regulatory bodies can utilize this research to formulate effective policies that encourage the adoption of sustainable fuel technology. Identification of factors influencing stakeholders' intentions to adopt technology provides insight for policy interventions designed to promote its adoption (Van Meir et al., 2022).

Environmental Implications: This research's impact can be seen on an international scale. By providing insight into perceptions about sustainable fuel technology's positive effect in terms of reduced environmental harm, this research highlights the necessity of policies that encourage eco-friendly practices within the container barging industry and reinforce the need for eco-friendly policies within container barging sector policies that incentivize environmentally conscious choices through incentives or rewards systems.

Policymakers could utilize these findings to create regulations which reward sustainable actions as part of regulations or initiatives to promote eco-friendliness within container barging sector policies or industry regulations which incentivize or reward their adoption within container barging industries or vice versa. If environmental harm reduction can be achieved via incentives schemes designed through policies created from this study's implications on various levels relating to container barging industry regulation by policymakers leveraging its implications (Doll et al., 2021).

Fostering Innovation: By highlighting variables influencing technological acceptability, this study inadvertently encourages innovation within the marine sector. By doing so, this research encourages technology developers to design solutions that address stakeholder preferences and address stakeholder concerns - thus driving a cycle of innovation driven by user feedback and real-world needs.

5.6 Limitations and Future Research Directions

Though this research offers valuable insights, it does have its limitations. While its sample size may be representative, it may not capture all nuances within the container bargaining industry; additionally, self-report surveys introduce potential biases; finally, its scope is limited to one geographic region, potentially restricting generalizability.

5.7 Future Research Directions

- ***Longitudinal Studies:*** Future research could take a longitudinal approach to examine how perceptions and attitudes toward sustainable fuel technology change over time, providing insights into factors impacting changes in technology acceptance and adoption intentions. Such investigations might also yield information regarding factors influencing these shifts.
- ***Comparative Studies:*** Conducting comparative studies across different regions and corridors could provide more robust validation of study findings on an international scale. Comparing adoption patterns and factors between maritime corridors can give more of a comprehensive picture of regional nuances.

- ***Qualitative Analysis:*** Supplementing quantitative data with qualitative methods such as in-depth interviews can offer greater insights into the motivations, concerns, and contextual factors driving stakeholders' technology acceptance decisions.
- ***Influence of Regulatory Frameworks:*** Examining the effect of existing regulatory frameworks on technology adoption can provide valuable insight into how policy environments influence stakeholders' decisions. Future Studies should delve deeper into the psychological and behavioral factors influencing stakeholders' technology adoption intentions, including individual risk perception, innovation readiness, and technological optimism (Shobayo et al., 2021). Doing so would offer a deeper insight into technology acceptance dynamics.
- ***Economic Considerations:*** Assessing the economic implications of adopting eco-friendly fuel sources - such as cost-benefit analyses and financial incentives - is vital for understanding whether transitioning is financially feasible.
- ***Cultural and Societal Factors:*** Examining how cultural and societal influences on technology adoption decisions can offer key insight into how broader social contexts shape stakeholders' attitudes.

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7 Appendix

Appendix I

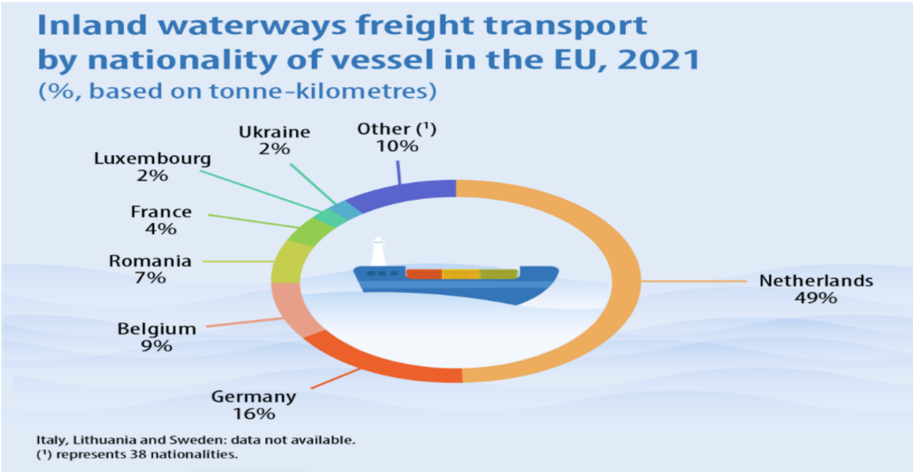
Assessing the Transition to Sustainable Fuel.

