



# Assessing the Viability of Arctic Shipping Under Climate Change - A Business Case for Hapag-Lloyd

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Dissertation submitted in partial fulfilment of requirements for the  
MSc in Business Analytics, at the Universidade Católica Portuguesa,  
30.05.2025.

## **Abstract**

Maritime shipping is increasingly affected by disruptions, especially due to the growing vulnerability of key maritime chokepoints. Large trade volumes are impacted as services from Asia to Europe are forced to re-route via much longer routes around the Cape of Good Hope, following ongoing rebel attacks leaving the Suez Canal non-navigable. At the same time, climate change is altering maritime conditions, potentially opening the Arctic as a new trade corridor. This thesis investigates the feasibility and economic viability of adopting Arctic routes for Hapag-Lloyd AG's Asia-Europe liner services over the next two decades, focusing on operational cost efficiency and navigational risk. Projections of sea ice conditions under a best- and worst-case climate scenario were translated into navigational risk indices and a least-cost path algorithm was applied to compute the safest and most cost-effective Arctic routes. The feasible Arctic passages were then compared against the traditional Suez Canal and Cape of Good Hope routes in terms of cost-competitiveness. Results show that while Arctic routes could offer substantial distance and absolute cost savings, Hapag-Lloyd AG's current fleet – composed entirely of Open Water vessels – cannot safely access these routes under current and projected ice conditions. Polar Class vessels would offer sufficient ice navigation capability, but their lower capacity leads to unfavorable per-unit (TEU) economics. Additionally, seasonally limited and volatile navigable periods limit the strategic relevance of the Arctic corridor. While regular navigation on the Arctic routes is judged non-viable for Hapag-Lloyd AG, the trend towards improving accessibility highlights the need for continuous monitoring.

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**Author:** Lisa Marie Sophie Pabel

**Keywords:** Maritime chokepoints, Suez Canal disruption, Arctic shipping corridor, Climate change impacts, Sea-ice projections, Navigational risk index, Least-cost path algorithm, Hapag-Lloyd AG

## **Resumo**

O transporte marítimo está cada vez mais sujeito a perturbações, especialmente devido à crescente vulnerabilidade de pontos estratégicos como o Canal de Suez. Consequentemente grandes volumes de comércio entre a Ásia e a Europa são afetados, com serviços forçados a contornar o Cabo da Boa Esperança, devido a ataques rebeldes que tornaram o Suez inavegável. Paralelamente, as alterações climáticas estão a transformar as condições marítimas, podendo abrir o Ártico como novo corredor de comércio. Esta dissertação analisa a viabilidade e rentabilidade económica da adoção de rotas árticas pelos serviços da Hapag-Lloyd AG entre a Ásia e a Europa nas próximas duas décadas, com foco na eficiência de custos operacionais e no risco de navegação. Foram projetadas condições de gelo marinho sob cenários climáticos otimistas e pessimistas, convertidas em índices de risco e aplicados algoritmos de menor custo para identificar as rotas mais seguras e económicas. As passagens viáveis foram comparadas com as rotas tradicionais pelo Suez e pelo Cabo da Boa Esperança. Os resultados mostram que, embora as rotas árticas ofereçam poupanças significativas em distância e custos absolutos, a frota atual da Hapag-Lloyd – composta por navios de águas abertas – não possui capacidade para navegar em segurança nessas condições. Navios com classificação polar seriam adequados, mas a sua menor capacidade reduz a eficiência económica por unidade (TEU). Além disso, a curta e volátil janela de navegação limita o seu valor estratégico. Conclui-se que, apesar da tendência de melhoria na acessibilidade, a viabilidade regular permanece limitada, exigindo monitorização contínua.

**Título:** Avaliar a viabilidade do transporte marítimo no Ártico sob as alterações climáticas - um caso de negócio para a Hapag-Lloyd

**Autor:** Lisa Marie Sophie Pabel

**Palavras-chave:** Gargalos marítimos, Interrupção do Canal de Suez, Corredor de navegação no Ártico, Impactos das alterações climáticas, Projeções de gelo marinho, Índice de risco de navegação, Algoritmo de rota de menor custo, Hapag-Lloyd AG

## **Acknowledgements**

I acknowledge the use of ChatGPT for grammar refinement, brainstorming ideas during early drafting stages and assistance in developing the fuel consumption estimation approach. It was also used for code debugging support, in addition to Microsoft Copilot for code development. All final content and analysis presented are my own.

Also, I want to express my gratitude to my supervisor, Miguel Nogueira, for his guidance and valuable feedback throughout the development of this thesis, and for the opportunity to learn something new under his mentorship.

