

DISSERTATION

The Importance of Green Ammonia in Namibia's Decarbonisation of Shipping: Economic Prospects and Port Infrastructure Obstacles

**Lazarus Emvula
Namibia**

A dissertation submitted to the World Maritime University in partial fulfilment
of the requirements for the award of the degree of Master of Science in Maritime
Affairs

2025

Declaration

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

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

(Signature): Lazarus

(Date): 23 September 2025

Supervised by: Dr. Fabio Ballini

Supervisor's affiliation: Associate Professor
Maritime Energy Management (MEM),
World Maritime University

Acknowledgements

I wish to express my sincere appreciation to Dr. Yohei Sasakawa, The Sasakawa Peace Foundation and The Nippon Foundation. Your generosity and vision for educational and research support in the maritime field made it possible for me to begin this academic journey.

I would like to thank my supervisor, Professor Fabio Ballini, for his genuine guidance, encouragement, and consistent support during my dissertation. His mentoring experience was essential for both the process and outcomes of my research.

I would like to give my sincere thanks to Professor Aykut I. Ölçer, Professor Alessandro Schönborn, and the entire MEM family for their academic support, constructive feedback and commitment to knowledge in maritime sustainability. Your support and encouragement made my experience much richer.

Lastly, I greatly appreciated the continuous support of the Directorate of Maritime Affairs (DMA), as well as the Emvula and Feris family. Their encouragement and belief in me gave me the platform to complete this dissertation.

I would also like to express my appreciation to the Nampont and Port of Antwerp-Bruges staff, who offered me time, thoughts, and data during my interviews. The information they shared was very important to the empirical basis of this research.

To all directly or indirectly contributing, I extend my sincere thanks.

Abstract

Title of Dissertation: **The Importance of Green Ammonia in Namibia's Decarbonisation of Shipping: Economic Prospects and Port Infrastructure Obstacles**

Degree: **Master of Science**

Green ammonia is starting to be viewed as a credible alternative fuel solution for maritime decarbonisation, however its implementation is limited in ports owing to various financial, regulatory and infrastructural constraints. This dissertation explores the feasibility of bunkering green ammonia in Namibia, drawing from the learnings of the Port of Rotterdam. The study utilizes a mixed-method approach, with semi-structured interviews of maritime engineers in the port, policy development experts, and risk managers that range across issues of stakeholder engagement, safety standards, and governance gaps. Scenario analysis can quantify the economic feasibility of bunkering under assumptions of vessel demand, fuel prices and capital expenditure.

In summary, the results of the study indicate that demand uncertainty, high upfront costs, and regulatory ambiguity are significant determinants of long-term feasibility. The study identifies opportunities for defining stakeholder engagement alongside economic modelling; creating a more cohesive framework for Namibia's ports to incorporate international best practice. The insights from the research have made a contribution to the existing policy and industry debate on ways for Namibia to position itself as a climate resilient and low-emission maritime hub.

KEYWORDS: CAPEX, Decarbonization, Bunkering, Green Shipping Corridors, Port Model

Table of Contents

Declaration	2
Acknowledgements	3
Abstract	4
Table of Contents	5
List of Tables	7
List of Figures	9
List of Abbreviations	10
Chapter 1: Background and Motivation	1
1.1 Background and Motivation	1
1.2 Namibia's renewable energy potential	2
1.4 The role of Walvis Bay port as a bunkering hub	4
1.3 Namport Governance Model	6
1.5 The role of the Namibian Maritime Authority	8
1.6 Problem Statement	9
1.7 Aims and Objectives	9
1.8 Research Questions	10
1.9 Assumptions and Potential Limitations	11
1.10 Research Scope	12
1.11 Ethical Issues	12
Chapter 2: Literature review	13
2. Literature review	13
2.1 Introduction	13
2.2 Overview of Alternative Fuels production in the Maritime Sector	13
2.2.1 SMR and PEM Hydrogen production	13
2.2.2 Green Hydrogen (GH ₂)	14

2.2.3 Green Ammonia (NH ₃)	15
2.3 Financial Drivers and Cost of Capital	15
2.3.1 Weighted Average Cost of Capital (WACC)	15
2.3.2 Levelized Cost of Hydrogen (LCOH)	18
2.3.3 Levelized Cost of Ammonia (LCOA)	19
2.3.4 Levelised Cost of Energy (LCOE)	20
2.4 Logistics: Transportation	22
2.5 Policy adoption	23
2.6 Environmental, Safety and Storage Considerations	24
2.7 Summary and Research Gap	24
Chapter 3: Methodology	26
3. Methodology	26
3.1 Introduction	26
3.2 Research Philosophy	26
3.3 Research Design	27
3.3.1 Literature review	28
3.3.2 Interviews	28
3.3.3 Mathematical Models and Crystal Ball: Monte Carlo Simulation	29
3.4 Data analysis	31
Chapter 4: Best Practices	32
4. Best Practice: Port of Rotterdam, Netherlands	32
4.1 Introduction	32
4.2 Identification of key uncertainty factors	34
4.2.1 Demand for Green Ammonia	34
4.2.2 Infrastructure Cost: CAPEX	35
4.2.3 Policy Environment	36

4.2.4 Infrastructure Development Timelines	36
4.3 Summary	37
Chapter 5: Case Study	38
Scenario Analysis	38
5.1 Baseline Scenario: Absence of alternative fuel bunkering facilities	38
5.2 Optimistic Scenario: Technical–Economic Assessment of Green Ammonia Production and bunkering at Nampont	41
5.2.1 Scenario Overview	41
5.2.2 Technical Configuration: Renewable Energy plant and bunkering setup	41
5.2.3 Inputs and Assumptions for the Green Ammonia Plant Bunkering	42
5.2.4 Financial Instruments: Payback, NPV and IRR	43
5.2.5 Financial Instruments: Tornado Model	46
5.3 Best Case Scenario: Favourable conditions - Landlord Model Scenario Overview	47
5.3.1 Projected Annual Vessel Calls for Green Ammonia Bunkering in Walvis Bay over a 15 year period	51
5.3.2 Simulated revenue distribution for green ammonia bunkering over a 15 year period	52
5.4 Worst Case Scenario: Unfavourable conditions Scenario Overview	53
5.5 Scenario Analysis	54
Chapter 6: Conclusion and Recommendations	56
6.1 Governance and Role	56
6.2 Safety of Ammonia Bunkering	57
6.3 Demand for green ammonia and profitability	57
6.4 Policy and Legislation	57
6.5 Recommendations	58

6.6 Future Research Scope	60
Bibliography	61
Appendices	74
Appendix 1	1
Appendix 2	2
Appendix 3	3

List of Tables

Table 1: CAPEX Table - Optimistic scenario	42
Table 2: OPEX Table - Optimistic Scenario	43
Table 3: Financial parameters by Nampont	47
Table 4: Estimated bulk carrier bunkering potential between 2025 - 2030	49
Table 5: Effect of Bunkering Scenarios on Project NPV	54

List of Figures

Figure 1: CO ₂ emissions by fuel or industry - Namibia	1
Figure 2: Wind power density (left) and total yearly solar irradiation (right)	3
Figure 3: Namport aerial view	5
Figure 4: Namport's Governance Philosophy	7
Figure 5: WACC of Cost Structure by Industry	17
Figure 6: Schematic Representation of Methodology Flow	27
Figure 7: Maasvlakte, Rotterdam	33
Figure 8: Concept design for ACE Terminal in Rotterdam	33
Figure 9: Namibia's current decarbonization position	38
Figure 10: Illustrated findings: Nominal vs Cumulative discounted cash flows	44
Figure 11: NPV and different discounted rates	45
Figure 12: Total Lifetime Cost (USD)	46
Figure 13: Walvis Bay as a Southern Node in the Gothenburg-Antwerp Green Corridor	50
Figure 14: Number of vessel calls (15 year period)	51
Figure 15: Revenue Streams (Over 15 year period)	52
Figure 16: Illustrated findings: Nominal vs Cumulative discounted cash flows	53
Figure 17: Cash-Flow Summary for Namport Favourable conditions - Landlord Model Scenario Overview cont.	74
Figure 18: Cash-Flow Summary for Namport Favourable conditions - Landlord Model Scenario Overview cont.	75
Figure 19: Figure 19: Modeling using Monte Carlo simulation (Vessel traffic and Revenue Potential)	76

List of Abbreviations

GHG	Greenhouse Gas
IMO	International Maritime Organization
IEA	International Energy Agency:
MME	Ministry of Mines & Energy
SADC	Southern African Development Community
MoU	Memorandum of Understanding
DMA	Directorate of Maritime Affairs
MEFT	Ministry of Environment, Forestry and Tourism
PPP	Public-Private Partnerships
R&D	Research & Design
WACC	Weighted Average Cost Capital
NMA	Namibia Maritime Authority
WMU	The World Maritime University
SMR	Steam Methane Reforming
PEM	Proton Electrolyser Membrane
NPV	Net Present Value
LCOE	Levelized Cost of Energy
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
LCOH	Levelized Cost of Hydrogen
LCOA	Levelized Cost of Ammonia
CRF	Capital Recovery Factor
IRR	Internal Rate of Return
DLCOA	Delivered Levelised Cost of Ammonia
RFP	Request For Proposal
LCOT	Levelised Cost of Transmission
O&M	Operation & Maintenance
STS	Ship-To-Ship
WPCAP	World Port Climate Action Programme
IAPH	International Association of Ports and Harbors
HES	Haven en Scheepvaart
APEC	Antwerp/ Flanders Port Training Center
POABI	Port of Antwerp Bruges
PEMWE	Proton Exchange Membrane Water Electrolysis
SEO	State Owned Enterprise
MWT	Ministry of Works and Transport
HFO	Heavy Fuel Oil
MGO	Marine Gas Oil
DC	Direct Current
AC	Alternating Current
VLCC	Very Large Crude Carriers

AfDB	African Development Bank
CF	Cash Flows
GSC	Green Shipping Corridor
EU	European Union
DCF	Discounted Cash Flow

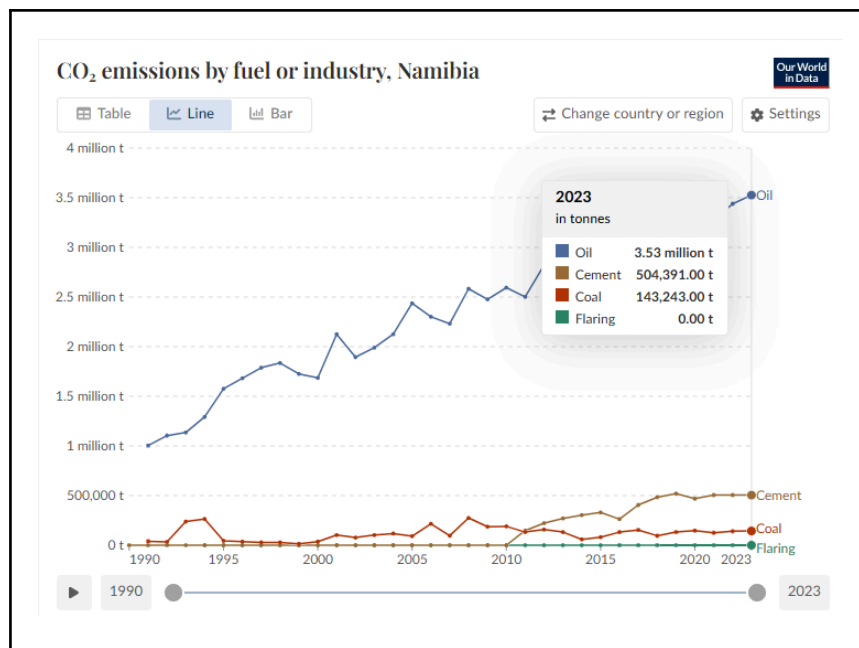
Chapter 1: Background and Motivation

1.1 Background and Motivation

Nevertheless, the maritime industry is also one sector of GHG emissions, specifically after the productive focus on sustainability initiatives, the International Maritime Organization (IMO) has years committed to having emissions levels decreased at least 50% by 2050. Namibia is committed to the Paris Agreement and taken deliberate and bold steps to reduce emissions and create and sustain a climate resilient economy.

In Namibia, economic growth and industrialisation has, over the last three decades, been fundamentally linked to fossil fuel use, especially in transport, manufacturing, and construction those being fossil fuel intensive sectors. While these developments created pathways to economic development, these have increased the ever-increasing annual growth of GHG emissions in the county.

Figure 1: CO₂ emissions by fuel or industry - Namibia



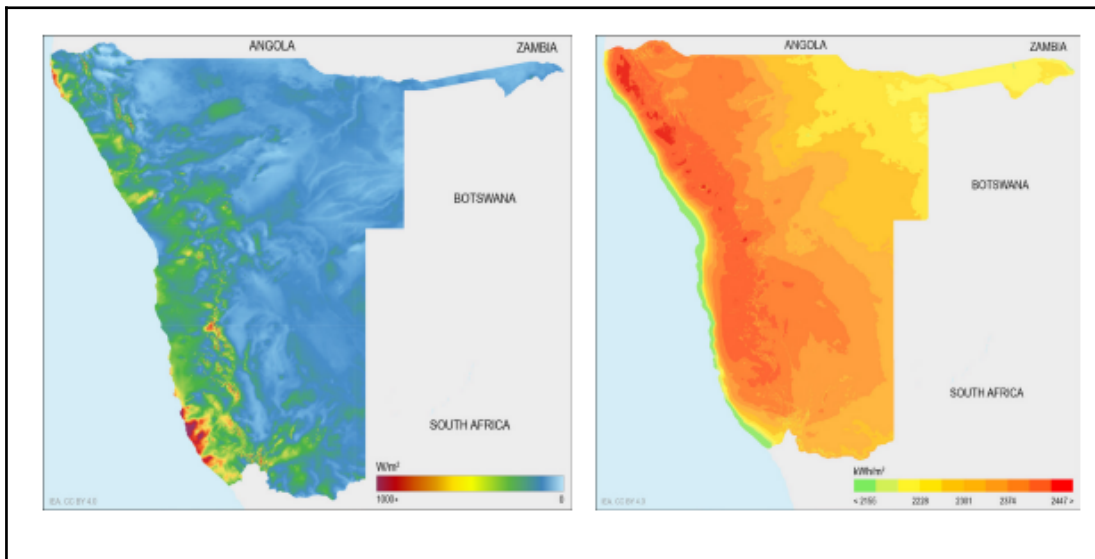
Source: Ritchie et al., (2020)

Oil constitutes the vast majority of Namibia's CO₂ emissions, rising from levels just above 1 Mt in 1990 to 3.53 mt in 2023, not only indicating the necessary shift away from oil for transport and industry, and even power generation, and an urgent need for a low-carbon alternative e.g., green ammonia in shipping. According to Amesho et al., (2022), the National pledges are generally to reduce emissions from the 2015-2030 BAU path and promote a cleaner and more efficient energy sector. In addition, Mapaure, (2022) states that Namibia increased its ambition to commit towards a 91% reduction in GHG emissions by 2030 avoiding 20 Mt CO₂e, with financing being drivers most limited; integrated policies to support industrial decarbonization renewable energy uptake, and cleaner fuels become more essential.

1.2 Namibia's renewable energy potential

Namibia is located in the Southern Africa region, consisting of a lengthy coastline and emerging marine economy leading it to sustainable shipping endeavors to help reduce GHG emissions. Namibia has a climate which produces high sunshine and low quantities of rainfall, providing suitable conditions for solar energy generation and storage. A study by Tilman and Kantel (2024), states that Namibia is competitive with solar and wind energy, which are crucial components that can be used to produce green hydrogen and derivatives that will contribute towards the decarbonization of the maritime industry. In addition, a study conducted by Gado et al., (2024) Namibia has no water stress levels, thus it is a promising green hydrogen spot as a result of its high levels of water availability for water electrolysis. Moreover, in terms of temperature Namibia is one of the countries alongside Egypt that illustrate the highest levels of global irradiance 6.96 kWh/m².

Figure 2: Wind power density (left) and total yearly solar irradiation (right)



Source: *International Energy Agency (IEA), (2024)*

Kamati et al., (2023), states that Namibia is well placed and fortunate to have access to wind and solar power that can be harnessed to reduce the country's dependence on coal-powered energy plants, such as that of Namibia Power Corporation (Proprietary) Limited, therefore increasing energy security. Harnessing the potential of energy resources provides a foundation for sustainable energy production. IEA, (2024) mentions that as a result of the high-quality solar and wind renewable energy potential, coupled with vast land availability for large scale projects, Namibia finds itself in an ideal position to produce renewable hydrogen and ammonia.

Altenburg et al., (2025) states that the global market for green ammonia is anticipated to expand rapidly and be used as a low-carbon shipping fuel, fertilizer production and other chemical industry applications in place of "grey" ammonia derived from fossil fuels. By 2030, green ammonia should be exported at competitive prices of about US\$400/t (per tonne), and by 2040, it should drop to US\$350/t; at lower prices, Namibian green ammonia would even be cost-competitive with grey ammonia.

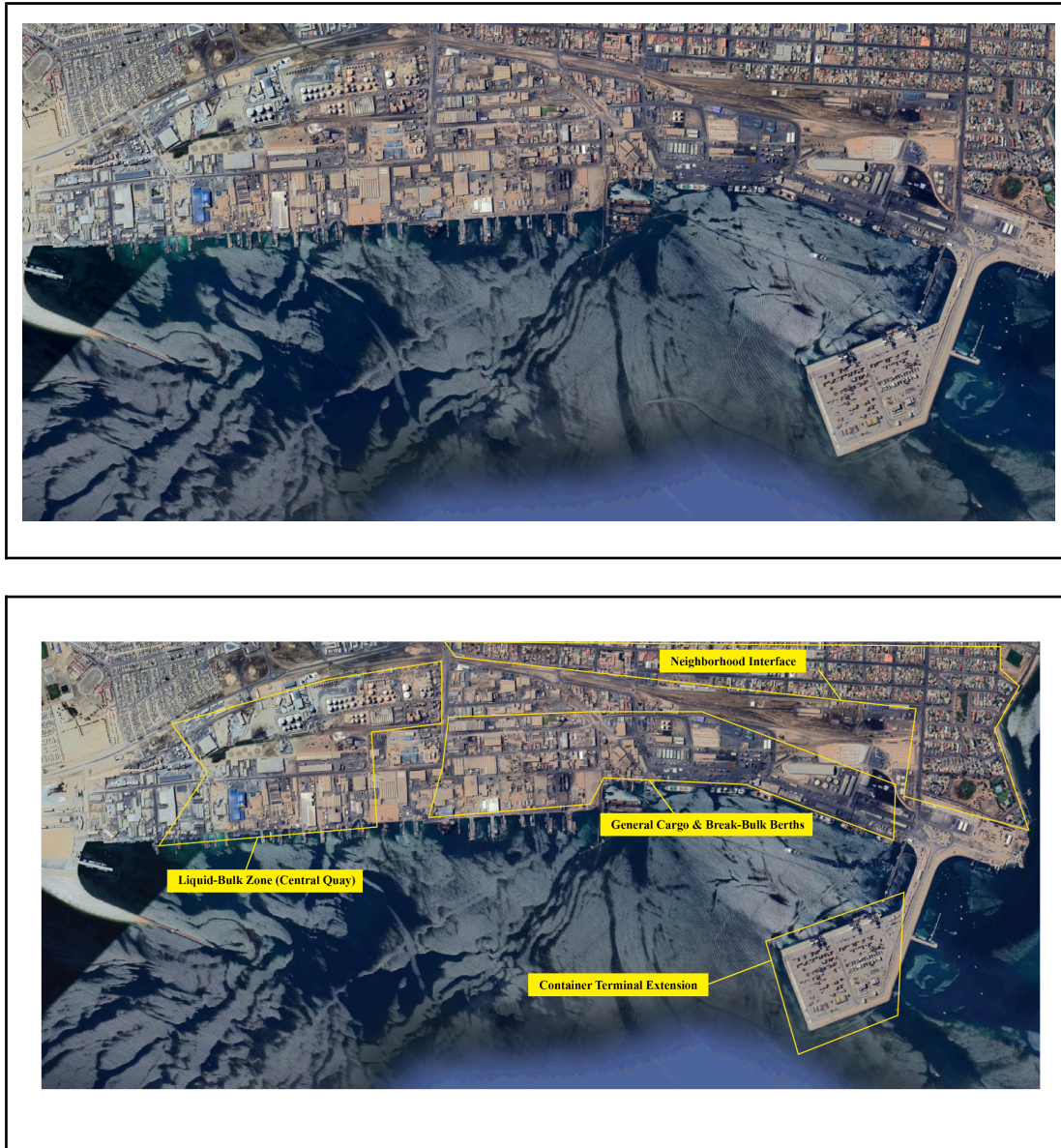
According to a report published by Ministry of Mines & Energy (MME) (2022), By generating an estimated 280,000 jobs by 2030 and 600,000 jobs by 2040, the hydrogen industry would also expand the domestic labor market. About 30% of these would come directly from the industry, 20% indirectly from goods and services, and 50% as a result of rising household incomes. Because Namibians lack the skills to perform all of these jobs, the government will fund training and customized immigration laws. In addition, Imasiku et al., (2021) states that the development of green hydrogen and green ammonia is a key component of Namibia's five-year economic strategy, according to the country's 2021 Harambe Prosperity Plan II. Further emphasizing that the goal of this project is to use Namibia's plentiful solar and wind resources to build facilities for downstream ammonia synthesis and large-scale electrolytic hydrogen production.