Table 1: Survey Questionary

Sr. No	Survey Questions
1	**How user-friendly do you find sustainable fuel technology for container bargaining? Depending on your perceptions, which of the following scenarios apply?** Responses: a) Difficult, b) Very Difficult , c) Neutral , d) Easy and e) Very Easy.
2	**How will using sustainable fuel technology enhance the efficiency and productivity of container bargaining operations?** Responses: (a) Not at All, (b) Slightly, (c) Moderately, (d) Considerably and (e) Significantly.
3	**How likely are you to adopt sustainable fuel technology for container bargaining, given you have access to necessary resources and support?** Responses: (a) Likely, (b) Unlikely , and (c) Neutral .
4	**Are the opinions and recommendations of your colleagues and peers influencing your decision to use sustainable fuel technology in container bargaining? Which category best describes their influence:** Responses: (a) Strong Influence, (b) Moderate Influence, (c) Slight Influence and (d) No Influence.
5	**How well do you understand the advantages of sustainable fuel technology for container bargaining?** Responses: (a) Very Well, (b) Slightly Well, (c) Moderately Well and (d) Not at All
6	**How confident are you that sustainable fuel technology will work effectively for container bargaining operations? When answering this question, choose from one of these options:** Responses: a) Very Confident, b) Moderately Confident , c) Slight Confident and d) Not Confident

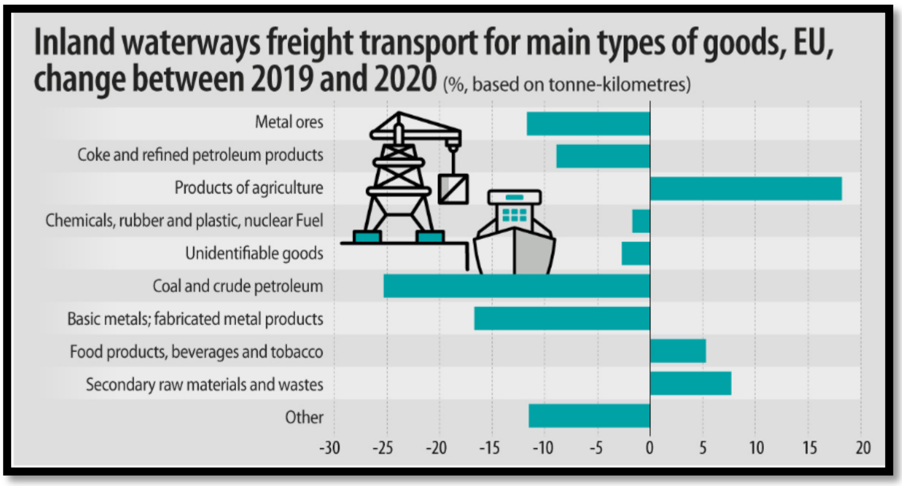
7	**How much effort would it take for you to learn and become proficient in using sustainable fuel technology for container bargaining?** Responses: a) A Lot of Effort, b) Quite A Bit Of Effort , and c) Moderate Effort
8	**How would you rate using sustainable fuel technology as an aid in terms of reduced environmental impact in container bargaining? To what extent do you believe that employing such technologies would have positive outcomes in terms of reduced environmental impact for container bargaining?** Responses: a) Strong Positive Outcomes, b) Moderate Positive Outcomes c) Slight Positive Outcomes and d) No Positive Outcomes
9	**How concerned are you about potential risks or challenges associated with using sustainable fuel technology in container bargaining?** Responses: (a) Very Concerned , (b) Moderately Concerned and (c) Not Concerned
10	**Overall, how likely are you to recommend sustainable fuel technology to others in the container bargaining sector?** Responses: (a) Very Unlikely to Recommend, (b) Unlikely to Recommend (c) Neutral, (d) Likely to Recommend and (e) Very Likely to Recommend

Appendix II

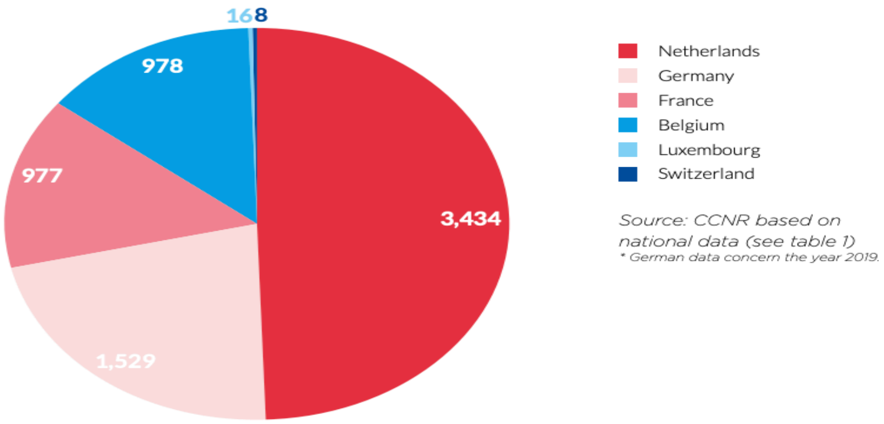


Supp. Figure 1: Inland waterways freight transport

(Source: iww_go_anave)



Supp. Figure 2: Inland waterways freight transport for main types of goods (source: Eurostat, 2021)



Supp. Figure 3: Number of dry cargo vessels in Rhine Countries, 2020