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## List of Abbreviations

ATAM	Arctic Transport Accessibility Model
CMIPx	Model Version x of the Coupled Model Intercomparison Project
IMO	International Maritime Organization
NEP	Northeast Passage
NSR	Northern Sea Route
NWP	Northwest Passage
OW	Open Water
PC6	Polar Class 6
POLARIS	Polar Operational Limit Assessment Risk Indexing System
SSP	Shared Socio-Economic Pathway
RCP	Representative Concentration Pathway
RIO	Risk Index Outcome
RV	Risk Value
TEU	Twenty-Foot Equivalent Unit
TSR	Transpolar Sea Route
UNCLOS	United Nations Convention on the Law of the Sea
UNCTAD	United Nations Conference on Trade and Development

# 1 Introduction

## 1.1 Background and Motivation

According to the United Nations Conference for Trade and Development – UNCTAD – 80% of global trade volume is transported by sea. With an expected annual growth of 2.5 percent throughout the next five years, global maritime trade continues to recover from the Covid Crisis. However, this recovery is challenged by several disruptive factors. One of the most critical challenges lies in the vulnerability of key maritime chokepoints, particularly the Suez Canal and the Panama Canal. These corridors, originally implemented as efficient shortcuts to intercontinental shipping routes, are facing the risk of disruption due to geopolitical tensions and conflicts, market growth and climate change (UNCTAD 2024b). Especially the routes usually navigating the Suez Canal are affected, as can be seen in Figure 1. Since the start of the Red Sea Crisis in October 2023, regular attacks on commercial vessels by Houthi Rebels have taken place, significantly threatening safety and thus disrupting operations on this crucial trade route (Aguiar 2025).

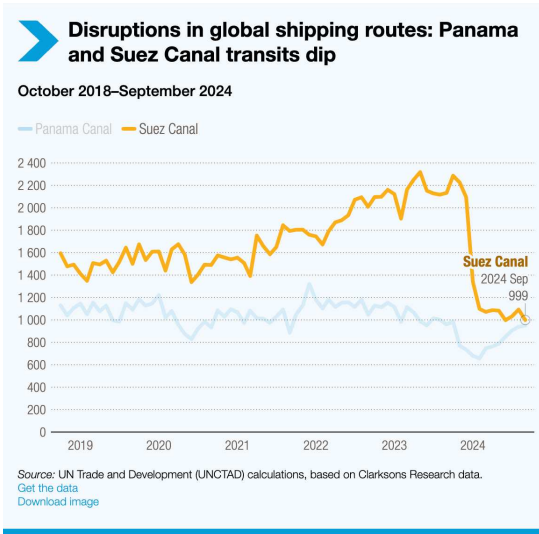


Figure 1: Suez Canal Transit Figures Trend (UNCTAD 2024b)

These disruptions cause the operating, as well as the ecological costs to rise, as to avoid the Suez Canal, services are commonly rerouted around the Cape of Good Hope. Being a significantly longer route, more container ships are needed to maintain the same service frequency and meet demand. Simultaneously ton-miles, measuring the total freight transported multiplied by the distance traveled, have increased (see Figure 2), in turn leading to rises in

fuel, wage and insurance costs. These costs are causing consumers around the world to experience a price rise, driving inflation and instability (UNCTAD 2024b).

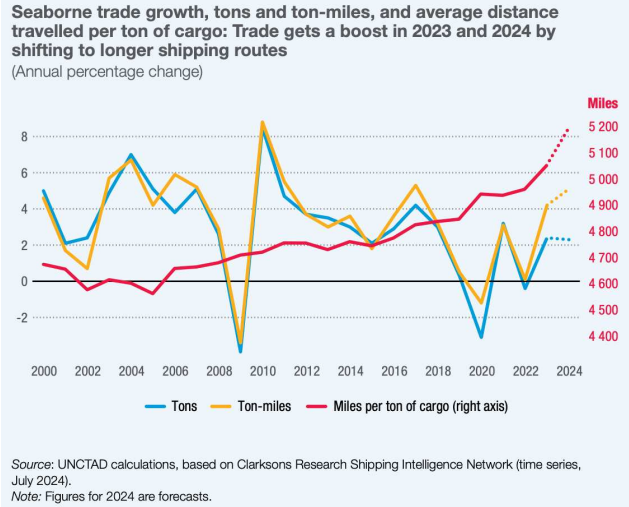


Figure 2: Ton-Miles and Miles Travelled per Ton of Cargo (UNCTAD 2024b)

In line with the current events, as can be seen in Figure 3, the reliability performance of services on the trade routes between Asia and Northern Europe, usually passing through the Suez Canal, is below average compared to other trade routes. Given that 22% of all containerized trade transits the Canal, while Asia handles 63% of global container trade (UNCTAD 2024b), this route requires immediate attention – especially as reliability is a key factor for further stabilization of maritime trade. The impact of these recent disruptions is further underscored in Figure 4, showing a clear downward trend in reliability performance since the start of the Red Sea Crisis in late 2023.