1.4 The role of Walvis Bay port as a bunkering hub

Ford (2006), states the outside world accounts for the vast majority of Africa's international trade, which should rise to much more than the 2% it currently claims as globalization pushes more imports, and as the rest of the world realizes how to tap into Africa's vast resources. This means Africa also needs to invest heavily, wisely, and purposely in ports, if it is to advance its international trade. In addition, Savage (2015), much of the developing world sees “gateway” status as desirable, and the development of logistics clusters has been developed as a tool to facilitate access to it. Henceforth, Namport Property Holdings (Pty) Ltd (2024), Namports Property Holdings (Pty) Ltd and Walvis Bay Park should be positioned as the SADC gateway, given its mid-coast position which offers shorter paths between Southern Africa and the European, Far East, and American markets. Namport Property Holdings (Pty) Ltd (2024), states Walvis Bay is the country's largest commercial port at (6.6 Mt/yr), and as a certified organizational to ISO 14001:2015, ISO 9001:2015 and ISO 45001:2018 and while complying with the ISPS Code, it handles containers plus bulk, break-bulk and transshipment cargoes. Namport Property Holdings (Pty) Ltd (2024) stated that North Port's new liquid-bulk jetties of vessels up to 90,000 dwt was built to allow for

potential future green-fuel supply, connected to pipelines and tank farms with 1.5 Mt/year capacity that could be adapted to handle green ammonia in five years and have enough land to position both sites as new industrial-energy hubs.

Figure 3: Namport aerial view



Source: Google Earth Pro, Imagery © 2025 CNES/Airbus, accessed 03 July 2025, 22°57'02"S, 14°29'31"E

The illustrated satellite image of the Namport-managed port complex in Walvis Bay shows large liquid-bulk storage tanks and special jetties located in the western part of the quay. These tanks currently hold petroleum products and grey ammonia, but they could be converted to pressurized or refrigerated green ammonia bunkering. A number of break-bulk berths that manage project cargo and mineral exports are located immediately eastward; their adaptable modular design provides room for loading arms or temporary ammonia storage skids. The newly built container terminal peninsula at the terminal's far left has large laydown yards, intermodal rail sidings, and deep-water access -16 m draft - suitable for ISO tank operations or specialized dual-fuel carriers. The visible rail spurs and the highway arteries that form the four key corridors in Namibia, Trans-Kunene, Trans-Kalahari, Trans-Oranje and Travel Bay - Ndola - Lubumbashi, may also be partially utilized for possible future pipeline or rail transportation for ammonia.

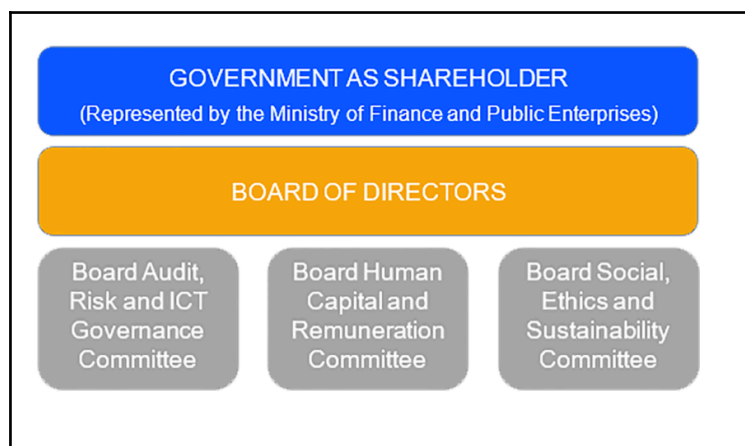
Lastly, as the port transitions to accommodating toxic or flammable alternative fuels, the adjoining residential communities emphasize the need for thorough safety practices, community engagement, and environmental monitoring. IMO Cares, (2024) states that Walvis Bay is Namibia's test site for cleaner shipping fuels, so it's more than just another port on the map. The port is spearheading a practical experiment in which tugboats and yard cranes will operate on a combination of hydrogen and diesel in accordance with the IMOCARES guidance. Namport and its German partner are establishing emergency protocols and safe on-dock hydrogen refueling stations in order to achieve that.

1.3 Namport Governance Model

The leadership team at Namport functions as a cohesive group of advisors, working together to maintain the port's smooth and responsible operation. According to Namport Property Holdings (Pty) Ltd, (2024), the Minister appoints seven independent directors who convene on a regular basis to make strategic decisions. While closely monitoring safety, finances, and ethics, they have given the CEO and

management clear "green lights" on what they can do on a daily basis. In addition, they have three dedicated committees to ensure that nothing is overlooked: one oversees the IT, audits, and risks; another ensures that employees are properly supported and compensated whilst the third looks out for social and environmental obligations.

Figure 4: Namport's Governance Philosophy



Source: *Namport Property Holdings (Pty) Ltd, (2024)*

Namport Property Holdings (Pty) Ltd, (2024) mentions that Namport's governance aligns with national policy, with the government setting rules and providing funding while Namport manages governance through regular meetings and reportbacks. Employees are informed and protected through processes like newsletters, training, and health safety and environment (HSE) initiatives. Customers from global shipping lines to local cargo owners receive regular communications to check in, ensuring bargain-pricing and fast turn-around times. Namport maintains suppliers through ongoing communication, updates to the website, timely payments, and ethical standards. Local communities and media are included to understand and build participation and trust.

According to the Namport Property Holdings (Pty) Ltd, (2024) report, Namport is actively changing its business strategy to become a full landlord port authority, which

would allow it to keep ownership of port infrastructure while contracting out all operational tasks to experts in the private sector. The planned concession of the new container terminal at Walvis Bay, which is scheduled for financial close in 2024–2025, this intermediate configuration sometimes referred to as a "tool port" model has already started to move toward landlord status. In order to guide this transition, the Namport has entered into a Memorandum of Understanding (MoU) with the Port of Antwerp-Bruges International to complete this migration over the next decade thereby focusing its resources more on core activities such as infrastructure investments and strategic asset management.

1.5 The role of the Namibian Maritime Authority

According to the Ministry of Works and Transport (2018), the Directorate of Maritime Affairs (DMA) is located within Namibia's Ministry of Works and Transport. Additionally, New Era Namibia (2006) elaborates on the DMA's functions as the state's maritime administration authority, which is defined in the Merchant Shipping Act (1951, as amended) and guided by policy directions. Its main functions involve protecting life and property at sea, controlling ship-source pollution and promoting Namibia's maritime interests. The DMA was first established in 1995 after independence, and became the executing arm of the government regarding maritime affairs, enforcing international conventions as well as maritime law, into Namibian waters. The DMA is in charge of carrying out the major IMO conventions such as SOLAS, MARPOL and STCW on a national level. Namibia Green Hydrogen Programme (2024), states that Namibia aspires to lead the world in the production of green hydrogen and ammonia, and the maritime industry is preparing to support the use of alternative fuels for shipping under the direction of the DMA.

This research aims to analyze and establish the economic benefits of adopting green ammonia and green hydrogen as alternative fuels as Namibia's transition away from the use of fossil fuels. This will be done through the local feasibility assessments, identifying the economic rewards, and assessing global trends. This study aims to

offer useful and practical results for Namibia's Maritime Authority as one of its considerations in its sustainable development strategy.

1.6 Problem Statement

According to Kaura, (2025), the Ministry of Environment, Forestry and Tourism (MEFT) indicates that Namibia is facing growing climate risks, including extreme drought, high temperatures, and water scarcity which could reduce GDP by as much as 3.6% annually by 2050 if there are no measures taken. However, at this downside of challenges and vulnerabilities, Namibia has great green strengths of renewable energy, and sustainable advantages in renewable energy, especially in solar and wind. The global shift towards decarbonization has resulted in the swift adaptation of alternative fuels in order to reduce GHG emissions in the maritime sector which has ports worldwide looking at investing in renewable technologies as part of the GHG emissions reduction strategy set by IMO, and to improve competitiveness. Presently, Namibia's ports are slow in implementation due to limited infrastructure, uncertainty in economic analysis and high costs in investments.

As a result of this uncertainty, the economic implications of alternative fuels hinder Namibia's Port Authority to develop empirical policies and lucrative investments. By addressing this gap, Namibia's maritime sector will be poised to have highly competitive ports in Southern Africa and contribute towards the country's decarbonization targets.

1.7 Aims and Objectives

The aim of this research is to evaluate the probable economic benefits for Namibia's Maritime Authority through the adoption of alternative fuels in order to align its policies and strategic position in Southern Africa. Moreover, this study looks at the IMO's emissions reduction strategy for 2050 to reach net zero emissions. By analyzing the potential economic benefits and hindrances, it will provide an

empirical framework that will serve as a reference for the port of Walvis Bay. Primarily this will be done through the scope of the two promising alternative fuels, mainly green ammonia and green hydrogen.

The significance of this thesis outlines economic conditions for Namibia's Maritime Authority in order to improve its competitive advantage. Additionally, it creates an opportunity for Namibia to demonstrate its commitment to reducing GHG emissions and align its national ambitions with the global environment. More generally, the proposed significance of this research will produce research-finds that will assist facilitators to come up with empirical strategies to green initiatives. Finally, this thesis will provide much needed information to be a leader in sustainable port operations in Southern Africa.

The research will focus on the three (3) objectives:

1. Assessment of the economic, environmental and possible functional consequences of green ammonia and/or green hydrogen for the Walvis Bay port infrastructure
2. To recommend ideal strategies to facilitate the adaptation of green ammonia and/or green hydrogen in relation with Namibia's decarbonization goals
3. Assessment of possible barriers to adaptation and implementation of alternative fuels

1.8 Research Questions

1. What are the techno-economic, environmental GHG and non-GHG and operational implications or consequences of green ammonia and green hydrogen into the Walvis Bay port infrastructure?
2. In what way could the National Maritime Authority of Namibia develop an alternative-fuel strategy for green ammonia and/or hydrogen aligned with

international best practice and supporting national decarbonization objectives?

3. What technical, regulatory, financial and institutional barriers must be addressed to enable the Maritime Authority's transition to green ammonia and hydrogen bunkering?

1.9 Assumptions and Potential Limitations

There are several assumptions in relation to the thesis conducted.

1. Assumptions About Consumer Preference for Green Fuels: According to global decarbonization trajectories, green hydrogen and green ammonia are expected to remain the preferred zero-carbon energy carriers in maritime bunkering during the study period.
2. Growing Awareness of Sustainable Shipping: The analysis predicts that as green-fuel-capable vessels are gradually adopted, so too will the need for green-fuel bunkering facilities in Southern Africa.
3. An environment of supportive policies: To reduce the risk associated with investments in green-fuel infrastructure, Namibian policymakers are expected to preserve or improve incentives such as Subsidies, Tax credits, Public-Private Partnerships (PPP), as well as regulatory clarity.
4. Production Technologies' Scalability: The study makes the assumption that storage, Haber-Bosch, and electrolyzer technologies will scale profitably to accommodate anticipated port-bunkering volumes without imposing unaffordable supply-chain or Research & Design (R&D) constraints.
5. Stable Financial Parameters: It is assumed that financial inputs such as exchange rates, Weighted Average Cost Capital (WACC) ranges remain within plausible bounds

The following limitations have been observed:

1. Time frame: The time required to conduct primary research extensively, along with economic analysis in relation to global trends is limited.
2. Uncertainty in global trends: Projections in relation to the availability, cost and uptake of alternative fuels such as green ammonia and green hydrogen are quite volatile, therefore technological breakthroughs and carbon pricing mechanisms could impact the long-term economic forecast presented in this study.
3. Data availability: Reliable and granular data specific to Namport and Namibia's maritime sector such as bunkering volumes and infrastructure readiness is limited and not readily accessible online. Therefore, most of the analysis is informed by Namport, Namibia Maritime Authority (NMA) officials and international analogues which may not perfectly reflect appropriate data.
4. Regulatory and Policy: The national decarbonization and energy framework is constantly evolving, therefore some policy references may be outdated by future legislation by the time this paper is published.

1.10 Research Scope

The study will focus on the possible usage of alternative marine fuels, particularly green ammonia and green hydrogen. The geographical area of concentration is focused on the Walvis Bay port, where the transition will be considered. Based on the contemporary techno-economic information, global trends and future predictions, the research looks to establish the economic implications and outcomes of utilizing either green ammonia or green hydrogen. Policy structures will be critical with a focus on international benchmarking and green port development conditions. In addition, this research will also look to determine the readiness of the Walvis Bay port in terms of infrastructure development through identification of potential financial and technical barriers to adoption.

1.11 Ethical Issues

This research study has been approved by The World Maritime University (WMU) Research and Ethics Committee, which maintains academic ethics and integrity. This study has followed all ethical standards, such as confidentiality, consent of data collected and has observed privacy rights. Chapter three (3) of this study explains the methodology used in the context of the study. It offers an overview of the research methodology, such as the rationale and techniques used for data collection and interpretation.

Chapter 2: Literature review

2. Literature review

2.1 Introduction

It is evident that shipping is one of the major contributors to international trade, yet it generates nearly 3% of anthropogenic CO₂ emissions. This has led to the motivation to investigate and explore the green energy alternatives and transporters such as hydrogen and its derivative ammonia increasingly. They are viewed to be one of the ideal zero carbon alternatives that can accompany renewable electricity in manufacturing applications and can be retrofitted combined with existing ports infrastructure.

2.2 Overview of Alternative Fuels production in the Maritime Sector

2.2.1 SMR and PEM Hydrogen production

The production of hydrogen can be achieved either through Steam Methane Reforming (SMR) or Proton Electrolyser Membrane (PEM). Kadam et al. (2025) undertake a comparative techno-economic assessment of (SMR) and (PEM) electrolysis for large-scale hydrogen production. They report that conventional SMR, where methane reacts with steam over a nickel catalyst generates approximately 9–12 kg CO₂ per kilogram of H₂, but that a sorption-enhanced SMR (SE-SMR) configuration, which integrates in-situ CO₂ capture using a calcium-based sorbent, can reduce net emissions to around 1.77 kg CO₂-e/kg H₂ while simultaneously boosting overall conversion efficiency.

In contrast, PEM electrolysis delivers electrical-to-hydrogen efficiencies of approximately 82 % on a higher-heating-value basis and supports rapid load-following, ramping from cold start to full capacity in seconds, which makes it especially compatible with variable renewable energy inputs. However, its high

current-density operation (up to 2 A/cm²) necessitates costly noble-metal catalysts and results in significant electricity demand: the 50 ton-per-day PEM plant modelled consumes 135 MW of power and 18.6 t/h of water to produce 2.08 t/h of hydrogen at 51.5 % efficiency, illustrating the trade-off between compact system design and elevated energy intensity. According to Barbir, (2005), PEM are built with corrosion-resistant metal components and noble-metal catalysts, these electrolyzers deliver ultra-pure (>99.9 %) hydrogen at pressures up to 200 bar without incurring major energy penalties. Typical energy use ranges between 4.5 and 6.0 kWh per normal cubic meter of H₂ (equivalent to 65–80 % efficiency on an HHV basis), although system-level efficiency can be reduced by power-conditioning losses when connected to intermittent renewables. In all, Barbir concludes that PEM electrolysis represents a compact, high-purity hydrogen production pathway perfectly suited to integration with renewable energy systems, despite its increased capital cost compared to alkaline technologies. Given this, the nature of this study will focus on PEM, as opposed to SMR.

2.2.2 Green Hydrogen (GH₂)

Squadrito et al., (2023), explains that green hydrogen earns the term "green" when there are no CO₂ emissions associated with its production, however the most adopted is through the using of renewable energy sources based on electrochemical water splitting also known as electrolysis. In addition, Hassan et al. (2023) describe green hydrogen, produced via water electrolysis powered by wind or solar, as a truly zero-emission fuel used across industries from power plants to trucks without any tailpipe CO₂. Ruppel and Katoole (2023) add that hydrogen's flexibility can strengthen energy security and spur local economies through new jobs in electrolyzer manufacturing and maintenance. Yet Vallejos-Romero et al. (2022) point out that hydrogen's ultra-low boiling point or high-pressure compression dramatically bumps up both equipment costs and energy consumption, while Ghafri et al. (2022) emphasize that few ports are equipped for cryogenic storage, slowing hydrogen's march into mainstream maritime use.

2.2.3 Green Ammonia (NH₃)

Al-Aboosi et al. (2021) argue that the green ammonia produced by synthesizing nitrogen with hydrogen produced from renewable resources meets the requirements established by the IMO for long-haul fuel and has a higher energy density than hydrogen on a per-liter basis, therefore simplifying the storage and reducing the cost of transportation. Currently, grey-ammonia facilities are planned in Walvis Bay, thereby facilitating a transition to green ammonia to be more of an upgrade than a new build. Kurien and Mittal (2022) confirm through experiments that conventional ship engines accept green ammonia with minimal adjustments. This is because ammonia remains liquid at near-ambient conditions. On the safety side, Chorowski et al. (2023) states that ammonia becomes dangerous at concentrations as low as 5–30 ppm and exposure above 300 ppm risks lung damage thus any bunkering terminal must invest in rigorous leak detection and emergency protocols.

2.3 Financial Drivers and Cost of Capital

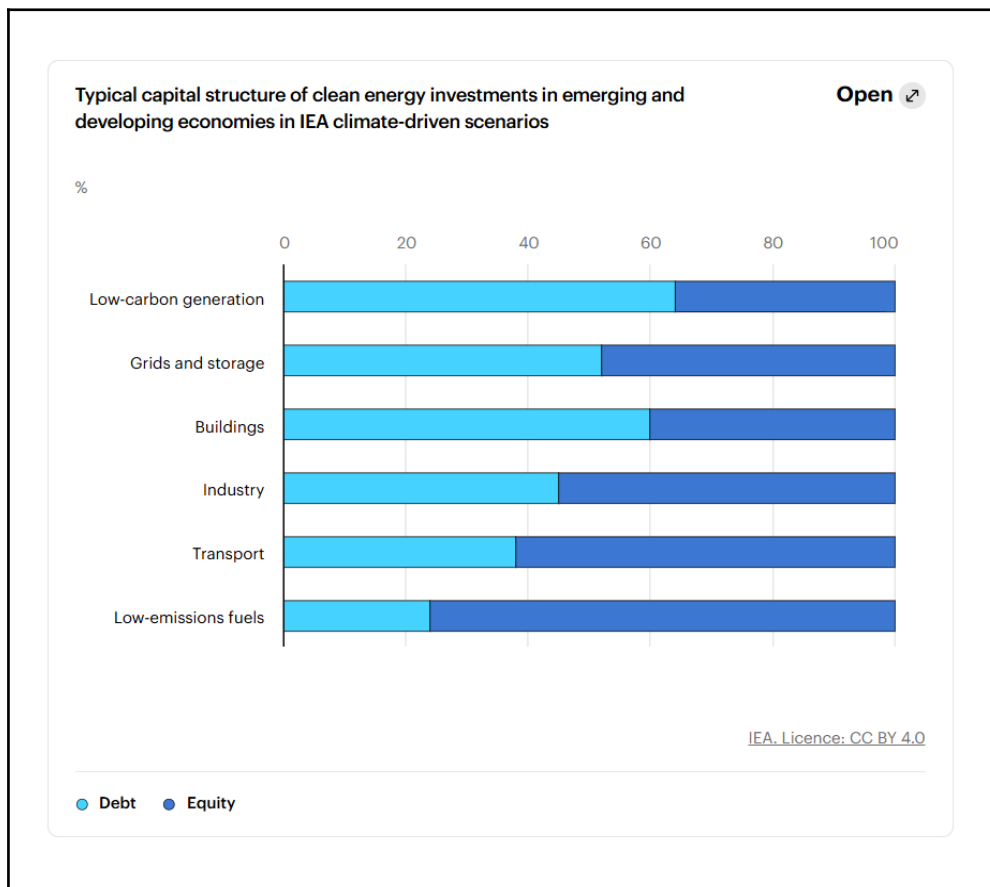
Effective decarbonization of maritime fuels hinges not only on technical performance but equally on the financial frameworks that underwrite capital-intensive infrastructure. The cost of capital and the debt equity composition is a critical feature of project economics in relation to renewable powered hydrogen and ammonia production because it is a determinant of the recovery of initial investments within a time frame. The following discussion, based on utility scale solar PV studies, provides evidence of how differences in the weighted average cost of capital (WACC) can introduce significant differences in levelized cost outcomes, as well as the importance of having access to low cost finance to unlock the economic potential associated with these emerging green fuel technologies.