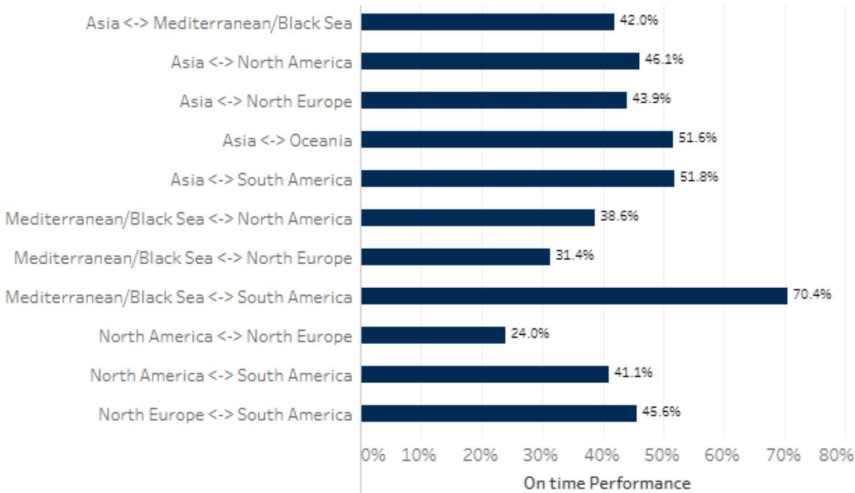


Figure 3: On-Time Performance per Trade Route (Radünzel 2025)

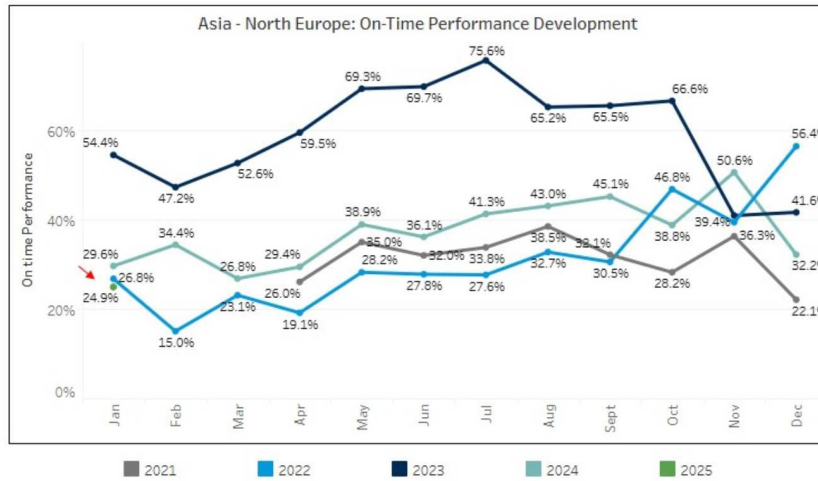


Figure 4: Development of Westbound Leg Performance of Asia - North Europe Trade (Radünzel 2025)

Hapag-Lloyd AG, henceforth referred to as Hapag-Lloyd, is one of the key operators on this trade lane and therefore severely affected by the Suez Canal blockage. The German shipping company, being the fifth-largest carrier in the world (Alphaliner 2025) and thus playing a central role in global trade flows, has responded to the growing need for schedule reliability by forming a strategic partnership with Maersk A/S, in the following referred to as Maersk, the second largest container shipping company in the world (Alphaliner 2025; Kuehne+Nagel 2024). This collaboration, known as the “Gemini Cooperation”, was launched in February 2025 (Hapag-Lloyd 2025b) and, apart from improving service reliability, is intended to help maintain cost competitiveness and establish a strong partnership for the key East-West trades (Hapag-Lloyd 2025a).

While such operational alliances offer shared efficiencies, each carrier must still maintain individual competitiveness and pursue its own strategy. In its recently published “Strategy 2030”, Hapag-Lloyd highlights its focus on making competitive offerings and the long-term goal of achieving more control along the container transport chain (2025a). Following this strategic direction, Hapag-Lloyd has the motivation to improve its risk tolerance by exploring and anticipating the potential of alternative routes and preparing for shifts in global maritime logistics – especially in response to the disruptions on the traditional corridors.