2.3.1 Weighted Average Cost of Capital (WACC)

According to Bancel et al., (2013), the WACC is a key concept in corporate finance, representing the benchmark discount rate for assessing new investments and measuring firm value. WACC is the foundation of Net Present Value (NPV) analysis in practice, directs large capital-allocation decisions, and provides the basis for fair-value estimates in financial reporting. Vartiainen et al. (2019), states that the WACC emerges as the dominant driver of utility scale solar PV economics, outweighing both capital and operating cost variations. The authors model Levelized Cost of Energy (LCOE) outcomes under nominal WACC rates of 2%, 5%, 7% and 10%, demonstrating that a rise in WACC from 2% to 10% nearly doubles the LCOE, whereas a $\pm 20\%$ swing in Capital Expenditure (CAPEX) or Operational Expenditure (OPEX) shifts LCOE by only $\pm 14\%$.

Steffen (2020) provides a comprehensive review of the WACC as applied to renewable-energy investments among three WACC formulations namely; vanilla, after-tax, and pre-tax with each reflecting the treatment of corporate taxation and regulatory frameworks, and emphasizes that WACC can account for 12–37% of solar PV LCOE in developed markets and up to 50% in emerging economies. Harvey (2020) argues that a single blended WACC may understate costs associated with projects when equity returns are sustainably reinvested at rates distinct from required returns by equity investors, while suggested separate levelized cost and associated weighted average cost of debt and equity should be computed based on the required returns of each owner based on their capital structure. Dato et al. (2025) point out that since many African projects will only see a 15% WACC compared to 10% in developed regions, there are a number of real and perceptual risks such as sovereign default, potential political instability and hedging on shockingly shallow financial markets. Collectively they represent higher barriers to capital-intensive electricity investments and low-carbon transitions.

Figure 5: WACC of Cost Structure by Industry



IEA (2021), Typical capital structure of clean energy investments in emerging and developing economies in IEA climate-driven scenarios, IEA, Paris

According to the IEA’s climate-driven scenarios for emerging and developing economies, the financing mix varies markedly across clean-energy value chains, with direct implications for green hydrogen and ammonia projects. Utility-scale wind and solar farms, which are classified as “low-carbon generation” are typically financed with approximately 65% debt and 35% equity, reflecting their established risk profiles and bankability . In contrast, the electrolytic hydrogen and Haber–Bosch ammonia synthesis facilities powered by those renewables fall under “low-emissions fuels,” where the capital structure shifts to roughly 25% debt and 75% equity, indicative of higher perceived project risk and lower availability of concessional finance.

2.3.2 Levelized Cost of Hydrogen (LCOH)

The levelised cost of hydrogen provides an insight into the economic performances of hydrogen use from renewable sources. According to Vartiainen et al. (2021), their analysis indicates that as of 2020, LCOH varies extremely by location, ranging from as low as 1.0 €/kgH₂ in high-irradiance locations like the Atacama Desert to approximately 2.7 €/kgH₂ in lower sunlight concentration locations like Helsinki. The significant differences in costs are primarily a result of solar availability and system load factors. As we advance, the authors project that mid-term LCOH levels (by 2030) could fall by one-third, to 0.7–1.8 €/kgH₂, if photovoltaic (PV) capital expenses from 0.43 to 0.25 €/Wp and electrolyzer expenditures (from 400 to 240 €/kWel) continue downward. By 2050, long-term projections expect LCOH to fall further to 0.3–0.9 €/kgH₂ as learning rates are boosted with cumulative PV and electrolysis system deployment. Moreover, further analysis indicated that parameters which could alter LCOH by 30% are WACC and solar irradiance availability in that specific region. Moreover, as the electricity price increases, it's important to monitor the cost reduction of solar PV as the decline in their prices could help absorb these costs.

The data gathered by Minutillo et al., (2021) indicate that the size of the plant is a huge determining factor in the outcome on the economic viability of the project. Adding that, the plant which had the highest capacity in terms of production of 200 kg/day had a 20% reduction in the LCOH, compared to the smallest one which had an output of 50 kg/day. In addition, Rivarolo et al., (2018) study found out that hydrogen produced from electrolysis and PV can has a cost that ranged from 15.55 €/kg to 22.5€/kg and this depended on the storage being utilized. In addition, the lowest LCOH of 9.29 €/kg H₂ occurs in a medium-scale station with a 50% grid and 50% of PV combination. It is also observed that the highest LCOH was in a micro scale station at 12.48 €/kg H₂ under 100% grid supply.

2.3.3 Levelized Cost of Ammonia (LCOA)

Prior to the adoption of green ammonia for Namibia, it's vital to consider the underlying costs associated with a large-scale green ammonia production plant. Shepherd et al., (2022) states the development of an open-source techno-economic model which can encompass all significant capital and operational expenses for a 1 MMT NH_3/yr under a step change scenario. The scenario highlights a 25 year plant life and a 7% discounted rate. The presupposed framework presumes a Polymer electrolyte membrane (PEM) electrolyser with a capital expenditure (CAPEX) of USD 643/kW and an operating expenditure (OPEX) of USD 20/kW per year, incorporating designated energy consumption of 50 kWh/kg H_2 . Similarly, a wind farm at USD 1,294/kW CAPEX with an OPEX of USD 18.14/kW per year, solar PV with CAPEX of USD 557/kW and with an OPEX of 12.33/kW per year - both at relevant periods of planned electricity output - and battery storage of 8 hours at a capital expenditure of USD 848/kW and an operating expenditure of USD 20/kW per year. In parallel, the framework states desalination for electrolyser water input and output with a CAPEX of USD 36,000/(m³/h) with an OPEX of 2% of this CAPEX, with energy input of 3.9 kWh/m³; an underground hydrogen storage this-home; a CAPEX of USD 459/kg with an OPEX of USD 75/kg per year; a Haber-Bosch synthesis; A CAPEX of USD 378/t NH_3 with an OPEX of 2% of the CAPEX; 0.03 kWh/kg NH_3 .

Taking these assumptions into account, the levelized cost of ammonia (LCOA) is estimated at USD 0.40/kg, which appears to be more cost competitive for bunkering than existing port infrastructure. A sensitivity analysis points out that even a 5% increase in the capacity factor or 10% CAPEX reduction of the electrolyser can lower the LCOA by approximately USD 0.02 - 0.04/kg. Moreover, Wang et al., (2023) has presented a mixed-integer programming model for off-grid green ammonia production which is directly relevant to Namibia's alternative fuel adoption. The study takes into account three (3) alternative scenarios namely; solar only, wind only and a hybrid renewable system paired with both flexible and

inflexible Haber-Bosch synthesis loops, hydrogen buffering and battery storage. The data showed that the LCOA is cheapest at AUD 659/t NH₃ for a hybrid system which utilizes both solar and wind with a flexible synthesis which enable to ramp up or down it's ammonia production, and the second best alternative is a solar power only system which averages AUD 960/t NH₃, followed by using an inflexible hybrid system which would see AUD 1,000/t NH₃ and lastly the most expensive would be utilizing wind power only, even in a flexible plant it would yield AUD 1,200/t NH₃.

Moreover, Wang et al., (2023) state that transforming an ammonia production plant from inflexible to flexible Haber-Bosch reactor would significantly reduce the LCOA by 30% and using a hybrid system reduces the strain of massive battery implementation and hydrogen storage. In addition, the sensitivity analysis indicated that the reactor's minimum load constraint is a major cost driver, the discounted rate of 7.5% WACC and using a hybrid system helps make up for the expensive equipment cost.

2.3.4 Levelised Cost of Energy (LCOE)

It is crucial to use a standardized metric that accounts for all lifetime costs on a per-unit basis before comparing energy generation options. LCOE is used to assess the energy generation costs of energy technologies. The Levelised Cost of Energy (LCOE) is a comprehensive, per-unit metric that translates every cost incurred over a generation asset's lifetime capital expenditure, operations & maintenance, fuel, and decommissioning into a single "cost per megawatt-hour." This enables cross-technological, cross-scale, and cross-location comparisons. Aldersey-Williams & Rubert (2019) define LCOE as the discounted lifetime cost of ownership and use, expressed in £/MWh. As a result, LCOE has emerged as the benchmark for assessing nuclear power, offshore and onshore wind, standalone photovoltaic (PV) arrays, biomass conversion, concentrated solar power (CSP) with thermal storage, battery energy storage, and even hybrid schemes (such as PV + battery + cogeneration). According to Parrado et al. (2016), utility-scale PV's LCOE is expected to decrease

from roughly 12.9 cUS\$/kWh in 2014 to 7.8–8.4 cUS\$/kWh by 2050, while CSP with up to 15 hours of molten-salt storage will decrease from approximately 15.3 cUS\$/kWh to 7.6–9.0 cUS\$/kWh during the same time frame. By mid-century, round-the-clock delivery is achieved at a blended LCOE of 7.7–8.6 cUS\$/kWh in a modeled 20 MWp PV + 30 MW CSP facility, which is comparable to standalone PV.

According to Sung & Jung, (2019), despite being a popular tool for comparing the long-term costs of energy technologies, LCOE doesn't always account for the complexity of actual investment decisions. The loan payback period usually ends before the entire lifespan of the project, and in instances where cash flow is frequent and steady, then it can be paid back sooner resulting in lower interest rates and an increase in equity internal rate of return (IRR). However, this isn't universal as some form of technologies such as renewables may not speed up repayments as they are often associated with fluctuations depending on the region. Ueckerdt et al. (2013) argue that traditional LCOE omits the integration costs caused by variable renewables: balancing, grid reinforcement and “profile” costs, over-generation and curtailed output when supply exceeds demand. They present System LCOE, in which the difference between residual system costs with and without renewables is equal to the marginal integration cost D . These integration costs, which are primarily caused by profile effects rather than balancing or grid upgrades, can equal wind's base generation cost in a generic European thermal system once wind penetration surpasses roughly 20% of annual generation. This framework emphasizes that low generation costs for solar and wind must be combined with integration strategies to maintain overall economic viability.

The additional costs of integrating variable renewables such as wind and solar into the power system are not taken into consideration by LCOE, despite the fact that it is a practical and generally recognized tool for comparing the lifetime costs of various energy technologies. Once renewables produce more than 20% of the country's electricity, these integration costs which include balancing, grid upgrades, and

overproduction losses can become substantial. To remedy this, Ueckerdt et al. (2013) propose System LCOE which does account for these additional costs and can thereby identify the "welfare-optimal" level of renewable penetration. The conclusion is that successful deployment of wind and solar can lead to low overall costs, but only with various system-level solutions, which include storage, some demand shifting, and a more resilient many of our grids.

2.4 Logistics: Transportation

This chapter analyzes the 100 km land-side link between a proposed green-ammonia plant proposedly located at –23.75, 14.25 and Walvis Bay Port, and considers factual CAPEX, reliability and emissions impacts of each mode of linking whether pipeline, rail or trucking. The previous work on identifying the operational and monetized costs and emissions of each transport mode by Wang et al., (2022), recognizes that some existing pipelines can transport liquid ammonia with few logistical modifications. In addition, Salmon et al., (2021) mentions that a standard route planning utilizes a scaling factor of 1.2 for terrain and right of way for sub-100 km transport; the pipeline does not require intermediate booster pumping stations and thus simplifies the drawn costs, known as DLCOA. Joseph Sekhar et al., (2024) mentions that the preliminary reports show benchmark figures of ammonia pipeline transport around USD 2 per tonne transported per 100 km, while reported pipeline figures by Hui et al., (2024) for hydrogen indicate the costs are much higher in terms of per kg, illustrating that ammonia has an economic advantage to be transported inland.

Genge & Müsgens (2025) indicates that modal economics are a function of demand; low demand less than approximately 100 GWh per annum, at approximately tens of kilotonnes typically favors trucking, moderate demand is suitable for rail, while pipelines should typically be suitable for higher demand where the amortized fixed CAPEX costs are neutralized. Furthermore, where cost is less of a factor return on investments for pipelines should strongest support "green" credentials due to its

reliability where Namibia presently lacks electric-trucks and hydrogen-rail infrastructure, while reducing the risk of not being reliably available (e.g. road induced traffic congestion) or damages on time-critical bunkering. All in all, Ștefan Cristian Galusnyak et al., (2023) mentions that a short ammonia pipeline appears to be the lowest-emissions, most reliable and potentially most economical option overall at a larger scale.

2.5 Policy adoption

In order to ensure wide and fast adaptation, it's important to shed light on policy and strategy interventions that are required to necessitate the large-scale adoption of green ammonia. According to Islam et al., (2024) financial incentives and clear market signals de-risk early investments in electrolyzer deployment. In addition, tax credits and subsidies are vital in early adoption and cost reductions, especially when it comes to equivalency between green hydrogen and other fuels. Moreover, PPP models lead to quick infrastructure scale up. It's important for governments to underwrite early pipeline projects and refueling stations through either offtake agreements or government grants. Ruppel and Katoole (2023) observe that Namibia's current energy framework resembles a loose mosaic its Electricity Act, Draft Gas Bill and Environmental Management Act each address pieces of the puzzle (licencing, tariffs, impact assessments), but no single statute governs the full green-hydrogen to ammonia value chain. Klagge et al. (2025) describe how the government is tightening up rules on public-private partnership agreements, land-use permits, export licenses without yet locking in a single industrial pathway.

Walker et al., (2025) explain that spatial-planning instruments were deployed to lock-in Namibia's inaugural green-hydrogen project, however they fall short of explicitly narrowing down the full scale of political-economic levers. According to Quang Vu Dinh et al., (2024), based on the sensitivity analysis conducted suggested that in order to reduce Levelised Cost of Transmission (LCOT) it's important to reduce the discounted rate in order to advance access to financing, either through

government backed project finance and increasing the capacity factor of the electrolyser and utilizing renewable energy sources such as solar and wind. If Namibia keeps these economic and regulatory levers tuned and taps into transparent incentives and strong international partnerships, it has a real shot at building a resilient green-fuel industry, not just a handful of pilot projects.

2.6 Environmental, Safety and Storage Considerations

Mallouppas et al., (2022) identified three non-greenhouse gas (GHG) environmental burdens related to green ammonia produced through renewable means and are mentioned as through toxicity, acidification and eutrophication if the entire life cycle assessment of green ammonia production and usage is considered. Asgharian et al., (2025) state that green ammonia production leads to mineral resource depletion, land acidification and freshwater eutrophication. In terms of safety regulations, green hydrogen and ammonia handling is of dire importance. Najjar, (2013) states that hydrogen is very light which leads to concerns of leakage and high flammability. In addition to that hydrogen has properties that make it very difficult to contain and store. In addition, Prakash Kumar Sarangi et al., (2024) state that green ammonia storage requires sophisticated tank designs which should take into account insulation technology and state of the art materials. Moreover, Salmon & Bañares-Alcántara (2021) mentioned that the severe issue with green ammonia is its toxicity. Moreover, Chorowski et al., (2023) mentions that ammonia is typically stored as a refrigerated liquid at atmospheric pressure ($-33\text{ }^{\circ}\text{C}$) or under moderate pressure at room temperature (approximately 10 bar) thus it makes it difficult to adopt ammonia storage systems.

2.7 Summary and Research Gap

This chapter has shown that the literature appears to be quite positive regarding both green ammonia and hydrogen as potential avenues for decarbonization of maritime activity. However, much of the literature is either demonstrably technologically

optimistic or economically optimistic, and paying little attention to the socio-political and regional contexts to which Namibia may be specifically relevant. While Namibia remains exceptionally well-positioned in relation to renewable sources, the lack of institutional support, concrete policies and economic infrastructure poses major barriers turn this potential into a viable reality. Thus, the studies from the global stage justify the focus of the dissertation to adjust international best practices to Namibia's contexts and illustrate the various extents to which bunkering operations are feasible especially when its established that the economic returns are not dependent on resource availability alone.

Chapter 3: Methodology

3. Methodology

3.1 Introduction

This chapter outlines the methodological approach used to look into the techno-economic implications of adopting green ammonia and green hydrogen as Namibia's chosen alternative fuels at the Port of Walvis Bay. The study seeks to adopt a mixed-method framework which combines qualitative policy analysis, international case study comparison and quantitative techno-economic modeling in order to provide a comprehensive evaluation of the study. In essence it provides the methodological approach to the research objectives identified in the first Chapter.

- Assessment of the economic, environmental and possible functional consequences of green ammonia and/or green hydrogen for the Walvis Bay port infrastructure
- To recommend ideal strategies to facilitate the adaptation of green ammonia and/or green hydrogen in relation with Namibia's decarbonization goals
- Assessment of possible barriers to adaptation and implementation of alternative fuels

3.2 Research Philosophy

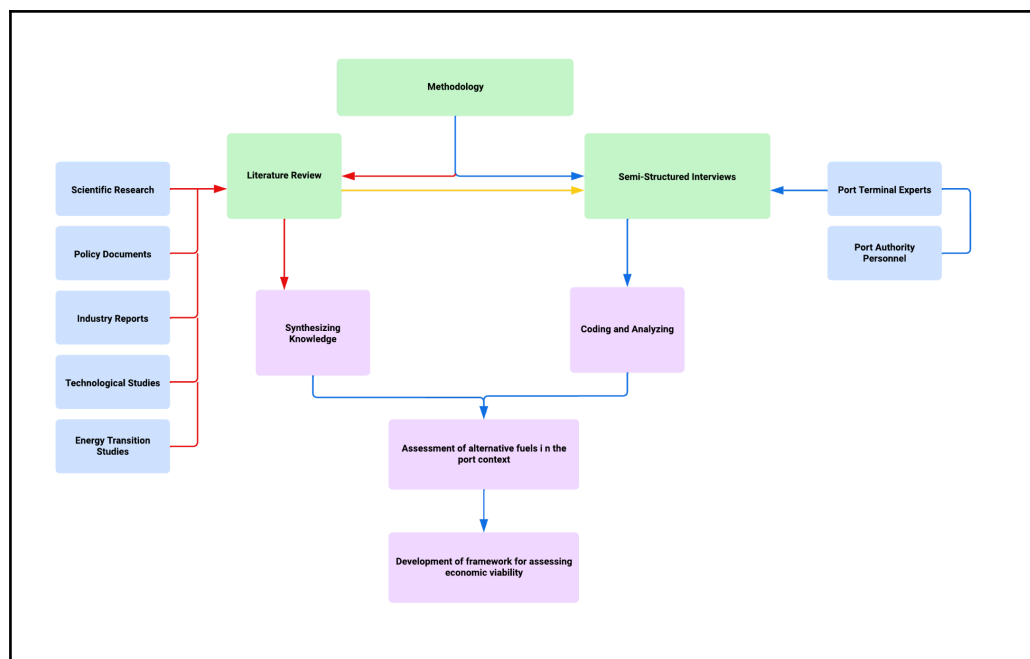
This research will be based in the pragmatism theory, which prioritizes workable solutions as opposed to philosophical purism that serves as the foundation of this study by Kaushik & Walsh, (2019). The theory of pragmatism provides the adaptability to integrate qualitative and quantitative methods in order to provide practical insight for Namibia's maritime energy transition. Therefore, it is necessary to establish both subjective stakeholder viewpoints and objective techno-economic models.

3.3 Research Design

The port of focus is Walvis Bay, Namibia which forms part of the comparative case study as this ensures a thorough analysis of infrastructure preparedness and opportunities to the port and policy frameworks in relation to the adoption of green marine fuel. The study looks at international benchmarking to advance Namibia's position to advance energy transition patterns. This design approach allows for an in-depth examination of port specific opportunities, policy frameworks and infrastructure readiness in relation to green marine fuel adoption. Focusing on the port of Walvis Bay allows for a targeted analysis of Namibia's strategic node for marine fuel transition. Comparable benchmarking is used to contextualize Namibia's status within broader global decarbonization trends.

To aid with this approach, Figure 4 provides a visual representation of the research design. It illustrates the use of global benchmarking, literature review and techno-economic modeling which are all integrated as part of the case study.

Figure 6: Schematic Representation of Methodology Flow



Source: Authors own illustration (2025)

3.3.1 Literature review

This study adopted a systematic literature review in order to gain a deeper understanding of how alternative fuels, especially green ammonia and green hydrogen are adopted in the maritime sector. According to Rother (2007), a systematic literature review is a well planned review which aims to answer specific research questions using systematic and explicit methodology in order to identify, select and critically assess the outcomes of the study. In addition, systematic literature reviews are considered genuine work because they're managed using rigorous methodological approaches. The study followed a structured approach to identify, show and synthesize studies that are relevant to ensure credible and topic specific articles are included. Through this process, recurring arguments were identified including infrastructure limitations, safety considerations and the importance of government policy which enables marine fuel transition. The review touches on notable gaps such as region specific data predominately in Sub-Saharan Africa which reinforces the need to hold stakeholder engagements and localized modeling.

3.3.2 Interviews

Based on findings from the literature review, semi-structured interview questions were created to gather information about the practical challenges and opportunities for developing green ammonia bunkering facilities. The interviews were meant to capture perceptions about the technical and regulatory aspects of implementation. Participants were selected using the rationale of their professional roles in port development and energy transition to capture varied perspectives. Interviews were conducted with a Port Engineer from Nampore, a Programme Manager for Climate Transition and Policy for the Port of Antwerp-Burgh, and an expert in Permitting and Risk Management for the Port of Antwerp-Burgh. This professional

representation allowed for a balanced representation of the engineering, policy, and regulatory aspects that will affect adoption.

3.3.3 Mathematical Models and Crystal Ball: Monte Carlo Simulation

According to Goldman (2003), Crystal Ball provides a resource of intuitive Microsoft Excel add-in software to evaluate the risks and uncertainties around your spreadsheet models. The suite includes analysis tools for Monte Carlo simulation (Crystal Ball). This simulation and time-series forecasting analysis tool provides a further awareness and quantification of the risks involved with a spreadsheet-based business decision. The proposed model simultaneously determines the ideal tank size, number of annual ship calls and bunkering costs to determine an optimal net present value (NPV) as well as IRRs. The objective function of the model balances capital expenditures, operating expenses, and ammonia bunkering fee revenues in order to maximize the net present value. The profit maximization problem is stated formally as follows.

The mathematical formulas used for modelling NPV and IRR in principle and MS Excel:

Net Present Value (NPV)

Žižlavský, (2018) mentions that the first principle of NPV approach is that a risky Euro in the future is less valuable than a certain Euro in the present and that therefore, future cash flows will be each discounted each passage of time. The discount rate reflects the opportunity cost of the capital mobilized and will increase with the estimated riskiness of the innovation opportunity. Indeed, it is expected that riskier projects will have a higher return. Similarly, Holtan, (2002) mention that the project NPV is defined to equal the difference between the sum of the present values of the revenue components and the sum of the present values of the cost components.

We applied the net present value (NPV) method to assess the financial feasibility of the green ammonia bunkering project. The net present value (NPV) is the sum of all expected net cash flows in present value terms, less the upfront capital cost. It can be mathematically stated as:

$$NPV = C_0 + \sum_{t=1}^n \frac{CF_t}{(1+r)^t}$$

CF_t = net cashflow

r = the discounted rate

t = time period

n = the projects total operational lifetime

C_0 = initial capital expenditure

Internal Rate of Return (IRR)

According to Yan & Zhang (2022), the IRR is referred to as that discount rate where a project will be evaluated when comparing project cash flows to an investment in the project itself. IRR is that discount rate where an investment in future cash flows are equivalent to the project's cash inflows and outflows. Similarly, Arshad (2012), mentions that the IRR stands for "Internal Rate of Return" and is how you find out what rate of return are you getting on a project. IRR will give you that answer in percent. You could also think of IRR as actually based on present value concept; which is that the amount of money you get today is worth more than the amount you get tomorrow. IRR was examined with NPV to assess the project's rate of return in percentage terms. The IRR is defined as the discount rate that makes the NPV equal to zero, or the break-even point between the present value of the inflows and present value of the outflows. It is mathematically calculated as solving:

$$0 = C_0 + \sum_{t=1}^n \frac{CF_t}{(1+IRR)^t}$$

where $x_{-}(s,t)$ indicates operational decisions like production and transport quantities for scenarios and time t , and $y_{-}i$ represents investment decisions (e.g., capacity of PV, wind, electrolyzer, Haber-Bosch units). Bunkering fees per kilogram of delivered ammonia are the main source of revenue, and fixed Operation & Maintenance (O&M) costs, truck and pipeline transportation costs, and electricity consumption are all included in operating costs. The model is subject to constraints that guarantee transport flow balances, ammonia demand satisfaction, capacity limits, and the availability of renewable resources.

3.4 Data analysis

Interview transcripts were methodically reviewed to uncover the most important and thus most useful information, which was subsequently coded and sorted into themes. The thematic orientation was combined with results from Crystal Ball Monte Carlo Simulation and key themes and insights from the literature review, facilitating the analysis could be done in a comprehensive manner, without compromising quality. The themes were further organized into themes and sub-themes to highlight important details. In this way, the analysis employed multi-method data to provide a holistic picture of the complex factors.

Chapter 4: Best Practices

4. Best Practice: Port of Rotterdam, Netherlands

4.1 Introduction

The Port of Rotterdam is Europe's largest port and a global leader in alternative fuel innovation, which makes it the most sophisticated, documented and operationally tested leader in green ammonia bunkering and it is against this background that the Port of Rotterdam is considered as the port of focus under ideal best practices. As a global leader in the development of green ammonia bunkering, Atchison, (2025) report underscores the importance of the first ever completed ship-to-ship (STS) green ammonia in early April 2025 between the vessels Oceanic Moon and Gas Utopia. In addition, the Port of Rotterdam's 'Port Readiness Level' designation for new marine fuels is advanced to the deployment phase, thanks to the successful pilot project.

Hendriks & de, (2023), state that the Port of Rotterdam is investing in renewable projects such as offshore wind energy, and enabling the construction of the infrastructure for the transport of green energy carriers, including hydrogen. The port is strategically positioned as operator, landlord, regulator and community manager to generate multi-lateral collaboration within the current port and its hinterland. Moreover, Samadi et al., (2016), explains that annual CO₂ emissions associated with the port are over 30 million tonnes per year. Given this situation in the context of the Rotterdam Climate Initiative, the Authority is aiming for a 50% reduction in emissions by 2025 and a 60% reduction in emissions by 2030 relative to 1990 levels.

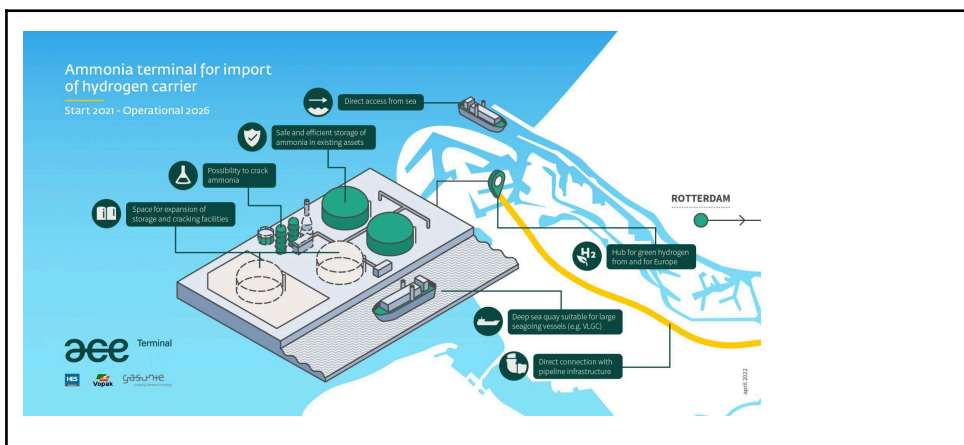
Figure 7: Maasvlakte, Rotterdam



Source: Google Earth Pro, Imagery © 2025 CNES/Airbus, accessed 05 August 2025, 51°57'58"N, 4°01'48"E

Figure 7 depicts the physical arrangement of the Port of Rotterdam, with refineries, petrochemical complexes, and the new green ammonia bunkering terminals shown. This underscores Rotterdam's position as a noted energy and maritime center for enabling Europe's energy transition.

Figure 8: Concept design for ACE Terminal in Rotterdam.



Source: Atchison, J. (2022, April 13). ACE Terminal: importing ammonia to Rotterdam from 2026. Ammonia Energy Association.

Figure 8 is sited at the Port of Rotterdam, a planned ammonia terminal will be fully built in 2026, while concurrently going online, and once complete, will have access for Very Large Gas Carriers, gained safe storage (structuring existing and new tanks), on-site ammonia cracker facilities, and additional room to grow both storage and cracking plants.

According to Vrijen (2023), Rotterdam's planned terminal will be uniquely positioned to link the North Sea and the industrial cluster around the port. Atchison (2022), a green-ammonia import terminal is a vital node in the hydrogen chain, enabling hydrogen import, production, transport and storage. In Rotterdam, Haven en Scheepvaart (HES International) has facilities with outstanding location and direct sea access, Gasunie has existing capacity with tanks and pipeline systems, and Vopak has experience of ammonia storage across six terminals, and thus assembled their assets to give themselves and their customers an excellent platform for creating a green ammonia import terminal within a few years. Mikail Rıza Onat & Demir (2025), state that retrofitting existing natural gas pipelines with booster stations would be a cost- and capacity-effective alternative.

4.2 Identification of key uncertainty factors

This section identifies the principal uncertain factors that drive variability in project outcomes, including demand fluctuations, technological advancements, energy market dynamics, policy and regulatory environments, and infrastructure development timelines.

4.2.1 Demand for Green Ammonia

Rouwenhorst (2025), observes that the Port of Rotterdam aims to import approximately 18 million tons of hydrogen equivalents. This notion alone certifies the Port of Rotterdam's ambitious plans and anticipations for large green ammonia bunkering volumes. In comparison, Namibia falls short in terms of bunkering

demand at an estimated less than 1,000 vessel calls per year. However, due to disruptions at the Suez Canal and underperformance by major competitors such as the port of Durban, South Africa, Namibia may cement its position in green ammonia bunkering in Southern Africa. Tunagur (2024) highlights that Namibia has a unique bunkering advantage through its offshore bunkering option. Moreover, Winter (2022) notes that Namibia is positioned to offtake approximately 300,000 tons of green ammonia annually as a result of its partnership with RWE and Hyphen. Fullerton et al. (2024) note that uptake of green ammonia as an alternative fuel remains low and as of 2023, only a small portion of the fleet globally is considering alternative fuels with almost no on-the-water operational use of ammonia. In support of this opinion, Bidwai (2023) estimates the green ammonia market is expected to expand from roughly USD 533 million in 2024 to USD 86.3 billion in 2034, compounded annually at 66.3%.

4.2.2 Infrastructure Cost: CAPEX

The Port of Rotterdam operates under a landlord model, thus investments into plant infrastructure expenditure and operations are the sole concern of the private operator. According to Erkelens (2022), in relation to green ammonia operations at Maasvlakte, there has been a collaboration between three (3) private firms namely; HES, Gasunie and Vopak. In contrast, Namibia presently operates as a tools port, in which case Namport may carry most of the CAPEX burden. However, Minchin (2024) notes that this investment will be co-financed by the Port of Antwerp Bruges (POABI) and APEC. In this regard, Namport is expected to have a higher investment contribution under this model as opposed to the Port of Rotterdam. Conventional Haber–Bosch ammonia is energy-intensive and complicates decarbonization, thus Adeli et al., (2023), states that several emerging methods target an efficiency improvement and a cut to emissions. PEM water electrolysis (H_2), catalysts using lower pressure and temperature, and promising advancements in materials for separating or storing hydrogen, will come from new, emergent or altered applications of an old process. However, Smart (2021), states that announced green-ammonia

capacity remains a miniscule share of total capacity due to high CAPEX. In contrast, Salehmin et al., (2022) states that by 2025, PEMWE costs will be approximately €1200/kW but will go down to the range of €300/€600 from 2030 onward , while again, hydrogen costs will still depend on priced electricity.

4.2.3 Policy Environment

Deibel (2019), states that Rotterdam is an example of how focused incentives and a cohesive city-port strategy can catalyze green-fuel utilization i.e., a climate-neutral shipping pilots program worth €5 million in 2018, which similarly Engelke & Webster (2023) say it's a techno-centric, port-centric decarbonization strategy to navigate opportunities. Wang et al., (2024) clarifies that early market development depends upon city-level initiatives like infrastructure, skills and awareness, demand stimulation using federal incentives i.e, taxation, grants and R&D in an integrated governance model, allowing for constraints provided by the deployment of technology and growth of market. Moreover, Uzoagba et al., (2025) mentions that across Africa, the major obstacle is fragmented fossil-fuel oriented policies have left hydrogen/ammonia regulation incomplete and lagging behind, leading to a refusal of investments; subsidies, tax credits, and public-private partnerships (PPPs) may alleviate the burden of high upfront capital expenses (CAPEX). In addition, leaders in hydrogen and ammonia development such as Namibia, South Africa, Egypt and Morocco are advancing experimentation and nascent frameworks, but further action is needed to regulate and fund the hydrogen and ammonia sector in order to maximise the socio-economic and environmental benefits.

4.2.4 Infrastructure Development Timelines

Ribeiro & Santos, (2025) mention that by imposing aggressive timelines or retrofitting and modifying existing ammonia pipelines deployment of green-ammonia infrastructure can be expedited and mitigate some CAPEX. Atchison (2025), mentions that while Rotterdam is already at level 7 ammonia-bunkering

readiness, having conducted safety procedures, Namport has not initiated green-ammonia bunkering but it does have climate neutrality as a goal by 2050. Separate studies by Pietrosemoli & Rodríguez Monroy (2013) and Assaf & Al-Hejji (2006) clarify that project delays are common; for example, in two separate studies of construction projects, 70% were delayed by 10–30% delaying payback, IRR and leading to productivity and revenue losses. As Namibia develops green-ammonia capability, reliance on a disciplined schedule and utilizing existing assets will help mitigate increased costs due to delay.

4.3 Summary

Rotterdam is the best benchmark for Namibia's ambitions for green-ammonia bunkering with infrastructure that is mature, established pilots of scale, and governance aligned with EU climate policy. It utilizes a landlord model where consortium partners share CAPEX risk, while Namibia's state-centric tools-port model does not provide this solution. Regardless of which model, uptake is not clear and depends on uncertainties in demand, technology CAPEX, policy, and timing of infrastructure delivery. Namibia cannot adopt Rotterdam's incentives and clarity of regulation but can reference the ultimate incentives and regulatory clarity of Ghana in Namibia's less mature and smaller framework.

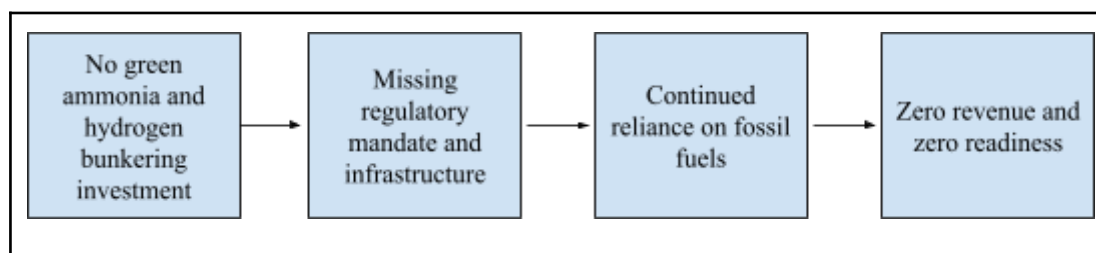
Chapter 5: Case Study Namibia

Scenario Analysis

Namibia still sits on the early, pre-deployment spectrum for green ammonia and hydrogen, with frameworks and pilots emerging but no bunkering activity yet. This chapter conducts a scenario analysis moving through the BAU baseline into progressive uptakes and potential scenarios comparing alternative bunkering configurations across different fuel volumes, vessel-call frequencies, vessel sizes, and benchmarking what they might cost, capacity, and operational considerations.

5.1 Baseline Scenario: Absence of alternative fuel bunkering facilities

Figure 9: Namibia's current decarbonization position



Source: Authors own illustration (2025)

The present scenario assumes that no green ammonia and hydrogen bunkering investments are made, no ships are calling the Namibian port for alternative fuels and this is a business as usual case. This scenario assumes a zero-revenue benchmark for green ammonia and hydrogen for financial modeling.

The Namibian Transport Policy (2018) specifies that Walvis Bay is one of the country's oldest ports and was established in 1793. Following independence from South Africa, Walvis Bay (hence the Port Authority of Namibia or Namport) became a state-owned port under the national government, with respect to maritime regulation the DMA being located in the Ministry of Works and Transport, which operates the state-owned port facility generally in collaboration with Namport. At

present time, bunkering is taking place only for conventional fuels (HFO/MGO), while alternative-bunkering is in the feasibility stage. Gunnar (2024) notes Namibia is pursuing a USD 10 billion green-hydrogen project with German partners, Sub-Saharan Africa's largest with plans to produce 2 Mt/yr of green ammonia from solar and wind resources, intended for regional and global markets. In the BAU baseline, however, with no enabling port infrastructure and weak coordination between upstream production and downstream logistics, it is possible Namibia could end up a transit-only exporter, losing value-added opportunities such as ship refuelling and even a regional bunkering hub.

According to Čučuk, (2023), the EU and the Netherlands have agreed to consider upgrading Walvis Bay into a hydrogen-enabled industrial logistics hub, but still haven't upgraded from plans to pre-implementation. Namibia has no substantive operational protocols, and safety standards for green ammonia/hydrogen handling and bunkering; without these and the corresponding infrastructure, deployment opportunities are very limited. In addition, the government is proactive, and is intent on making partnerships with foreign investors, however it truly needs to step up and take regulatory action to move to implementation. According to IMO Cares (2023), Namport consumes an average of 397,911 kWh on a monthly basis and 4.77 million kWh annually. Moreover, equipment at the port such as tugboats and forklifts are diesel powered, and ship to shore cranes are electric powered.

According to IMO CARES (2023), while Namport has no infrastructure for green ammonia or hydrogen, it has 13 commercial berths and a newly established dedicated tanker jetty, and with about 1,500 ha of port footprint, there is space to support energy-transition projects. Emissions reporting (Scopes 1-3) indicates that Scope 1 emissions rose by 563 tCO_{2e}, greater diesel use from port equipment, Scope 2 emissions fell 487 tCO_{2e}, less electricity use due to idle STS cranes, and Scope 3 emissions increased with 29% more in vessel calls resulting in greater waste generation; overall emissions were elevated by 7.1% year-on-year, 1,205 tCO_{2e} more

relative to FY2023. Present gaps in regulations and lack of skilled personnel have made it difficult to effectively execute flag, port and coastal state operations. According to Namibian Transport Policy (2018), this negatively impacts Namibia's logistical hub strategy. MWT together with the IMO, looked at replacing the pre-independence maritime legislation with current and modern maritime legislation which would enable for the establishment of NMA. The NMA would be responsible for functions and powers that protect and promote the interest of the state and until the NMA is formally established the regulatory space will remain to be fragmented and riddled with administrative uncertainty posing a massive barrier to progress in port side developments. de Klerk (2022), Namport's strong credit categorization is strengthened by its close collaborative efforts to the Namibian government, which owns the Namibian Ports Authority and provides guarantees for servicing its loan from the African Development Bank (AfDB) and covering more than 90% of the debt. In principle, this allows for Namport to have strong financial backing and ensures Namport's operational stability and access to beneficial lending terms especially during periods of high leverage.

The baseline for Namibia is one of institutional, regulatory and infrastructural inaction, which prevents any meaningful step towards alternative-fuel bunkering at Walvis Bay despite the country's renewable potential. Namport financially is healthy, but operationally must deal with a fragmented legal environment, the absence of enabling directives, port-side assets, and skilled human resources. This forces Namport to conduct operations geared to conventional-fuels and losing potential near-term opportunities for green ammonia. In this way, the chapter describes zero readiness and zero revenues as the baseline so that final financial projects and scenario analysis have a determined benchmark.

5.2 Optimistic Scenario: Technical–Economic Assessment of Green Ammonia Production and bunkering at Namport

5.2.1 Scenario Overview

In this optimistic scenario, Namibia constructs a new green ammonia production plant that is some 100 km inland from the Port of Walvis Bay and operates as a public port model. This site offers a strategic balance of maximising high-quality wind and solar resources, land availability, accepting environmental impacts and proximity to grid and water infrastructure. The produced ammonia is transported via a dedicated 100 km pressurised liquid ammonia pipeline directly to a refrigerated storage and bunkering terminal within the port zone, which is part of Namport's Marine Services offering. The revenue and expense figures are derived from the Namport 2024 report to account for revenue and operating costs which have an overall impact on the financial feasibility of the project.

5.2.2 Technical Configuration: Renewable Energy plant and bunkering setup

The production plant has a designed output capacity of 1,080 t/day of green ammonia, enough to refuel two Very Large Crude Carriers (VLCCs) per day on an annual basis at USD 710/t of green ammonia. Under this scenario the plant is expected to produce 1 million tonnes of green ammonia per year generated through an electrolyzer capacity of 2 GW (PEM) under a hybrid renewable energy generation system comprised of Solar PV of 833,000 panels with a capacity factor of 25% which is supplied to the electrolyser load during the day and takes up 1,333,000 m². In addition, the Wind farm comprises 50 turbines, with a capacity factor of 40% which will cover the night-time supply gaps and has a 5 MW rating. Moreover, in this scenario no large scale batteries are included as part of the CAPEX. The pipeline's operating temperature is estimated to be 5°C in order to maintain the green ammonia in a liquid state. The Namport ammonia bunkering terminal has a storage

capacity of 10,000 tonnes and has capabilities for shore to ship cryogenic loading arms.

The Green ammonia CAPEX figures are derived from Mikail Rıza Onat & Demir, (2025) and OPEX figures are estimated as percentages of the CAPEX as illustrated in table 1. In addition, this scenario assumes that green ammonia bunkering regulatory requirements are fully supported and adopted into the national legislation allowing for swift adoption and construction of the project within 3 years and the 4th year being that of full scale bunkering operations.