## 1.2 Problem Statement

At the same time, as the traditional routes become increasingly vulnerable due to various risk factors, the UN Trade and Development calls for “strengthened international cooperation to [...] enhance resilience and minimize supply chain disruptions from geopolitical and climate-related risks”, as well as the “diversification of shipping routes to reduce dependence on vulnerable maritime corridors like the Suez and Panama Canals” (UNCTAD 2024b). This raises the question for the maritime shipping industry of how global supply chains can be adapted to face these challenges successfully while maintaining reliability and economic efficiency. The Gemini Cooperation partly addresses these issues with an adapted supply chain setup following a Hub and Spoke concept that routes cargo through central hub ports for consolidation and transshipment to smaller spoke ports and thus leads to fewer port calls and shorter transit times (Hapag-Lloyd 2024d; Kuehne+Nagel 2024). However, this might not solve the problem entirely, as this concept still relies on traditional corridors. Additionally, as of now, the cooperation is operating an adapted network following a routing via the Cape of Good Hope until the Red Sea routes are safe to be operated again (Maersk 2025). This, however, is leading to significantly longer routes, as will be shown in Chapter 4.1.

Emanating from climate change, new routes through the arctic might present itself as viable alternatives for trade services between Europe and Asia. As the rising temperatures increasingly reduce sea ice in the Arctic, passages that were previously not navigable may open up for longer periods each year. A detailed overview of these routes, including graphical representations, is provided in Chapter 2.1. These passages could shorten transit times and therefore reduce various operational costs – but they also come with challenges such as unsteady weather, limited infrastructure, and safety risks posed by ice. In 2019, Hapag-Lloyd announced to refrain from using Arctic routes, citing environmental concerns. However, the decision was also mainly driven by the present lack of economic viability, as the current ice conditions still require high investments in vessels, offsetting the financial benefits of the shorter Arctic routes (Hapag-Lloyd 2019).

This thesis aims to explore whether this assessment of economic viability changes for the future under different climate scenarios and whether these routes eventually become economically viable, considering the ongoing impacts of climate change in the upcoming years. Due to scope limitations, this thesis assumes progress in the development of climate friendly ships and sustainable operations in the frame of being a key initiative of Hapag-Lloyd (Hapag-Lloyd

2025b) and therefore only examines the economic viability, disregarding environmental implications.

### **1.3 Research Objectives and Questions**

The main question this study wants to hence focus on is

**“How viable is it for Hapag-Lloyd’s Asia-Europe container services to adopt the Arctic route as an alternative to traditional routes – via the Suez Canal and the Cape of Good Hope – considering cost efficiency and navigability risk, throughout the next two decades under different climate scenarios?”**

### **1.4 Scope and Significance of the Study**

With its case study focus on Hapag-Lloyd, this thesis combines scientific and business data for enhanced practical decision-making in the company. Also, as Maersk and Hapag-Lloyd jointly cover over 20% of the market share (Alphaliner 2025) and therefore are main and industry-shaping players, the findings here offer broader applicability for other stakeholders in the market. Since this thesis is an applied work, it will not contribute in depth to the fields of business analytics methodology and scientific climate risk management. It will however add the perspective of an economic assessment of the arising opportunities within the field. It frames climate risk management as a source of strategic potential rather than solely as a challenge to be mitigated and further promotes a proactive approach to risk management, in this case to diversify risk exposure and thus enhance business resilience. Ultimately, it will equip Hapag-Lloyd and industry stakeholders with helpful insights, enabling informed decisions in the development of strategies for balancing emerging opportunities and risks in the maritime environment.

## **1.5 Thesis Structure Overview**

This thesis continues as follows: Chapter 2 reviews the relevant literature and their findings, including literature on traditional and emerging maritime routes, climate impacts and the Arctic environment, as well as accessibility and economic viability assessment approaches. It also presents the research gaps these studies left unaddressed. In chapter 3 the methodology applied in this thesis is described, including the data collection and analytical frameworks, as well as their limitations. In chapter 4 the comparative analysis conducted and the results obtained are presented and contextualized within the existing literature. Chapter 5 discusses these findings, including their implications for Hapag-Lloyd and other industry stakeholders, and critically reviews the limitations of the analysis. Finally, Chapter 6 summarizes the key insights and concludes with further research suggestions.