5.2.3 Inputs and Assumptions for the Green Ammonia Plant Bunkering

Table 1:CAPEX Table - Optimistic Scenario

Item	Units	Inputs	Sources
Green Ammonia Production Plant cost in USD	USD	2,792,700,000	Mikail Rıza Onat & Demir, (2025)
Electrolysers (2 GW capacity)	USD/kW	$1,800 \times 2,000,000 \text{ kW} = 3,600,000,000$ (embedded in plant CAPEX)	Mikail Rıza Onat & Demir, (2025)
Air Separation Units (ASU)	USD	$197 \times 1,000 \text{ t/d capacity}$ (embedded in plant CAPEX)	Mikail Rıza Onat & Demir, (2025)
Haber–Bosch Synthesis Unit	USD	$510 \times 1,000 \text{ t/d capacity}$ (embedded in plant CAPEX)	Mikail Rıza Onat & Demir, (2025)
Renewable Energy Generation (Solar + Wind)	USD	Included in plant CAPEX	Mikail Rıza Onat & Demir, (2025)
Pipeline (100 km)	USD/Km	$500,000 \times 100 = 50,000,000$	Mikail Rıza Onat & Demir, (2025)
Small scale Ammonia Bunkering Terminal	USD	13,524,614	The Hydrogen System Is Taking Shape Port of

			Rotterdam, (2025)
Onsite Ammonia Storage Tanks (Port)	USD	Included in terminal CAPEX	The Hydrogen System Is Taking Shape Port of Rotterdam, (2025)
Civil Works & Support Infrastructure	USD	Included in plant and terminal CAPEX	The Hydrogen System Is Taking Shape Port of Rotterdam, (2025)

Total CAPEX = USD 4,739,524,614

Table 2: OPEX Table - Optimistic Scenario

Item	O&M % of CAPEX	Amount (USD)
Production plant & Renewable Energy infrastructure	2.5%	90,000,000
Pipeline	2%	22,520,000
Bunkering terminal	2.5%	338,115

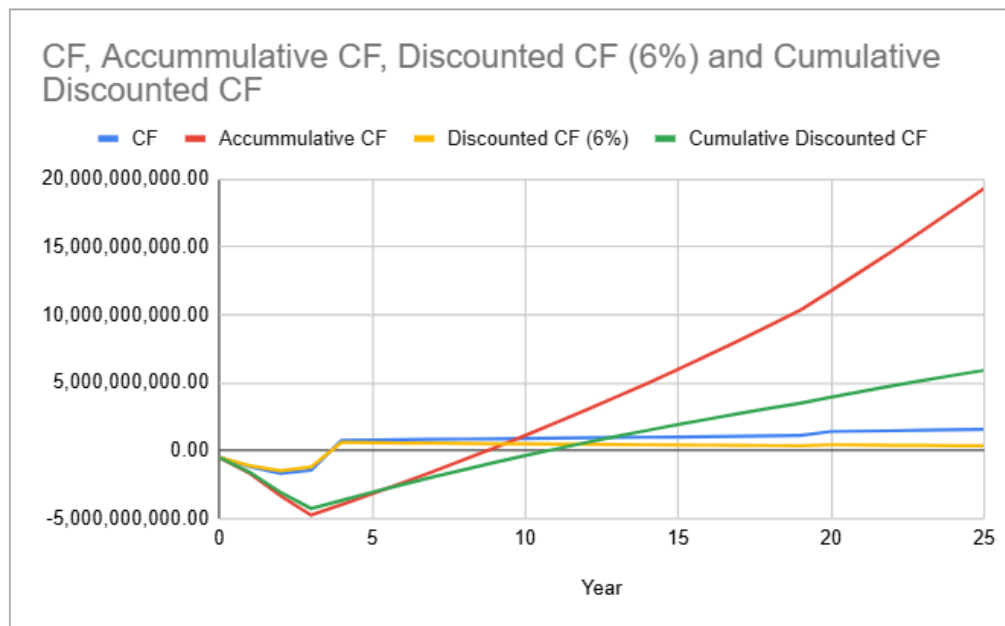
Total CAPEX = USD 112,858.115

5.2.4 Financial Instruments: Payback, NPV and IRR

In the optimistic situation, financing involves 30% equity (USD 856,867,384) from Namport and private partners and 70% debt through a concessional AfDB loan equal to 50% CAPEX (USD 1,428,112,307 bn at the concessional rate of 1.45%) and a commercial loan of 20% (USD 571,244,923 at 6%). This capital structure captures and aligns incentives for investors, ensures limits to leverage, and reduces the weighted average cost of capital with, in this case, the viability being anchored by AfDB's low cost of finance and affordability. This model also applies 2% pa inflation to revenues and operating costs. Financial modelling utilized Excel to undertake payback on a P&L basis, cumulative cash flow (nominal), discounted cash flow at

6% to factor in the time value of money, and a measure of payback based on cumulative discounted CF, which would be the most relevant for investors.

Figure 10: Illustrated findings - Nominal vs Cumulative discounted cash flows



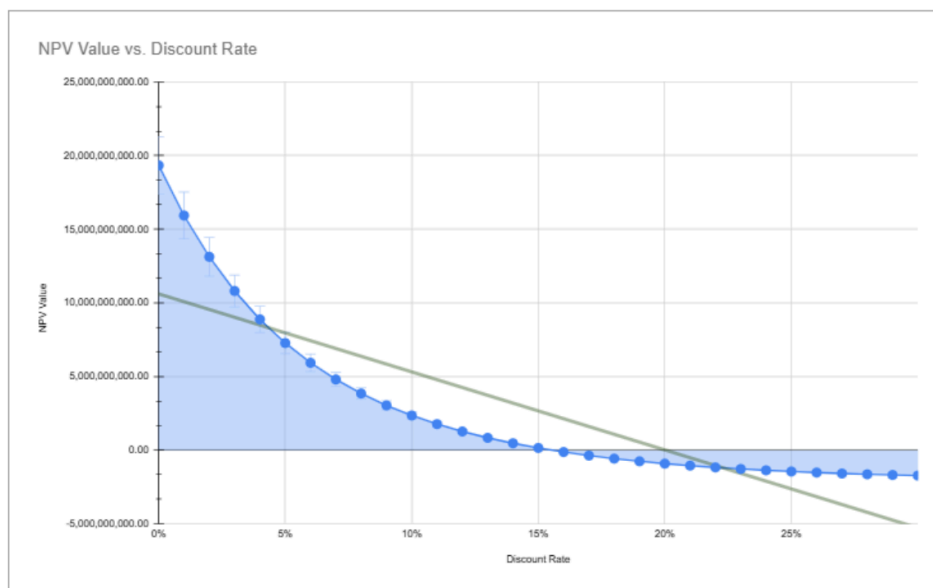
Source: Author's simulation using MS 365 Excel (2025)

In the optimistic scenario, the cash flow analysis revealed a clear contrast in nominal versus discounted payback periods for the investment. Annual cash flows (CF) remained negative during the first four years, where the investments in a new ammonia production facility, the pipeline and the bunkering terminal were significant capital expenditures. Starting in Year 4, the operating revenues become stable and annual cash flow remains positive through to the end of the project. In year 6, the NPV is projected at USD 5,927,408,815.13. In Year 9, the project starts to recover its full nominal cash flows, where cumulative cash flow becomes positive for the first time, ending at USD 223,277,846.25 and we find nominal payback at Year 9 (for which we have ignored the time value of money). With a 6% discount rate (WACC), the cumulative discounted cash flow line arrived at cumulative payback in Year 11 when cumulative discounted cash flow was USD 131,834,677.77. Hence, some of

the future earnings have immediate lower present value due to discounting (6%). The IRR in this case was observed to be 15.51%.

This is a reminder of the importance of including discounted estimates when evaluating project performance since the amount of approximate nominal payback in Year 9 may falsely overstate early profitability. Overall, in nominal and discounted terms, the cash flow from savings projects up to a payback period was markedly positive, and demonstrates continued value-creating, long-term successful financial performance of the bunkering project undertaken over the study horizon with the technical–economic conditions assumed.

Figure 11: NPV and different discounted rates



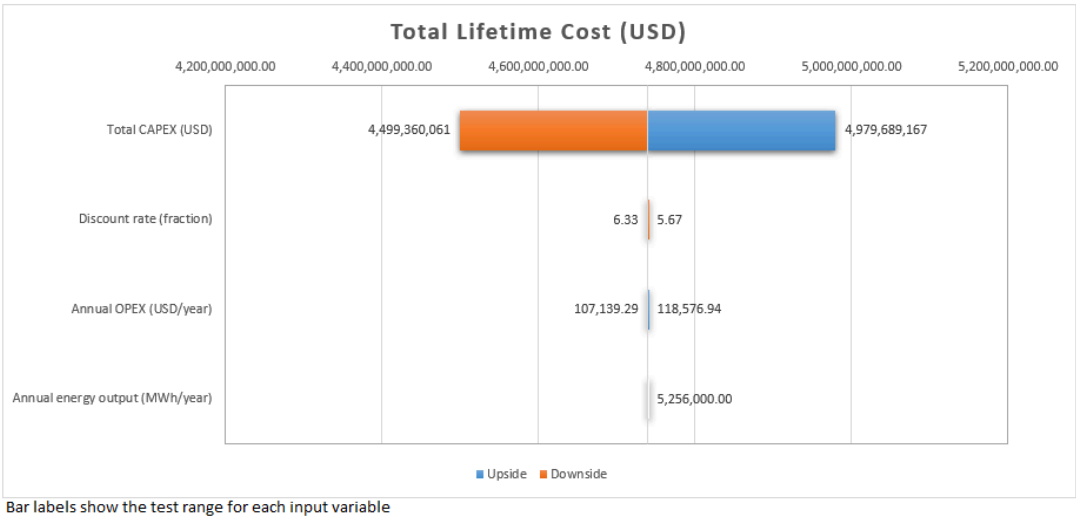
Source: Author's simulation using MS 365 Excel (2025)

The NPV sensitivity implies a strong inverse correlation between discount rate and project value. With very long-dated cash flows for years 30–40 years, NPV = USD 19.34 bn at 0% as undiscounted cash flow, and robust NPV of USD 5.93 bn at the

project WACC of 6.3% versus CAPEX USD 4.74 bn. The curve declines steeply from 0%-10%, and approaches breakeven or NPV = 0, at 15.8% and is –USD 130 m at 16%. This indicates high sensitivity to financing (discounting) costs if discount rates are close to feasible range under the optimistic case, while bigger changes occur at very high rates. The implied IRR is 15.51%, the discount rate when NPV = 0. Overall, the optimistic case is plausible with low–moderate capital costs; otherwise, higher capital costs would materially undermine any plausible economics.

5.2.5 Financial Instruments: Tornado Model

Figure 12: Total Lifetime Cost (USD)



Source: Author's simulation using Oracle Crystal Ball (2025)

The author created all graphs labeled "Author's simulation using Oracle Crystal Ball," from outputs generated using Excel-linked Monte Carlo methods.

The tornado chart illustrates that the primary driver of cost variability is Total CAPEX (USD), which accounts for almost all of the explained variation, with potential swings in costs between USD 4.5 billion and USD 4.98 billion. This emphasizes the capital-heavy nature of green ammonia infrastructure. The discount rate is a less significant dollar-value driver but is significant in its long-term financial

impact against the costs. Annual OPEX presents moderate variability, reflecting stable operational costs. Annual energy output has no observable impact on total lifetime cost, likely because it represents efficiency measures (e.g., LCOE) rather than cost figures. In addition, the tornado chart demonstrates that CAPEX is the most vital input affecting project financial viability followed by the discount rate and OPEX.

5.3 Best Case Scenario: Favourable conditions - Landlord Model

Scenario Overview

In this paradigm, Namport as a port landlord, becomes only an enabler and regulator of port services without taking ownership. Namport provides core infrastructure (quays, berths, access roads) under a long term concession for core port operators (25 years, with performance-based options for renewal). Each terminal operator finances, builds, and operates the commercial assets (storage, pipelines, bunkering) and assumes OPEX, shifting funding and operational risks to the private sector. Namport avoids risks associated with fluctuating fuel demand, uncertainty in both technology and regulatory changes while earning concession fees, port dues and related services. The structure maintains the strategic flexibility for Namport to scale its involvement down, or exit, without long-tenure financing related commitments.

Table 3: Financial parameters for Namport

Item	USD
Civil Works & Support Infrastructure (2 year operation)	777,160.80 - Estimate based on Global Centre for Maritime Decarbonisation, (2023) SGD=USD at 0.78 (12/08/25)
AfDB Loan (1.45%) - 50% of CAPEX	388,580.40
Commercial loan (6%) - 20% of CAPEX	155,432.16
Equity - 30% of CAPEX	233,148.24

Namport plans to service the civil-works debt from current revenue streams, along with an operator upfront concession payment of 20% and annual concession payments. Under these parameters, Namport experiences no material losses and would retain good margins. **Reference to Figure 17: Appendix 1**

The figure consolidates Namport revenues from its business line (cargo handling, vessel dues/access charges, synchrolift/dockyard, ship-repair, marine services) along with concession income and compares them with operating and maintenance (O&M) and scheduled debt service on the investment. Indicative to this is that in each year of operation cash flow from operations (Total Revenue - O&M) provides sufficient income coverage of annual debt service, so that the debt will be serviced from normal port revenues. Net cash flow remains positive as coverage is strong. **See reference to Figure 17: Appendix 1**

Under the Best-Case Landlord scenario, Namport's civil-works CAPEX shows negative cash flows in years 0-2 only; from Year 3, operating inflows (concession income and port revenues) exceed O&M and debt service and cumulative discounted cash flow is positive by Year 3. At a 6% discount rate the 25-year NPV is USD 9,669,363,507.11 indicating Namport has recovered its enabling-works investment without any reliance on operator fuel sales. The model produces an IRR of 1,241.22% only, which reflects the port-authority-only investment case (small public CAPEX recovered across larger port revenue streams) not the economics of those relating to the private bunkering operation. Put simply, Namport acts as a public infrastructure enabler and its returns are driven by concession revenue and port service income while the private operator retains all fuel-asset obligations.

From a private-operator perspective, annual bunkering demand was estimated using the global orderbook for ammonia powered/ready bulk carriers, aligning routes for vessels with planned entry-into-service dates, and assigning a conservative share of

those vessels to routes that call Walvis Bay. Based on Rouwenhorst (2025), in June 2025 there were 146 ammonia powered and 239 ammonia ready vessels announced; within the powered element, 64 firm orders include those 29 ammonia carriers and 29 bulk carriers with first deliveries in 2026-2027. This data informs the near-term vessel count assumptions in the operator model.

Table 4: Estimated bulk carrier bunkering potential between 2025 - 2030

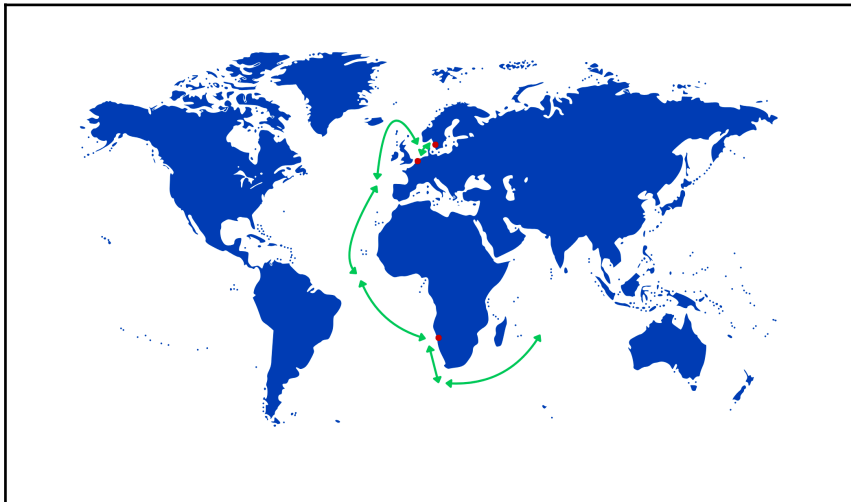
Period	Estimated bulk carrier port calls	Total tank capacity (3,000 cubic meters per vessel)
2025 - 2028	0 - 5 vessels per annum	15,000 m ³
2029 - 2030	5 - 15 vessels per annum	45,000 m ³
2030 onwards	20 - 30 vessels per annum	90,000 m ³

The scenario will assume these figures to estimate the potential number of vessel calls annually at USD 710/t of green ammonia and does not take into account green ammonia carrier transport figures but bunkering alone. Moreover, Bahtić, (2024) disclosed that a bulk carrier the size of 210,000-ton had a fuel capacity of 3,000 cubic meters. Similarly, a report by STAR, (2023) states that the minimum tank holding capacity has to be 1,3000 cubic meters, with 5% pilot fuel. It's against this background that we opted to use 3,000 m³. The scenario further assumes that at -33°C, the density is approximately 0.682 tonnes per m³. For example, at 3,000m³ x 0.682t/m³=2,046tonnes. This means, with a 3,000 m³ tank, under this model the 5 vessels would generate around USD 7.27 million in bunkering revenue at \$710/t for the private operator.

According to Atchison, (2024), the Sweden–Belgium Green Shipping Corridor, spanning over 2,500 km of decarbonised route and linking Gothenburg, Antwerp-Bruges and North Sea Port, is a multimodal, high-capacity trade corridor within Northern Europe. The corridor is intra-European in focus but its members are

also significant trans-shipment, deep-sea trade ports connecting Europe with Asia, Africa and the Americas. In this regard, Namport and Walvis Bay could extend this corridor to the Southern Hemisphere by establishing green ammonia bunkering and trans-shipment facilities in Walvis Bay for vessels that are transiting the Cape of Good Hope. This would be for deep-sea vessels seeking to avoid the Suez Canal for reasons of geopolitical risk and assignment congestion risk.

Figure 13: Walvis Bay as a Southern Node in the Gothenburg-Antwerp Green Corridor



Source: Authors own illustration (2025)

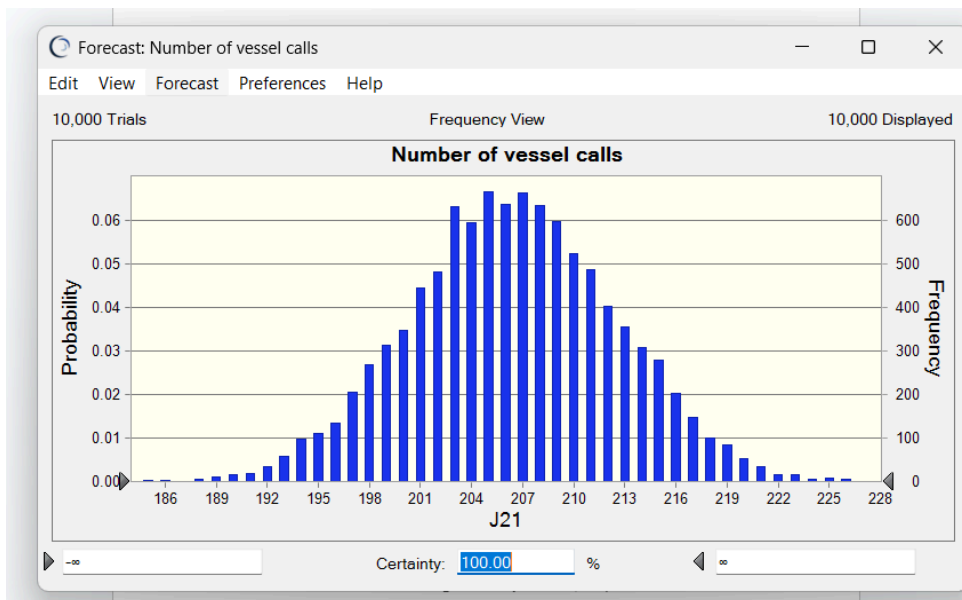
The diagram demonstrates a Walvis Bay bunkering hub's integration with the Sweden-Belgium green corridor for Cape-route traffic, providing a refuelling node for deep-sea bulk carriers which are rerouted from the Suez Canal. The node reinforces supply security and underpins the orderbook-based demand estimates by holding inter-bunkering legs within typical deep-sea ranges, and tapping into Southern African hinterland logistics with the green corridor.

In addition, Ismail et al., (2024) mention that subsequent to the Clydebank Declaration at COP 26, various governments continue to collaborate through signing a MOU or commencing projects to fulfil their environmental targets. Additionally, a

wide variety of ports also contributed to the Green Shipping Corridor (GSC) projects that were signed on by vessel operators. Namport already has an MoU with the Port of Antwerp regarding green hydrogen, thus the development of green shipping corridor between Walvis Bay into the EU not only reduces GHG emissions but also provides a major economic opportunity for green ammonia vessels looking to operate in that route.