## 2 Theoretical Foundation

### 2.1 Overview of Maritime Routes

Maritime trade has connected countries for centuries, allowing for the significant growth of world trade and the formation of the modern international trade network (Rodrigue, Notteboom, and Pallis 2022). Today, there are a few key corridors facilitating this global trade:

The Suez Canal connects the Mediterranean Sea to the Red Sea since its opening in 1869, allowing for significantly shorter transit times between Asia and Europe compared to the route around the Cape of Good Hope in Southern Africa (Fisher and Smith 2025). Annually, over 20,000 vessels use this corridor and transport – reaching its peak in 2023 – over 1.3 billion tons of cargo (Suez Canal Authority 2025). The 2021 disruption caused by the “Ever Given”, one of the world’s largest container vessels, underlined the importance of the Suez Canal for global supply chains. The 6-day blockage affected around 400 ships and is estimated to have caused costs to the global economy of up to 2.5 billion euros (Vasic 2022). Like the Suez Canal, the Panama Canal is a critical connector between the Atlantic and the Pacific Ocean. Completed in 1914, it shortens voyages by up to 8,000 nautical miles – 15,000 kilometers (Bray and Padelford 2025) – and is used by over 13,000 vessels yearly (Panama Canal Authority 2022). Additionally, there are natural straits like the Strait of Hormuz, providing a passageway between the Persian Gulf and the Gulf of Oman, hence playing a critical role in the oil trade, and the Strait of Malacca, situated between Indonesia and Malaysia. The latter is accommodating vessels jointly carrying approximately 30% of global trade (Boston Consulting Group 2024).

As indicated, disruptions on these waterways have extensive effects on global supply chains and can lead to substantial changes in network configurations and trade patterns (UNCTAD 2024b). As much as 50% of global trade is estimated to be vulnerable to disruption, mainly due to geopolitical, environmental or capacity risks. The attacks on commercial ships in the Suez Canal – that halved the canal’s transit figures in 2024 (Suez Canal Authority 2025) – lead to extended lead times within the supply chain, as the rerouting around the Cape of Good Hope adds approximately 9-17 days of voyage time (Boston Consulting Group 2024). Similar geopolitical tensions are affecting the Strait of Hormuz. Additionally, the Strait of Malacca, already experiencing high levels of congestion and collisions today, is expected to reach its capacity limits by 2030 as traffic continues to increase (Feingold and Willige 2024).

Arctic sea routes have emerged as potential alternatives to some of these traditional corridors from the ongoing effects of climate change. As the ice cap in the Arctic continues to diminish, navigation of these routes is expected to become increasingly feasible and reliable and could mitigate some of the disruptions on the traditional routes. There are three prominent routes discussed in the literature, illustrated in Figure 5: the Northwest Passage – short NWP –, the Northern Sea Route, also referred to as Northeast Sea Route or Passage – short NSR or NEP respectively – and the Transpolar Sea Route – short TSR –, sometimes also called Trans Arctic Sea Route or Central Arctic Shipping Route (Arctic Portal 2024).



Figure 5: Arctic Routes (green: NWP, blue: TSR, pink/red: NSR/NEP) with Economic Zones (Arctic Portal 2022)

The Northwest Passage (NWP) runs along the Northern coast of Canada and mainly through the waters of the Arctic archipelago, thus offering several potential straits. It is currently the shortest possible route between the east coast of the United States of America and Alaska but is also in discussion as a feasible trade route to and from Asia, and thus a potential alternative to both the Suez Canal route and the Panama Canal route. The route is expected to become increasingly valuable with ongoing climate change but offers little developed infrastructure as of today (Arctic Portal 2025b). The Northern Sea Route (NSR), being not one fixed route but composed of several different potential straits similar to the NWP, runs along the North coast

of Russia, thus governed by Russia, and is already used commercially, mainly for domestic transportation. Both passages are as of now limited in their use, due to the extreme nature of their climate conditions but are believed to become increasingly favorable with ongoing climate change (Arctic Portal 2025a). The Transpolar Sea Route (TSR) is the third emerging Arctic route. Unlike the NSR and the NWP it mainly crosses international waters and connects the North Pacific and the North Atlantic via the North Pole and thus will eventually offer the shortest possible distance. Today it is often heavily ice-covered, therefore of low feasibility for navigation, but is considered as the most promising route in the future (Zhang et al. 2023). One benefit is that it is significantly deeper than the NSR and the NWP and would thus be non-restrictive to the vessel size (Bradley Arant Boult Cummings LLP 2023).

These routes offer significantly shorter distances compared to the traditional corridors, as can be seen in the graphical representation of the routes in below Figure 6.

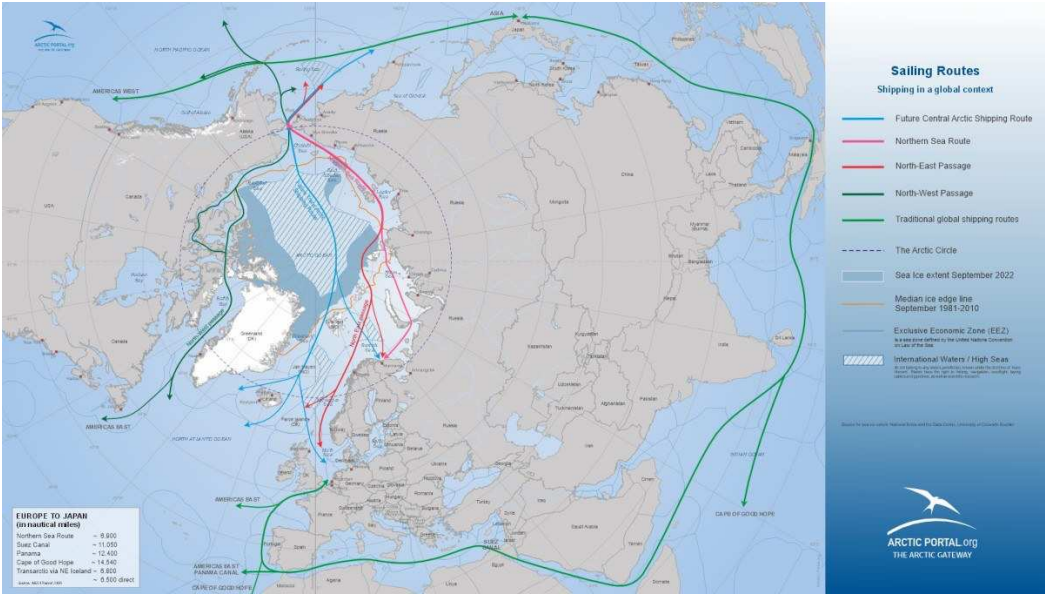


Figure 6: Traditional and Arctic Shipping Routes (Arctic Portal 2025a)

## 2.2 Climate Change and the Arctic Environment

The beforementioned traditional corridors and the overall shipping industry do not only suffer from geopolitical and capacity factors but also face challenges arising from climate change. The Panama Canal for instance suffered from reduced water levels in recent years, with record drought conditions in 2023 and 2024 (Panama Canal Authority 2024), in turn limiting the

number of transits and the cargo volume allowed to transport, causing long waiting times and delays (Feingold 2023). Also in India, the moonsoons, amplified in their effects by climate change, affect shipping operations by posing severe on-sea risks for life and damage port and transportation infrastructure (Maritime Mutual 2024).

Despite being one of the regions of the world hit disproportionately by climate change, the Arctic presents the opposite scenario for the shipping industry: with melting ice, the routes presented before open up, offering novel opportunities for navigation, potentially being able to mitigate the disruptions caused by climate change on other shipping routes. According to a study conducted by Rantanen et al. in 2022, the arctic has been warming up approximately four times as fast as the rest of the world in recent years. This is partly explained by the mechanism of melting ice exposing more dark surfaces, leading to diminished natural reflectivity and therefore cooling capacity of the region. Additionally, the thawing permafrost releases large amounts of stored carbon dioxide and methane, which in turn intensify global warming (Bennett et al. 2020). Research however disagrees on the rate of deicing and the most likely temperature increase scenario and therefore many studies produced varying projections. Although the specific point in time when a completely ice-free Arctic Ocean might occur is under dispute, many studies and the Intergovernmental Panel on Climate Change – IPCC – projects that a nearly ice-free summer could emerge by mid-century under all emission scenarios (IPCC 2021).

This aspect indicates the annual cycle of Arctic sea ice. Even though an overall decreasing trend in sea ice can be observed, the presence of ice is still subject to high seasonal variability. The highest reduction in sea ice can be seen for the month of September, whereas the ice amounts in winter remain stable, however less thick (Hansen et al. 2016). With ongoing climate change it is also observed that the melting of ice starts increasingly early in the year and extends to longer seasons. This in turn shortens the time periods where highly reflective ice covers the waters, intensifying the diminishing of the beforementioned inherent cooling capacity and in turn accelerate the ice reduction (Bennett et al. 2020). These changes in sea ice thickness play a critical role for the economic viability of the Arctic waters as they lengthen the navigable period (Zhang et al. 2023). The navigable period is seen to increase for all Arctic routes in all reviewed projections, with more details presented in a later chapter. A study by Cao et al. (2022) even found that Arctic routes become navigable faster than models projected.