5.3.1 Projected Annual Vessel Calls for Green Ammonia Bunkering in Walvis Bay over a 15 year period

Figure 14: Number of vessel calls (15 year period)



Source: Source: Author's simulation using Oracle Crystal Ball (2025)

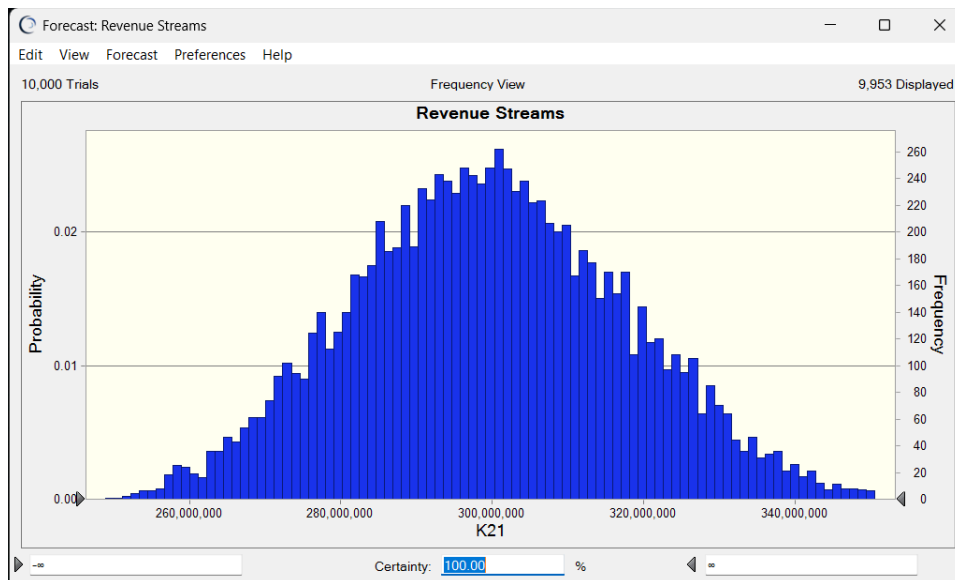
The author created all graphs labeled "Author's simulation using Oracle Crystal Ball," from outputs generated using Excel-linked Monte Carlo methods.

The model used Crystal Ball's Monte Carlo simulation method with 10,000 trials to generate probability distribution observations. The BetaPERT distribution method was used to interpolate between the scenario distributions and provide a simulated

realistic look at the range of vessel traffic. As a total, there was an objective view of the annual frequency show that the most likely annual number of vessel calls is between 205 and 208, with an increased probability density near the maximum. The view of the output distribution indicates that there is not a significant spread, and that there's reasonable strong confidence in the mid-scenario estimates observed.

5.3.2 Simulated revenue distribution for green ammonia bunkering over a 15 year period

Figure 15: Revenue Streams (Over 15 year period)



Source: *Source: Author's simulation using Oracle Crystal Ball (2025)*

The author created all graphs labeled "Author's simulation using Oracle Crystal Ball," from outputs generated using Excel-linked Monte Carlo methods.

As shown in figure 4.6, the total ammonia bunkering revenue was forecasted using a Monte Carlo simulation in Oracle Crystal Ball while accounting for uncertainty around demand and price. To produce a revenue estimate, Crystal Ball conducted 10,000 simulations generating its output by varying the inputs such as the number of

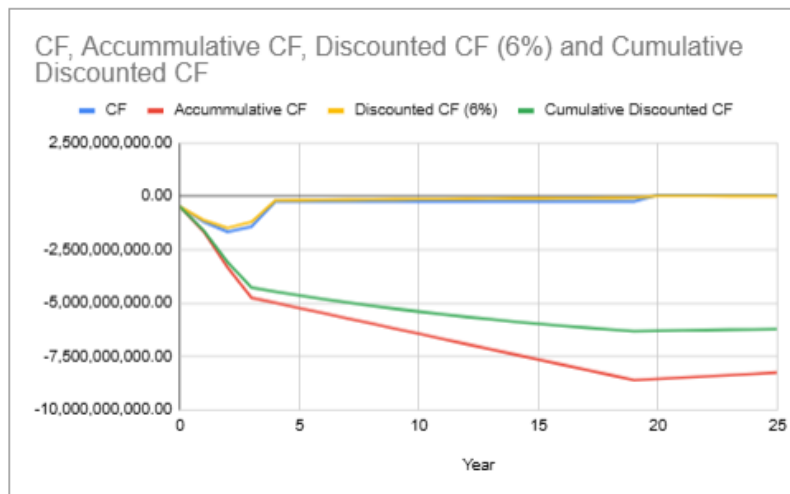
vessels per year, tank size, ammonia density and fuel price over the ranges defined using a BetaPERT probability distribution. This output is the cumulative revenue over a period of 15 years, based upon an Excel input table. The output revealed most probable revenue would be around USD 300 million, and a 90% confidence interval of approximately USD 270 million and USD 330 million. Given the range of potential operational circumstances, it indicates the private operator's revenue stream is resilient, this lends credibility to the potential commercial viability of green ammonia bunkering within a landlord port model.

5.4 Worst Case Scenario: Unfavourable conditions

Scenario Overview

In this scenario, Namport pursues a state-driven investment approach, developing both civil and bunkering infrastructure without private operators. Under this scenario, slow demand uptake occurs with only 0-3 vessels calling per year from 2025-2030, with delays in IMO fuel adoption and a global glut in green ammonia and other operational revenue drops by 30% due to vessels opting to take their business elsewhere and the incremental 2% inflation rate to both revenue and operational costs are discarded. The scenario observes the drop in green ammonia price to USD 450/t due to global oversupply and the regulatory framework is uncertain as a result of delayed ammonia fuel regulations by the IMO. The scenario observes a CAPEX of USD 4.7 billion funded through public debt in a public port model.

Figure 16: Illustrated findings: Nominal vs Cumulative discounted cash flows



Source: Author's simulation using MS 365 Excel (2025)

Figure 4.9 depicts the new investment based on a 6% discount rate over a time horizon of 25 years. The first couple of years show high negative cash flows given the significant initial capital expenditure which results in a sharp decline in both accumulative and DCF. The blue line shows there is little variability in annual revenues and costs while accumulative CF and cumulative DCF show that throughout the project there is no recovery of initial investment over the 25 time horizon. Even as discounted at 6%, the cumulative DCF remains negative, indicating a negative net present value (NPV). The conclusion is that at the current assumptions for the project it is not financially viable and thus either CAPEX must be reduced, better revenue streams or bunkering volumes or access to concessional finance must be found in order to make the project more economically viable. At 6% the project yields an NPV of USD -6,209,853,069.02 and an IRR of -24.08%.

5.5 Scenario Analysis

Table 5: Effect of Bunkering Scenarios on Project NPV

Scenario	NPV at 6% (USD)	Notes
Optimistic (Favourable)	5,927,408,815.13	High CAPEX, High Demand, Stable fuel prices at USD 710/t, High debt financing (Public Port Model)
Best Case (Moderate)	9,669,363,507.11	Lower CAPEX, Steady concession revenue streams, Low debt financing (Landlord Model)
Pessimistic (Unfavourable)	-6,209,853,069.02	High CAPEX, Low Demand, Unstable fuel prices at USD 450/t, High debt financing (Public port Model)

Intriguingly, the Optimistic (Favourable) scenario, while forecasting significantly larger marine bunker fuel volumes, has a lower NPV than the Best Case (Moderate) scenario, largely because of higher capital requiring higher investment and lower projected, near-term, revenues to be discounted over the project horizon. Even with the assumed risks of a higher but predictable volume, the capital investment scenario will detract more from its present value scale than it will add to the contract's net present values over the project's discounted length. However, the Moderate case's assumptions favoured a higher NPV due to the levels of investment matching realistic project, in this example, coastal demand planning. The finding in this analysis has explicitly demonstrated NPV's sensitivity to CAPEX and the need to right-size planned, importance of securing demand guarantees and financed infrastructure.

Chapter 6: Conclusion and Recommendations

The outcomes of the semi-structured interview were organized using a thematic approach based on the literature review, to identify the commonalities and unique perspectives of port professionals from Namibia and Antwerp-Burges on the topics of green ammonia bunkering infrastructure. This allowed for grouping the outcomes into key themes, which incorporated both the aspects of opportunities and challenges presented in developing green ammonia bunkering infrastructure. Some themes were consistently mentioned by all of the interviewees such as safety culture, regulatory clarity, and infrastructure readiness, while some themes emerged as context-specific, and therefore incorporated unique aspects of the institutional and development context the two ports were in. In the following sections, we present each of the identified themes along with respondent feedback, situating them relative to existing literature and also where applicable, referencing the simulation findings for example, chart findings. This mixed-methods triangulation allows experience to explain, qualify or even challenge the quantitative risk profile, providing a more rigorously decision-relevant feasibility study.

6.1 Governance and Role

The port governance plays an important role which can have adverse impacts on the financial, risk and overall direction of the port authority. This echoed during the interviews with personnel from the Port of Antwerp-Burges, who stated that they operate on a landlord and concession agreement model. They stated that they operate under a landlord model and put concession agreements in place to companies who wish to exploit such potentially lucrative activities. In addition, they stated that provided that they lack expertise in certain areas such as green hydrogen cracking they would best leave that to the experts. Similarly, a port engineer from Namport has aired the same sentiments that it's best those expertise are left to companies who specialise in that line of work and they mainly focus on concession agreements. Moreover, Hendriks & de, (2023) mentioned in his literature that the port is

positioned as operator, landlord, regulator. Namport personnel stated that Namport aims to transition to a landlord model, as opposed to the tool port which they are at the moment.

6.2 Safety of Ammonia Bunkering

All interview participants acknowledged the importance of safety when handling ammonia. Personnel from the port of Antwerp-Burges state that ammonia has some risk elements to it in terms of bunkering. This speaks to the literature from Chorowski et al. (2023) who speaks on ammonia toxicity and calls for implementing measures such as leak detection measures and emergency protocols. In addition, the Port of Antwerp-Burges conducts a risk analysis and has a bunker map which illustrates which parts of the port are safe to bunker which type of fuel. They conducted a feasibility study together with Det Norske Veritas (DNV) of bunkering new fuels in different scenarios on a theoretical basis around the port. Namport port has also acknowledged concerns with ammonia's chemical compound and risks in

6.3 Demand for green ammonia and profitability

The demand of green ammonia is an imperative aspect which dictates revenue streams especially for Namport or any port operator hoping to capitalize on green ammonia bunkering. A clear indicator for predicting ammonia bunkering volumes is through the Clarkson's database and companies that are linked to those vessels and which routes they would take. Personnel at the port of Antwerp-Burges state that they do not receive revenue from bunkering operations but rather indirect costs as a result of shore side bunkering activities such as port dues and other services. This sentiment rains true in the moderate case scenario where a landlord model is utilized and revenue from bunkering operations doesn't relate to the NPV and the port authority does not profit off it.

6.4 Policy and Legislation

There's little confidence which dictates if green ammonia is the fuel of the future, however ports such as Antwerp-Burges and Namport are making preparations in anticipation of this green transition. Both ports (Antwerp–Burges and Namport) have a MoU to fast track ammonia and hydrogen production and shipping. However, both parties express that there are uncertainties especially in the wake of the IMO net-zero framework and mandatory emission limits.

The interviews produced useful qualitative findings about stakeholder perceptions and catenae of policy challenges; the scenario analysis offered a contrasting quantitative account of the financial and operational performance in undertaking green ammonia bunkering. Although the results described a nuanced landscape for green ammonia bunkering in Namibia, there are indications that the economic potential is considerably affected by the underlying demand and capital expenditure assumptions. For example, although the best-case scenario required higher capital expenditure, it produced a better NPV because there were predictable vessel calls while the moderate case, which made the relatively lower investment produced poorer returns. This difference demonstrates that demand uncertainty remains paramount, a general point which was mentioned to be a concern by both Namport and Antwerp experts. Overall, the relative associations between regulatory certainty, stakeholder confidence and the level of committed investment are described with a view to creating the conditions which will allow the prospective economic opportunities explored in this study to be realised into practice.

6.5 Recommendations

Namibia has a unique advantage in wind-solar resource endowment, which gives it an in-built upside for green ammonia but the strategy should be clearly regional, risk-aware, and modular. Not as a stand-alone port play but as a nexus upon which to build a Cape of Good Hope Green Arc connecting Namibia to Angola (Lobito

corridor), Botswana and South Africa (Trans-Kalahari to Gauteng , Saldanha) and to Zambia/DRC (Trans-Capriivi to the Copperbelt). In this context, Namport is not just a landlord; it is a platform curator which offers bundled access to its quay, storage and safety systems alongside cross border logistics, data such as vessel ETA, fuel reservations and standard form contracts that reduce the entry costs for early movers. Financing should incorporate a mixture of PPP concessions with risk de-risking instruments that are bespoke for first-of-kind fuels. In order to minimize public balance sheet over-exposure, Namport's involvement must be in regulated-asset-base style returns on core civil works while private operators are responsible for financing tanks and pipelines, and bunkering assets, through performance-based concessions.

On market formation, Walvis Bay has the opportunity to establish itself as the southern anchor of the Antwerp–Sweden green corridor. Its mirroring incentive stack would include lower port dues for vessels leading in CII and EEXI, guaranteed green-fuel time windows for diversions from the conventional Cape of Good Hope route, and an interoperable corridor Measurement, Reporting and Verification (MRV) regime capable of including North Sea MRV standards. Where neighbouring ports can be treated as partners rather than competitors, coordinated tariff signals and common safety protocols amongst SADC ports will produce a larger, and more predictable demand basin than any single port could achieve. Implementation must be done in phases, and be bankable: (i) pilot berth with shore-to-ship connection and safety training, (ii) a concession instrument that scales automatically and expands the storage and line capacity as the pre-booked tonnage exceeds target thresholds, and (iii) corridor participation agreements that secure take or pay bills of lading with commitment from cross-border cargo owners and select liner services to lock in minimum volumes.

In summary, we suggest to treat Walvis Bay as a regional coordination node, socialise the risk of only the open-access infrastructure using PPPs, crowd-in private capital to invest in the fuel assets, hard-wire corridor participation alongside

neighbouring countries so that demand, standards and incentives scale; maximizing climate impact and economic resilience while maintaining fiscal responsibility.

6.6 Future Research Scope

Future research should examine how Namibia's green ammonia infrastructure can be part of a regional corridor network rather than a stand alone port project. Further research is also required involving scaling new risk-sharing instruments such as phased concessions and corridor agreements, to enable early private capital to be leveraged and long term demand guarantees from the whole Southern African region.

For yet another resource for future researchers who would rather opt out of utilizing excel, I developed a user interface to simplify the calculation of NPV and IRR. This is available in the appendix 2.

Bibliography

- Abánades, A., de Gracia, M. D. S., Martínez Fondón, P., & Saborit, E. (2025). Design of a flexible, modular, scalable infrastructure to inland intake of offshore hydrogen production. *International Journal of Hydrogen Energy*, 142, 1–8. <https://doi.org/10.1016/j.ijhydene.2025.05.285>
- Adeli, K., Nachtane, M., Faik, A., Saifaoui, D., & Boulezhar, A. (2023). How Green Hydrogen and Ammonia Are Revolutionizing the Future of Energy Production: A Comprehensive Review of the Latest Developments and Future Prospects. *Applied Sciences*, 13(15), 8711. <https://doi.org/10.3390/app13158711>
- African Development Bank. (2025, July 16). *ADF Applicable Lending Rates for the third quarter of 2025*. African Development Bank Group. <https://www.afdb.org/en/documents/adf-applicable-lending-rates-third-quarter-2025>
- Aldersey-Williams, J., & Rubert, T. (2019). Levelised cost of energy – A theoretical justification and critical assessment. *Energy Policy*, 124(1), 169–179. <https://doi.org/10.1016/j.enpol.2018.10.004>
- Altenburg, T., Kantel, A., & Institute, G. (2025). Green hydrogen in Namibia. Opportunities and risks. *INIS – International Nuclear Information System*, 6/2024. <https://inis.iaea.org/records/hnb8m-7kd77>
- Amesho, K. T. T., Edoun, E. I., Likela, S., Kadhila, T., & Nangombe, L. R. (2022). An empirical analysis of the co-benefits of integrating climate change adaptation and mitigation in the Namibian energy sector. *Journal of Energy in Southern Africa*, 33(1), 86–102. <https://doi.org/10.17159/2413-3051/2022/v33i1a8362>
- Arshad, A. (2012, December 1). *Net Present Value is better than Internal Rate of Return*. INTERDISCIPLINARY JOURNAL of CONTEMPORARY RESEARCH in BUSINESS. https://www.academia.edu/33482682/INTERDISCIPLINARY_JOURNAL_OF_CONTEMPORARY_RESEARCH_IN_BUSINESS_Net_Present_Value_is_better_than_Internal_Rate_of_Return
- Asgharian, H., Lund, H., Zinck Thellufsen, J., Iov, F., Nielsen, M. P., & Liso, V. (2025). Green ammonia production in Denmark: Assessing future potentials and challenges. *Fuel*, 387, 134423. <https://doi.org/10.1016/j.fuel.2025.134423>

- Assaf, S. A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. *International Journal of Project Management*, 24(4), 349–357.
<https://doi.org/10.1016/j.ijproman.2005.11.010>
- Atchison, J. (2022, April 13). *ACE Terminal: importing ammonia to Rotterdam from 2026*. Ammonia Energy Association.
<https://ammoniaenergy.org/articles/ace-terminal-importing-ammonia-to-rotterdam-from-2026/>
- Atchison, J. (2024, June 25). *Sweden-Belgium shipping corridor to be serviced by ammonia-fueled ro-ro vessels*. Ammonia Energy Association.
<https://ammoniaenergy.org/articles/sweden-belgium-shipping-corridor-to-be-serviced-by-ammonia-fueled-ro-ro-vessels/>
- Atchison, J. (2025, April 22). *First ammonia bunker pilot completed in Rotterdam*. Ammonia Energy Association.
<https://ammoniaenergy.org/articles/first-ammonia-bunker-pilot-completed-in-rotterdam/>
- Bahtić, F. (2021, September 3). *World's 1st green ammonia terminal wins major governmental grant*. Offshore Energy.
<https://www.offshore-energy.biz/worlds-1st-green-ammonia-terminal-wins-major-governmental-grant/>
- Bahtić, F. (2024). Construction begins on “world’s first” ammonia dual-fuel bulk carrier. *Offshore Energy*. <https://doi.org/10.29130443/37743>
- Bancel, F., Quentin, L., & Lhuissier, A. (2013). *Why is “your” WACC necessarily wrong? BANCEL Franck* (Professor, ESCP Europe and Labex Réfi) LATHUILLE Quentin (Investment Banking Analyst, ESCP-MIM Alumni) LHUISSIER Alban (Investment Banking Analyst, ESCP-MIM Alumni)*.
https://www.academia.edu/9366256/Why_is_your_WACC_necessarily_wrong_Professor_ESCP_Europe_and_Labex_R%C3%A9fi_LATHUILLE_Quentin_Investment_Banking_Analyst_ESCP_MIM_Alumni_LHUISSIER_Alban_Investment_Banking_Analyst_ESCP_MIM_Alumni_Draft_June_2013
- Barbir, F. (2005). PEM electrolysis for production of hydrogen from renewable energy sources. *Solar Energy*, 78(5), 661–669.
<https://doi.org/10.1016/j.solener.2004.09.003>
- Bidwai, S. (2023, July). *Green Ammonia Market Size, Trends, Growth, Report 2030*. www.precedenceresearch.com.
<https://www.precedenceresearch.com/green-ammonia-market>

- Cepeda, M. F. S., Gore, K., & Mao, X. (2025). *The potential of Brazilian ports as renewable marine fuel bunkering hubs MARICRUZ FUN SANG CEPEDA, KETAN GORE, AND XIAOLI MAO ACKNOWLEDGMENTS*. International Council on Clean Transportation.
https://theicct.org/wp-content/uploads/2025/06/ID-297-%E2%80%93-Brazil-bunkering_report_final.pdf
- Chidiebele E. J. Uzoagba, Ikpeka, P. M., Somtochukwu Godfrey Nnabuiife, Onwualu, P. A., Fayen Odette Ngasoh, & Kuang, B. (2025). Development of the Hydrogen Market and Local Green Hydrogen Offtake in Africa. *Hydrogen*, 6(3), 43–43. <https://doi.org/10.3390/hydrogen6030043>
- Chorowski, M., Lepszy, M., Machaj, K., Malecha, Z., Porwisiak, D., Porwisiak, P., Rogala, Z., & Stanclik, M. (2023). Challenges of Application of Green Ammonia as Fuel in Onshore Transportation. *Energies*, 16(13), 4898. <https://doi.org/10.3390/en16134898>
- Dato, P., Dioha, M., Hessou, H., Houenou, B., Mukhaya, B., Okyere, M. A., & Odarno, L. (2025). Computation of weighted average cost of capital (WACC) in the power sector for African countries and the implications for country-specific electricity technology cost. *Applied Energy*, 397, 126333. <https://doi.org/10.1016/j.apenergy.2025.126333>
- de Langen, Peter. W. (2005). Trends and Opportunities for the Long-Term Development of Rotterdam's Port Complex. *Coastal Management*, 33(2), 215–224. <https://doi.org/10.1080/08920750590919691>
- Deibel, I. (2019, January 1). *Port of Rotterdam – Incentive scheme for climate-friendly shipping – World Port Sustainability Program*. Sustainableworldports.org.
<https://sustainableworldports.org/project/port-of-rotterdam-incentive-scheme-for-climate-friendly-shipping/>
- Devkota, S., Ban, S., Shrestha, R., & Uprety, B. (2023). Techno-economic analysis of hydropower based green ammonia plant for urea production in Nepal. *International Journal of Hydrogen Energy*.
<https://doi.org/10.1016/j.ijhydene.2023.03.087>
- Ellersdorfer, P., Wang, C., Saydam, S., Canbulat, I., MacGill, I., & Daiyan, R. (2024). Unlocking new export opportunities: An open-source framework for assessing green iron and steel supply chains. *International Journal of Hydrogen Energy*, 92, 1366–1374.
<https://doi.org/10.1016/j.ijhydene.2024.10.163>