The navigable period however also depends on the vessel intended to be used. In regard to Arctic operations, there are different classifications of ships and their readiness to navigate the

polar waters, varying depending on the classifying authority and area of operation. The International Maritime Organization – IMO – divides vessels into three categories – A, B and C – based on the general sea ice conditions. It then further refines the classification into seven polar classes, with “Polar Class 7” ships being the least capable, restricted to summer and thin ice, and “Polar Class 1” ships being able to operate in ice-covered waters all year (DNV GL 2017). The Russian authorities implemented a slightly different ice class system, ranging from “Arc9” to “Arc4” vessels, that will apply in waters under Russian sovereignty (Russian Maritime Register of Shipping 2017). Further, on some passages Icebreaker support is required that is costly and might not be available at any time due to the small size of the fleet. Additionally, some straits on the Arctic passages limit the vessels to a certain size, as of today often being significantly smaller than the vessels passing through the traditional corridors such as the Suez Canal (Hansen et al. 2016).

Despite these restrictions, traffic in the region increases. According to the Arctic Council, the majority of ships are fishing vessels with a share of 44% (Arctic Council 2024). However, other sources state that vessels transporting goods are the primary type traversing through arctic waters, with cargo ships being the largest vessel type observed. Most of these recorded vessels operate under the Russian flag, making the country the biggest active party in the Arctic waters (Bartolini Cavicchi 2024). Also, some of the large shipping companies are exploring the emerging opportunities and conducting trials in Arctic waters. The first cargo vessel with containerized cargo on board was the Chinese vessel “Yong Sheng”, operated by the world’s 4th biggest shipping company “COSCO” in 2013. It navigated the NSR on its route from Dalian in China to Rotterdam in the Netherlands and completed the journey in 35 days. The motivation stated was the desired diversification of shipping routes to mitigate the risks of geopolitical instability along the traditional corridors (Hansen et al. 2016). Maersk also followed this example and conducted a declared “one-off trial”, sending its ice-class ship “Venta Maersk” through the NSR in 2018. The ship departed in Busan, Korea, with a stop at the Russian port in Vladivostok and final arrival in Bremerhaven, Germany (Booth and Ferris-Rotman 2018). The trial was judged to be successful and valuable for gaining operational experience but considered the NSR a non-viable alternative to the existing routes for the company at that time (Humpert 2018).

## **2.3 Regulatory, Economic and Environmental Considerations**

As indicated, Arctic navigation is not only influenced by climate change but also by the interaction of regulatory frameworks, economic interests and environmental challenges. The Arctic is governed by the 1982 United Nations Convention on the Law of the Sea – short UNCLOS –, stating that coastal states enjoy sovereign and resource rights in their economic zones. Additionally, it contains the so-called “Arctic Exception”, Article 234, granting coastal states additional authority over extensively ice-covered areas within their economic zones. This empowers coastal states to implement local regulations in terms of environmental standards and navigation rules with the goal of protecting this sensitive environment (Bartenstein 2011). Canada and Russia both base the implementation of regulatory measures in the waters of the NWP and the NSR respectively on this clause, despite being challenged due to the constant reduction in sea ice. Both claim the passages as internal waters, with Russia even establishing an authorization and fee collection procedure for navigation through the NSR, whereas the United States of America consider it as an international corridor and claim freedom of navigation (Gavrilov, Dremluga, and Nurimbetov 2019). The United States of America further published a “National Strategy for the Arctic Region” in 2022, which comprises concepts for infrastructure and economic development, as well as environmental considerations and emphasizes a strong focus on national security by calling for enhanced defense capabilities and the fostering of international partnerships to address the evolving environmental and geopolitical challenges in the Arctic (The White House 2022). Russia similarly uses the Arctic strategically as a military base and since the outbreak of the war in the Ukraine also performs joint military exercises with China, despite previous efforts to constrain China’s activities in the Arctic that were publicly mainly focused on the exploitation of the region’s minerals, while in fact conducting intelligence-gathering activities (Bradley Arant Boult Cummings LLP 2023). The Arctic’s richness in minerals, as well as oil and gas, offers lucrative opportunities and motivates stakeholders to develop suitable and sufficient infrastructure, such as ports, roads and search and rescue (Arctic Portal 2025b). For now, the region lacks this sophisticated infrastructure – there are only few deep-water ports, needed for repair and refueling as well as navigation support systems and specialized equipment. Also, coverage of search and rescue facilities is limited, and the icebreaker fleets are not sufficiently large. Currently, the “Administration of the Northern Sea Route”, the Russian institution administering the NSR, owns the largest icebreaker fleet and offers paid escort services for transits that are not allowed to trespass without assistance, as defined in their vessel requirements for different ice conditions