- Engelke, P., & Webster, J. (2023, March 22). *Rotterdam, Netherlands: An integrated approach to decarbonization*. Atlantic Council.
<https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/rotterdam-netherlands-an-integrated-approach-to-decarbonization/>
- Erkelens, E. (2022, April 11). *Gasunie, HES International and Vopak join forces to develop an import terminal for a hydrogen carrier in the port of Rotterdam*. HES International.
<https://www.hesinternational.eu/en/newsroom/gasunie-hes-international-and-vopak-join-forces-to-develop-an-import-terminal-for-a-hydrogen-carrier-in-the-port-of-rotterdam>
- Ford, N. (2006). African ports and harbours Africa's gateway to world trade. *African Business*, 321, 14+. Gale Academic OneFile.
<https://link.gale.com/apps/doc/A147297737/AONE?u=anon~fdf344aa&sid=googleScholar&xid=40c7e0d7>
- Fullonton, A., Lea-Langton, A. R., Madugu, F., & Larkin, A. (2024). Green ammonia adoption in shipping: Opportunities and challenges across the fuel supply chain. *Marine Policy*, 171, 106444.
<https://doi.org/10.1016/j.marpol.2024.106444>
- Genge, L., & Müsgens, F. (2025). *Green Ammonia: A Techno-Economic Supply Chain Optimization*. <https://arxiv.org/abs/2507.02412>
- Global Centre for Maritime Decarbonisation. (2023). *Safety and Operational Guidelines for Piloting Ammonia Bunkering*. GCMD.
<https://gcformd.org/wp-content/uploads/2023/04/GCMD-ammonial-bunkering-report-executive-summary-Updated-28-Jun-2024.pdf?>
- Goldman, L. L. (2003). Crystal Ball Professional introductory tutorial. *IEEE Xplore*.
<https://doi.org/10.1109/wsc.2002.1166430>
- Hansen, K. (2019). Decision-making based on energy costs: Comparing levelized cost of energy and energy system costs. *Energy Strategy Reviews*, 24, 68–82.
<https://doi.org/10.1016/j.esr.2019.02.003>
- Harvey, L. D. D. (2020). Clarifications of and improvements to the equations used to calculate the levelized cost of electricity (LCOE), and comments on the weighted average cost of capital (WACC). *Energy*, 207, 118340.
<https://doi.org/10.1016/j.energy.2020.118340>
- Hendriks, C., & de, G. V. (2023). Towards sustainable port areas: Dynamics of industrial decarbonization and the role of port authorities. *Handle.net*.
<https://hdl.handle.net/2066/291818>

- Holtan, M. (2002). *Using simulation to calculate the NPV of a project*.
<http://www.investmentscience.com/Content/howtoArticles/simulation.pdf>
- Hui, Y., Wang, M., Guo, S., Akhtar, S., Bhattacharya, S., Dai, B., & Yu, J. (2024). Comprehensive review of development and applications of hydrogen energy technologies in China for carbon neutrality: Technology advances and challenges. *Energy Conversion and Management*, 315, 118776–118776.
<https://doi.org/10.1016/j.enconman.2024.118776>
- IEA. (2021, December 17). *The cost of capital in clean energy transitions – Analysis*. IEA.
<https://www.iea.org/articles/the-cost-of-capital-in-clean-energy-transitions>
- IEA. (2024, November 5). *Renewable Energy Opportunities for Namibia – Analysis - IEA*. IEA.
<https://www.iea.org/reports/renewable-energy-opportunities-for-namibia>
- Imasiku, K., Farirai, F., Olwoch, J., & Agbo, S. N. (2021). A Policy Review of Green Hydrogen Economy in Southern Africa. *Sustainability*, 13(23), 13240.
<https://doi.org/10.3390/su132313240>
- IMO Cares. (2024). *GUIDANCE AND TECHNICAL OVERVIEW* (pp. 5–9).
<https://imocares.imo.org/wp-content/uploads/2024/02/Guidance-and-technical-overview-2.pdf>
- Ishaq, H., Shehzad, M. F., & Crawford, C. (2023). Transient modeling of a green ammonia production system to support sustainable development. *International Journal of Hydrogen Energy*, 48(99), 39254–39270.
<https://doi.org/10.1016/j.ijhydene.2023.07.036>
- Islam, A., Islam, T., Mahmud, H., Obayed Raihan, Md. Shahinoor Islam, Marwani, H. M., Marwani, H. M., Rahman, M. M., Rahman, M. M., Asiri, A. M., Asiri, A. M., Md. Munjur Hasan, Md. Munjur Hasan, Md. Munjur Hasan, Md. Nazmul Hasan, Md. Nazmul Hasan, Md. Nazmul Hasan, Md. Shad Salman, Md. Shad Salman, & Md. Shad Salman. (2024). Accelerating the green hydrogen revolution: A comprehensive analysis of technological advancements and policy interventions. *International Journal of Hydrogen Energy*, 67, 458–486. <https://doi.org/10.1016/j.ijhydene.2024.04.142>
- Ismail, A. M., Ballini, F., Ölçer, A. I., & Alamoush, A. S. (2024). Integrating ports into green shipping corridors: Drivers, challenges, and pathways to implementation. *Marine Pollution Bulletin*, 209, 117201.
<https://doi.org/10.1016/j.marpolbul.2024.117201>

- Joseph Sekhar, S., Samuel, M. S., Glivin, G., Le, T., & Mathimani, T. (2024). Production and utilization of green ammonia for decarbonizing the energy sector with a discrete focus on Sustainable Development Goals and environmental impact and technical hurdles. *Fuel*, 360, 130626. <https://doi.org/10.1016/j.fuel.2023.130626>
- Kadam, R. S., Sutar, P. R., & Yadav, G. D. (2025). Energy and environmental assessment of industrial-scale hydrogen production: Comparison of steam methane reforming, electrolysis, and Cu–Cl cycles. *International Journal of Hydrogen Energy*, 106, 994–1005. <https://doi.org/10.1016/j.ijhydene.2025.01.439>
- Kara, E., Mikail Rıza Onat, Demir, M. E., & Kinaci, O. K. (2025). Techno-economic analysis of offshore renewable energy farms in Western Spain using fuzzy AHP & TOPSIS methodology. *Renewable Energy*, 122361–122361. <https://doi.org/10.1016/j.renene.2025.122361>
- Kaura, U. (2025, May 14). *Namibia's Long-Term Low-Emission Development Strategy: A Strategic Policy Shift for Climate-Resilient Economic Development*. UNDP. <https://www.undp.org/namibia/blog/namibias-long-term-low-emission-development-strategy-strategic-policy-shift-climate-resilient-economic-development>
- Kaushik, V., & Walsh, C. A. (2019). Pragmatism as a research paradigm and its implications for social work research. *Social Sciences*, 8(9), 1–17. Mdpi. <https://doi.org/10.3390/socsci8090255>
- Klagge, B., Walker, B., Kalvelage, L., & Greiner, C. (2025). Governance of future-making: Green hydrogen in Namibia and South Africa. *Geoforum*, 161, 104244. <https://doi.org/10.1016/j.geoforum.2025.104244>
- Kołakowski, P., Gil, M., & Wróbel, K. (2024). Stakeholders' view on selecting a prospective location for marine alternative fuels bunkering station. *Marine Policy*, 164, 106164. <https://doi.org/10.1016/j.marpol.2024.106164>
- Kumar, S., Baalisampang, T., Arzaghi, E., Garaniya, V., Abbassi, R., & Salehi, F. (2023). Synergy of green hydrogen sector with offshore industries: Opportunities and challenges for a safe and sustainable hydrogen economy. *Journal of Cleaner Production*, 384, 135545. <https://doi.org/10.1016/j.jclepro.2022.135545>
- Kumar, S., Wickramasooriya, A., & Dilini, S. (2022). Analysis of ammonium nitrate detonation destruction in Beirut city using geospatial techniques. *Spatial Information Research*. <https://doi.org/10.1007/s41324-022-00459-0>

- Mallouppas, G., Ioannou, C., & Yfantis, E. Ar. (2022). A Review of the Latest Trends in the Use of Green Ammonia as an Energy Carrier in Maritime Industry. *Energies*, 15(4), 1453. <https://doi.org/10.3390/en15041453>
- Mapaure, I. (2022). Chapter 21: Review of the Climate Change Situation in Namibia: Projected Trends, Vulnerability and Impacts. *Nomos Verlagsgesellschaft MbH & Co. KG EBooks*, 533–560. <https://doi.org/10.5771/9783748933564-533>
- Marais, H. (2006). *Participatory Review and Evaluation of Co-operation between Namibia and Sweden in the Transport and Communications Sectors -Resource Paper 2 - Co-operation between Namibia and Sweden in the Transport and Communications Sectors -Commercialisation of Namibian Transport and Communications Operations- REPUBLIC OF NAMIBIA MINISTRY OF WORKS, TRANSPORT AND COMMUNICATION*. https://www.transcomreform.seydack.org/docs/final_report/Annex%20%20-%20Resource%20Paper%20%20-%20Commercialisation.pdf
- Mikail Rıza Onat, & Demir, M. E. (2025). Techno-economic assessment of green ammonia and hydrogen distribution from offshore wind farms to European ports. *International Journal of Hydrogen Energy*. <https://doi.org/10.1016/j.ijhydene.2025.03.123>
- Minchin, J. (2024). *Namibia's Walvis Bay could become key green bunkering hub*. Lloyd's List. <https://www.lloydslist.com/LL1149066/Namibia%E2%80%99s-Walvis-Bay-could-become-key-green-bunkering-hub>
- Ministry of Works and Transport . (2018). *Custodian OMA: Ministry of Works and Transport 2018 Namibian Transport Policy Implementation Period (2018 -2035)* (p. 25). https://www.giz.de/en/downloads/Namibian%20Transport%20Policy_Print.pdf
- Minutillo, M., Perna, A., Forcina, A., Di Micco, S., & Jannelli, E. (2021). Analyzing the levelized cost of hydrogen in refueling stations with on-site hydrogen production via water electrolysis in the Italian scenario. *International Journal of Hydrogen Energy*, 46(26), 13667–13677. <https://doi.org/10.1016/j.ijhydene.2020.11.110>
- MME. (2022). *Republic of Namibia Namibia. Green Hydrogen and Derivatives Strategy II* (p. 31). e Ministry of Mines and Energy Namibia. <https://gh2namibia.com/wp-content/uploads/2022/11/Namibia-GH2-Strategy-Rev2.pdf>

- Najjar, Y. S. H. (2013). Hydrogen safety: the Road toward Green Technology. *International Journal of Hydrogen Energy*, 38(25), 10716–10728. <https://doi.org/10.1016/j.ijhydene.2013.05.126>
- Namibia Green Hydrogen Programme. (2024). *Republic of Namibia Traction II Namibia's Green Hydrogen Overview and Report 2024* (p. 25). <https://gh2namibia.com/wp-content/uploads/2024/12/Traction-2.pdf>
- Namport Property Holdings (Pty) Ltd. (2024). *INTEGRATED ANNUAL REPORT* (pp. 6–7). https://www.namport.com.na/files/documents/278_Annual%20Report%2012%20Months%20ended%2031%20March%202024.pdf
- Namport Property Holdings (Pty) Ltd, (2024). (2025). *Namport Corporate Governance Philosophy - Namibian Ports Authority*. Namport.com.na. <https://www.namport.com.na/about-namport/namport-corporate-governance-philosophy/564/>
- New Era Namibia. (2006, September). *Maritime Accident Reporting and Analysis Systems in Namibia*. Neweralive.na. <https://neweralive.na/maritime-accident-reportingand-analysis-systems-in-namibia/>
- Notteboom, T., & Haralambides, H. (2023). Seaports as green hydrogen hubs: advances, opportunities and challenges in Europe. *Maritime Economics & Logistics*. <https://doi.org/10.1057/s41278-023-00253-1>
- Notteboom, T., Pallis, A., & Rodrigue, J.-P. (2021). Port Economics, Management and Policy. *Port Economics, Management and Policy*, 1. <https://doi.org/10.4324/9780429318184>
- Parrado, C., Girard, A., Simon, F., & Fuentealba, E. (2016). 2050 LCOE (Levelized Cost of Energy) projection for a hybrid PV (photovoltaic)-CSP (concentrated solar power) plant in the Atacama Desert, Chile. *Energy*, 94, 422–430. <https://doi.org/10.1016/j.energy.2015.11.015>
- Pietrosemoli, L., & Rodríguez Monroy, C. (2013). The impact of sustainable construction and knowledge management on sustainability goals. A review of the Venezuelan renewable energy sector. *Renewable and Sustainable Energy Reviews*, 27, 683–691. <https://doi.org/10.1016/j.rser.2013.07.056>
- Prakash Kumar Sarangi, Srivastava, R. K., J. Gitanjali, Govindasamy Sathiyam, Venkatesan, G., & Kandasamy, S. (2024). Exploring cutting-edge advances in green ammonia production and storage technologies. *Fuel*, 371, 131863–131863. <https://doi.org/10.1016/j.fuel.2024.131863>

- Quang Vu Dinh, Pedro H.Todesco Pereira, Van Nguyen Dinh, Nagle, A. J., & Leahy, P. G. (2024). Levelised cost of transmission comparison for green hydrogen and ammonia in new-build offshore energy infrastructure: Pipelines, tankers, and HVDC. *International Journal of Hydrogen Energy*, 62, 684–698. <https://doi.org/10.1016/j.ijhydene.2024.03.066>
- Ribeiro, C., & Santos. (2025). Transitioning Ammonia Production: Green Hydrogen-Based Haber–Bosch and Emerging Nitrogen Reduction Technologies. *Clean Technologies*, 7(2), 49–49. <https://doi.org/10.3390/cleantechnol7020049>
- Ritchie, H., Roser, M., & Rosado, P. (2020, May 11). *CO₂ and Greenhouse Gas Emissions*. Our World in Data. <https://ourworldindata.org/co2/country/namibia?country=~NAM#what-are-the-country-s-annual-co2-emissions>
- Rivarolo, M., Improtta, O., Magistri, L., Panizza, M., & Barbucci, A. (2018). Thermo-economic analysis of a hydrogen production system by sodium borohydride (NaBH₄). *International Journal of Hydrogen Energy*, 43(3), 1606–1614. <https://doi.org/10.1016/j.ijhydene.2017.11.079>
- Rother, E. T. (2007). Systematic Literature Review X Narrative Review. *Acta Paulista de Enfermagem*, 20(2), v–vi. <https://doi.org/10.1590/S0103-21002007000200001>
- Rouwenhorst, K. (2025a). *LEAD: Ammonia-Fueled Vessels*. Ammonia Energy Association. <https://ammoniaenergy.org/lead/vessels/>
- Rouwenhorst, K. (2025b, July 29). *Ammonia bunkering: moving from demonstrations to operations*. Ammonia Energy Association. <https://ammoniaenergy.org/articles/ammonia-bunkering-moving-from-demonstrations-to-operations/>
- Rouwenhorst, K. (2025c, August 7). *Renewable ammonia price discoveries: a closer look at the H2Global and SECI auctions*. Ammonia Energy Association. <https://ammoniaenergy.org/articles/renewable-ammonia-price-discoveries-a-closer-look-at-the-h2global-and-seci-auctions/>
- Ruppel, O. C., & Katoole, M. (2023). A regulatory green hydrogen framework for Namibia. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4504076>
- Salehmin, M. N. I., Husaini, T., Goh, J., & Sulong, A. B. (2022). High-pressure PEM water electrolyser: A review on challenges and mitigation strategies towards green and low-cost hydrogen production. *Energy Conversion and Management*, 268, 115985. <https://doi.org/10.1016/j.enconman.2022.115985>

- Salmon, N., Bañ Ares-Alcá, R., & Nayak-Luke, R. (2021). Optimization of green ammonia distribution systems for intercontinental energy transport. *IScience*. <https://doi.org/10.1016/j.isci>
- Salmon, N., & Bañares-Alcántara, R. (2021). Green ammonia as a spatial energy vector: a review. *Sustainable Energy & Fuels*, 11. <https://doi.org/10.1039/d1se00345c>
- Samadi, S., Lechtenböhmer, S., Schneider, C., Arnold, K., Fishedick, M., Schüwer, D., & Wuppertal, A. (2016). *Decarbonization Pathways for the Industrial Cluster of the Port of Rotterdam On behalf of*. <https://www.portofrotterdam.com/sites/default/files/2021-06/rapport%20decarbonization%20pathways%20for%20the%20industrial%20cluster%20of%20the%20port%20of%20rotterdam.pdf>
- Samsatli, S., & Samsatli, N. J. (2018). A multi-objective MILP model for the design and operation of future integrated multi-vector energy networks capturing detailed spatio-temporal dependencies. *Applied Energy*, 220, 893–920. <https://doi.org/10.1016/j.apenergy.2017.09.055>
- Savage, C. J. (2015). The Proposed Walvis-Bay Port-Centric Hub Development: A Blessing or a Curse? | Botswana Journal of Business. *Journals.ub.bw*, 7(1). <https://journals.ub.bw/index.php/bjb/article/view/300>
- Schreuder, W., Slootweg, J. C., & van der Zwaan, B. (2025). Techno-economic assessment of low-carbon ammonia as fuel for the maritime sector. *Applications in Energy and Combustion Science*, 22, 100330. <https://doi.org/10.1016/j.jaecs.2025.100330>
- Seddiek, I. S., & Ammar, N. R. (2023). Technical and eco-environmental analysis of blue/green ammonia-fueled RO/RO ships. *Transportation Research Part D: Transport and Environment*, 114, 103547. <https://doi.org/10.1016/j.trd.2022.103547>
- Shepherd, J., Haider Ali Khan, M., Amal, R., Daiyan, R., & MacGill, I. (2022). Open-source project feasibility tools for supporting development of the green ammonia value chain. *Energy Conversion and Management*, 274, 116413. <https://doi.org/10.1016/j.enconman.2022.116413>
- Smart, K. (2021). Review of Recent Progress in Green Ammonia Synthesis. *Johnson Matthey Technology Review*, 66(3). <https://doi.org/10.1595/205651322x16334238659301>

- Sornn-Friese, H. (2024). *Ports as Energy Transition Hubs An Exploratory Study*.
https://research-api.cbs.dk/ws/portalfiles/portal/110673309/ports_as_energy_transition_hubs._an_exploratory_study.pdf
- Squadrito, G., Maggio, G., & Nicita, A. (2023). The Green Hydrogen Revolution. *Renewable Energy*, 216, 119041.
<https://doi.org/10.1016/j.renene.2023.119041>
- STAR, G. (2023). *Green Shipping Programme: Ammonia powered bulk carrier Pilot report* (pp. 38–43).
<https://greenshippingprogramme.com/wp-content/uploads/2023/06/Ammonia-powered-bulk-carrier.-Pilot-report..pdf>
- Ștefan Cristian Galusnyak, Petrescu, L., Sandu, V.-C., & Călin-Cristian Cormoș. (2023). Environmental impact assessment of green ammonia coupled with urea and ammonium nitrate production. *Journal of Environmental Management*, 343, 118215–118215.
<https://doi.org/10.1016/j.jenvman.2023.118215>
- Steffen, B. (2020). Estimating the cost of capital for renewable energy projects. *Energy Economics*, 88, 104783. <https://doi.org/10.1016/j.eneco.2020.104783>
- Sung, S., & Jung, W. (2019). Economic Competitiveness Evaluation of the Energy Sources: Comparison between a Financial Model and Levelized Cost of Electricity Analysis. *Energies*, 12(21), 4101.
<https://doi.org/10.3390/en12214101>
- The hydrogen system is taking shape | Port of Rotterdam*. (2025). Port of Rotterdam.
<https://www.portofrotterdam.com/en/news-and-press-releases/hydrogen-system-taking-shape>
- Tunagur, E. (2024). *Namibia and Mozambique bunker demand jumps amid South Africa constraints*. Lloyd's List.
<https://www.lloydslist.com/LL1148042/Namibia-and-Mozambique-bunker-demand-jumps-amid-South-Africa-constraints>
- Ueckerdt, F., Hirth, L., Luderer, G., & Edenhofer, O. (2013). System LCOE: What are the costs of variable renewables? *Energy*, 63, 61–75.
<https://doi.org/10.1016/j.energy.2013.10.072>
- Vartiainen, E., Breyer, C., Moser, D., Román Medina, E., Busto, C., Masson, G., Bosch, E., & Jäger-Waldau, A. (2021). True Cost of Solar Hydrogen. *Solar RRL*, 6(5). <https://doi.org/10.1002/solr.202100487>

- Vartiainen, E., Masson, G., Breyer, C., Moser, D., & Román Medina, E. (2019). Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity. *Progress in Photovoltaics: Research and Applications*, 28(6), 439–453. <https://doi.org/10.1002/pip.3189>
- Vigneswaran, V. S., Gowd, S. C., Ravichandran, V., Karthikeyan, M., Ganeshan, P., Kandasamy, S., Lee, J., Barathi, S., & Rajendran, K. (2025). Green ammonia as hydrogen carrier: current status, barriers, and strategies to achieve sustainable development goals. *Science of the Total Environment*, 982, 179646. <https://doi.org/10.1016/j.scitotenv.2025.179646>
- Vrijen, E. (2023, February 20). *ACE Terminal*. Gasunie. <https://www.gasunie.nl/en/projects/ace-terminal>
- Walker, B., Klagge, B., & Haid, R. (2025). Spatial planning policies for export-oriented green-hydrogen projects in Chile, Namibia, and South Africa. *Land Use Policy*, 157, 107672. <https://doi.org/10.1016/j.landusepol.2025.107672>
- Wang, B., Ni, M., & Jiao, K. (2022). Green ammonia as a fuel. *Science Bulletin*, 67(15), 1530–1534. <https://doi.org/10.1016/j.scib.2022.06.023>
- Wang, C., Walsh, S. D. C., Longden, T., Palmer, G., Lutalo, I., & Dargaville, R. (2023). Optimising renewable generation configurations of off-grid green ammonia production systems considering Haber-Bosch flexibility. *Energy Conversion and Management*, 280, 116790. <https://doi.org/10.1016/j.enconman.2023.116790>
- Wang, H., Lin, N., & Arzumanyan, M. (2024). The Market for Low-Carbon-Intensity Ammonia. *Gases*, 4(3), 224–235. <https://doi.org/10.3390/gases4030013>
- Wang, Y., Dong, G., Yu, J., Qin, C., Feng, Y., Deng, Y., & Zhang, M. (2025). In-situ green hydrogen production from offshore wind farms, a prospective review. *Renewable Energy*, 239, 122099. <https://doi.org/10.1016/j.renene.2024.122099>
- Winter, O. (2022, December 2). *RWE and Hyphen explore offtake of green ammonia from Namibia*. Rwe.com. <https://www.rwe.com/en/press/rwe-supply-and-trading/2022-12-02-rwe-and-hyphen-explore-offtake-of-green-ammonia-from-namibia/>
- Yan, R., & Zhang, Y. (2022, March 26). *The Introduction of NPV and IRR*. www.atlantis-Press.com; Atlantis Press. <https://doi.org/10.2991/aebmr.k.220307.241>

- Yu, Q., Hao, Y., Ali, K., Hua, Q., & Sun, L. (2024). Techno-economic analysis of hydrogen pipeline network in China based on levelized cost of transportation. *Energy Conversion and Management*, 301, 118025. <https://doi.org/10.1016/j.enconman.2023.118025>
- Žižlavský, O. (2018). Net Present Value Approach: Method for Economic Assessment of Innovation Projects. *Procedia - Social and Behavioral Sciences*, 156, 506–512. <https://doi.org/10.1016/j.sbspro.2014.11.230>

Appendix 1

Figure 17: Cash-Flow Summary for Namport Favourable conditions - Landlord Model Scenario Overview

		Financial Performance Report - Q3 2023																																																																																																																																																																																														
																																																																																																																																																																																																

Source: Author's simulation using MS 365 Excel (2025)

Figure 18: Cash-Flow Summary for Nampot Favourable conditions - Landlord Model Scenario Overview cont.

Table3										
#	Year	#	CF	#	Accumulative CF	#	Discounted CF (6%)	#	Cumulative Discounted CF	NPV (Running)
	0		-310,864.32		-310,864.32		-310,864.32		-310,864.32	
	1		-271,006.28		-581,870.60		-255,666.30		-566,530.62	
	2		-194,290.20		-776,160.80		-172,917.59		-739,448.21	
	3		740,457,882.00		739,681,721.20		621,702,716.00		620,963,267.79	
	4		754,839,364.28		1,494,521,085.48		597,903,477.21		1,218,866,745.00	
	5		769,944,705.08		2,264,465,790.56		575,347,473.52		1,794,214,218.53	
	6		785,352,152.68		3,049,817,943.24		553,642,277.99		2,347,856,496.52	
	7		801,067,749.25		3,850,885,692.49		532,755,805.13		2,880,612,301.65	
	8		817,097,657.74		4,667,983,350.23		512,657,179.06		3,393,269,480.71	
	9		833,448,164.40		5,501,431,514.63		493,316,687.94		3,886,586,168.65	
	10		850,125,681.19		6,351,557,195.82		474,705,740.10		4,361,291,908.75	
	11		867,136,748.33		7,218,693,944.15		456,796,821.83		4,818,088,730.57	
	12		884,488,036.80		8,103,181,980.95		439,563,456.74		5,257,652,187.31	
	13		902,186,351.04		9,005,368,331.99		422,980,166.70		5,680,632,354.02	
	14		920,238,631.57		9,925,606,963.56		407,022,434.20		6,087,654,788.22	
	15		938,651,957.71		10,864,258,921.27		391,666,666.14		6,479,321,454.36	
	16		957,433,550.37		11,821,692,471.64		376,890,159.01		6,856,211,613.37	
	17		976,590,774.88		12,798,283,246.52		362,671,065.32		7,218,882,678.69	
	18		996,131,143.89		13,794,414,390.41		348,988,361.41		7,567,871,040.10	
	19		1,016,062,320.27		14,810,476,710.69		335,821,816.33		7,903,692,856.43	
	20		1,036,819,795.54		15,847,296,506.23		323,285,313.18		8,226,978,169.61	
	21		1,057,556,191.45		16,904,852,697.69		311,085,867.40		8,538,064,037.01	
	22		1,078,707,315.28		17,983,560,012.97		299,346,778.06		8,837,410,815.07	
	23		1,100,281,461.59		19,083,841,474.56		288,050,673.23		9,125,461,488.30	
	24		1,122,287,090.82		20,206,128,565.38		277,180,836.51		9,402,642,324.81	
	25		1,144,732,832.64		21,350,861,398.02		266,721,182.30		9,669,363,507.11	\$9,669,363,507.11

Source: Author's simulation using MS 365 Excel (2025)

Figure 19: Modeling using Monte Carlo simulation (Vessel traffic and Revenue Potential)

[illegible]

Appendix 2

NPV, IRR and Payback user interface (Python + Streamlit)

Save Python file as NotePad, Save as, All files and provide name of choice, e.g, “Laz.py”. Open Anaconda prompt, activate your streamlit-environment with (conda activate streamlit-env) and navigate to project folder via this input (cd C:\Users\YourName\Desktop\Nameoffolder and run this input: streamlit run app.py

```
import re
import math
import numpy as np
import pandas as pd
import altair as alt
import streamlit as st

# =====
# Helpers
# =====

def parse_cashflows(text: str) -> list[float]:
    """Parse comma/newline/semicolon-separated numbers into a float list."""
    tokens = re.split(r"[,\n\r;\t]+", text.strip())
    vals: list[float] = []
    for t in tokens:
        t = t.strip()
        if t:
            vals.append(float(t))
    return vals

def xnpv(rate: float, cfs: list[float]) -> float:
```

```

"""NPV with year spacing 1.0 between periods (year 0..n)."""
return sum(cf / ((1.0 + rate) ** t) for t, cf in enumerate(cfs))

def xirr(cfs: list[float]) -> float:
    """
    IRR via bracketing + bisection. Returns float('nan') if it can't be found.
    """
    # Need both signs
    if not any(cf > 0 for cf in cfs) or not any(cf < 0 for cf in cfs):
        return float("nan")

    low, high = -0.9999, 10.0 # -99.99% to 1000%+
    f_low, f_high = xnpv(low, cfs), xnpv(high, cfs)

    # Expand high until we bracket a root (sign change) or give up
    attempts = 0
    while f_low * f_high > 0 and attempts < 50:
        high *= 2
        f_high = xnpv(high, cfs)
        attempts += 1
        if high > 1e6:
            return float("nan")

    # Bisection
    mid = (low + high) / 2
    for _ in range(200):
        f_mid = xnpv(mid, cfs)
        if abs(f_mid) < 1e-7:
            return mid

```

```

    if f_low * f_mid < 0:
        high, f_high = mid, f_mid
    else:
        low, f_low = mid, f_mid
    mid = (low + high) / 2
return mid

def payback_year(cum_series: list[float], period_flows: list[float]) -> float:
    """
    Returns the fractional year when cumulative cash flow first becomes >= 0.
    float('nan') if it never does.
    """
    for t in range(1, len(cum_series)):
        if cum_series[t] >= 0:
            prev = cum_series[t - 1]
            cf_t = period_flows[t]
            if cf_t == 0:
                return float(t)
            frac = (-prev) / cf_t # linear interpolation within the year
            return (t - 1) + max(0.0, min(1.0, frac))
    return float("nan")

# =====
# UI
# =====

st.set_page_config(page_title="Finance Metrics (Streamlit)", layout="centered")
st.title("Finance Metrics (Streamlit)")
st.caption("Build v2 — charts enabled • Enter a discount rate and cash flows; click  

**Compute**. Year 0 is the initial outlay.")

```

```

rate_input = st.number_input(
    "Discount rate (decimal or %)",
    value=0.08,
    step=0.01,
    format="%.4f",
    help="Examples: 0.08 for 8%. If you type 8, I'll treat it as 8%."
)

cash_text = st.text_area(
    "Cash flows (comma- or newline-separated)",
    value="-1000000, 300000, 320000, 340000",
    height=130,
    help="Use negatives for costs/outlay. Example: -1_500_000, 400_000, 420_000, 450_000, 480_000"
)

compute = st.button("Compute", type="primary")

if compute:
    # Accept decimal or percent
    r = rate_input / 100.0 if rate_input > 1 else rate_input

    if r <= -0.999:
        st.error("Discount rate must be greater than -100%.")
        st.stop()

    try:
        cfs = parse_cashflows(cash_text)
    except:
        if not cfs:

```

```

st.error("No cash flows provided.")
st.stop()

years = list(range(len(cfs)))
disc = [cf / ((1 + r) ** t) for t, cf in enumerate(cfs)]
cum = list(np.cumsum(cfs))
cum_disc = list(np.cumsum(disc))

npv = float(sum(disc))
irr = xirr(cfs)
spb = payback_year(cum, cfs)
dpb = payback_year(cum_disc, disc)

# ---- results cards ----
c1, c2, c3, c4 = st.columns(4)
c1.metric("NPV", f"{npv:,.2f}")
c2.metric("IRR", "N/A" if math.isnan(irr) else f"{irr*100:,.2f}%")
c3.metric("Simple Payback", "No payback" if math.isnan(spb) else
f"{spb:.2f} yrs")
c4.metric("Discounted Payback", "No payback" if math.isnan(dpb) else
f"{dpb:.2f} yrs")

# ---- table ----
df = pd.DataFrame({
    "Year": years,
    "Cash Flow": cfs,
    "Discounted CF": disc,
    "Cumulative CF": cum,
    "Cumulative Discounted CF": cum_disc,

```

```

})

st.subheader("Cash-Flow Table")
st.dataframe(df, use_container_width=True)

# ---- charts (Altair) ----
st.subheader("Cash Flow by Year")
bar = alt.Chart(df).mark_bar().encode(
    x=alt.X("Year:O", title="Year"),
    y=alt.Y("Cash Flow:Q", title="Cash Flow"),
    tooltip=["Year", alt.Tooltip("Cash Flow:Q", format=",.2f")]
)
st.altair_chart(bar, use_container_width=True)

st.subheader("Cumulative vs Discounted Cumulative Cash Flow")
lines_df = df.melt(
    id_vars=["Year"],
    value_vars=["Cumulative CF", "Cumulative Discounted CF"],
    var_name="Series",
    value_name="Value"
)
lines = alt.Chart(lines_df).mark_line(point=True).encode(
    x=alt.X("Year:Q", title="Year"),
    y=alt.Y("Value:Q", title="Cumulative Value"),
    color=alt.Color("Series:N"),
    tooltip=["Year", "Series", alt.Tooltip("Value:Q", format=",.2f")]
)
st.altair_chart(lines, use_container_width=True)

```

```

# ---- downloads ----
st.subheader("Export")
st.download_button(
    label="Download CSV (table)",
    data=df.to_csv(index=False).encode("utf-8"),
    file_name="cashflow_table.csv",
    mime="text/csv",
)

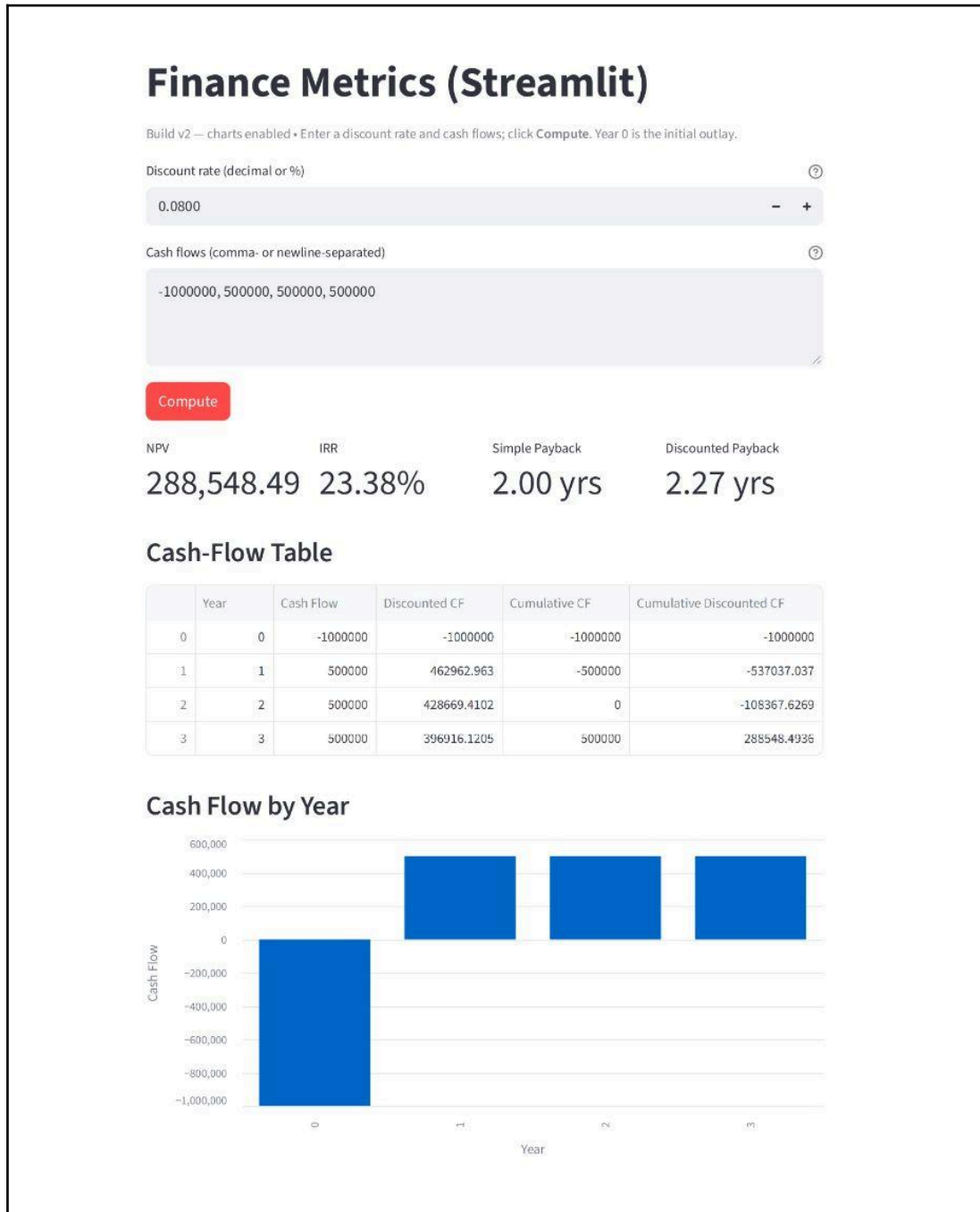
summary = pd.DataFrame(
    {
        "NPV": [npv],
        "IRR_%": [None if math.isnan(irr) else irr * 100.0],
        "Simple_Payback_years": [None if math.isnan(spb) else spb],
        "Discounted_Payback_years": [None if math.isnan(dpb) else dpb],
        "Rate_decimal": [r],
    }
)

st.download_button(
    label="Download CSV (summary metrics)",
    data=summary.to_csv(index=False).encode("utf-8"),
    file_name="cashflow_summary.csv",
    mime="text/csv",
)

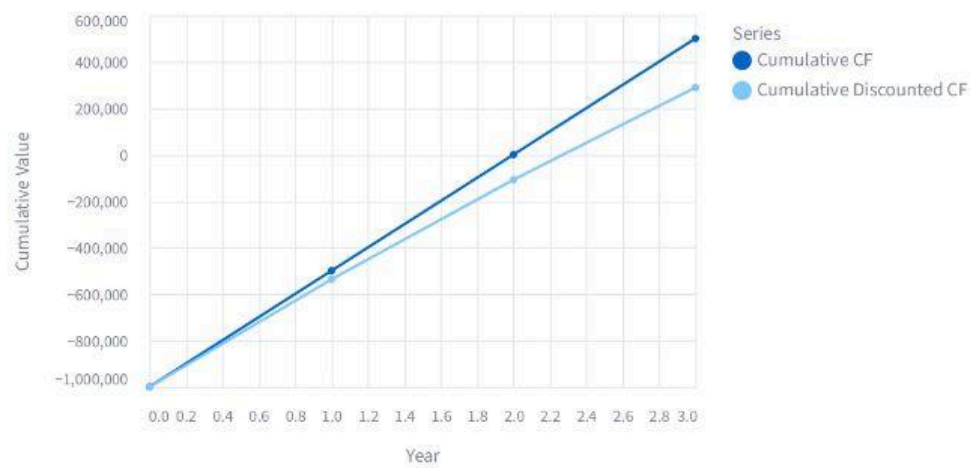
except ValueError as e:
    st.error(f"Could not parse your inputs: {e}")

```

Streamlit Application Interface (Auto calculates NPV, IRR and Payback)



Cumulative vs Discounted Cumulative Cash Flow



Export

[Download CSV \(table\)](#)

[Download CSV \(summary metrics\)](#)

Appendix 3

Interview Questions

Interview No. 1

Port Engineer - Nampont

1. Is it economically viable for nampont to invest in the production of alternative fuels?
2. Regarding the prospective multi-purpose terminal, what would you envisage the feasibility of applying more than one alternative fuel - for example, green ammonia and hydrogen? In addition, what influence could a diversified fuel offering have on the competitiveness within the market?
3. Is there a strategy to electrify even more of port operations beyond the existing electrification of the terminal? Could you envision Nampont in the future using electric-powered vehicles (i.e., trucks) for moving cargo from the terminal?
4. In your opinion, what factors may serve as barriers for the uptake of green ammonia or green hydrogen?

Interview No. 2

Programme Manager for Climate Transition and Policy - Port of Antwerp-Burges

1. Am I correct to assume that the Port of Antwerp is dominantly a landlord port, which is organized through concession agreements for relevant port operations?
2. In the context of a one-year output or fuel cracking production process, will these actions be done by someone other than the Port Authority?
3. Are the Port Authority's monetary benefits limited to concession fees paid by third-party operators or is it possible the port is entitled to other monetization advantages such as bunkering possibilities?

4. Regarding safety, does the Port Authority routinely carry out stakeholder engagement? Specifically in respect to the port-city relationships and if yes, how does this typically occur?
5. What supply routes do you see as most effective for alternative fuels like hydrogen or ammonia? For example, would you see pipelines, ship-to-ship transfer, trucking or other options as more suitable for a port operation?
6. Is there a mechanism for determining potential demand for the fuels, e.g. green ammonia, at the port?

Interview No. 3

Permitting and Risk Management - Port of Antwerp-Burges

1. When planning and making decisions, did the Port Authority engage with stakeholders such as municipal governments or others?
2. Is there a mandatory set of standards, etc., for a terminal or terminal facility operator requesting a permit or license, prior to the permit or license issued?
3. Are there any insights or estimates available as to the CAPEX needed to build green ammonia bunkering models?
4. What are the differences in safety considerations when you simply compare the ship-to-ship bunkering with ship-to-shore bunkering?
5. What is your perspective towards using alternative platforms such as floating bunkering facilities. Would these be perceived as safer or riskier than traditional land-based infrastructure?