(Hansen et al. 2016). Complementing these national regulations and the UNCLOS, the IMO is a key regulatory instance for the Arctic. It implemented the “International Code for Ships Operating in Polar Waters” – also called “Polar Code” in 2017, a regulatory framework intending to ensure that ships navigating polar waters are designed, constructed, and operated safely. It comprises safety standards for vessels, such as special equipment and design specifications, practices such as crew preparation and necessary protocols, as well as operational measures to minimize environmental impact (IMO 2017). Increased navigational and economic activity with the advancing opening of the Arctic routes intensifies this potential for negative environmental impacts. Oil spills during extraction or transportation pose a considerable threat to the biodiversity of the Arctic (Bartolini Cavicchi 2024). Also, vessel emissions and specifically so-called “black carbon”, particles released in the burning of fossil fuels, threatens the Arctic heavily by darkening the ice surface and thus reducing the reflection of sun light, in turn leading to faster ice melting (Hansen et al. 2016), amplifying the dark surface exposure effects of the melting ice mentioned in Chapter 2.2.

## **2.4 Business Analytics and Arctic Navigability**

With more extensive melting of the ice, the number of studies addressing several perspectives on the topic of Arctic navigation has increased over the past years. As the economic feasibility of the emerging routes is uncertain, modern maritime risk management makes use of a variety of analytics models for decision-making.

### **Climate and Ice Simulation Models**

One approach is the usage of climate and ice simulation models. Together with routing algorithms they allow to project the future degree of accessibility for the Arctic routes. As a basic introduction to these models, the key components will be briefly explained:

“CMIP” – the “Coupled Model Intercomparison Project” – provides the basis for most studies involving climate-related projections. It is a project of the World Climate Research Programme, aiming to understand changes in climate in the past, present and future by using a multi-model approach. There are different versions of CMIP, the most recent being CMIP6 (CMIP n.d.). With CMIP6, the so-called “Shared Socio-Economic Pathways” – “SSPs” – have been

introduced, building upon the previously used “Representative Concentration Pathways” – “RCPs”. While the RCPs were developed for the use in climate models, the SSPs comprise the socio-economic developments leading to a specific emission scenario, as well as the implicit challenges in mitigating the arising changes, and thus a more holistic view (ClimateData.ca n.d.). The SSPs are subdivided into different levels of radiative forcing in 2100, with the main scenarios ranging from SSP1-2.6 to SSP5-8.5, as shown in blue in below Figure 7.

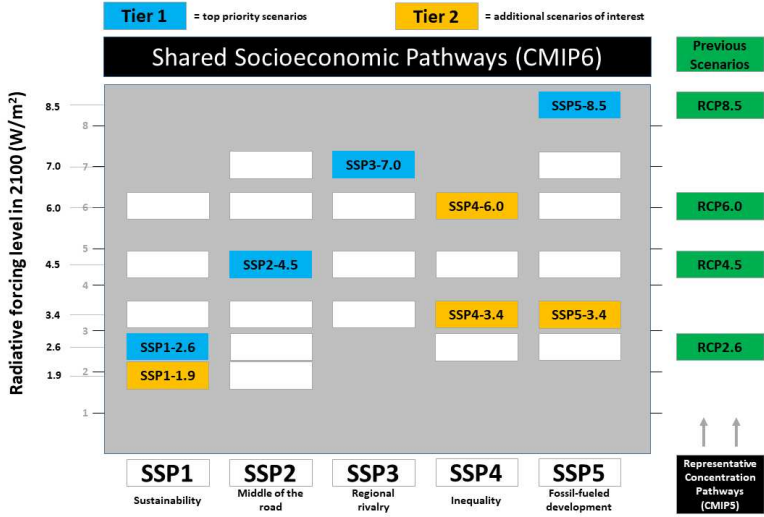


Figure 7: Shared Socio-Economic Pathways under different radiative forcing levels in 2100 (Canadian Climate Data and Scenarios 2023)

Further, many climate simulation studies in the Arctic context make use of the “ATAM” – the “Arctic Transport Accessibility Model” – to assess the level of accessibility. It is a framework provided by the Arctic Ice Regime Shipping System – AIRSS – a regulatory standard of the Canadian Government intended to increase navigation safety by allowing to assess the potential ice damages to vessels (Transport Canada n.d.). Some studies alternatively apply the “POLARIS” – “Polar Operational Limit Assessment Risk Indexing System” – framework, published by the IMO, which – similar to the ATAM – assesses the feasibility of navigation in sea ice areas based on the vessel characteristics and the sea ice conditions (Zhang et al. 2024).

There are various such studies, amongst those the one conducted by Melia, Haines and Hawkins (2016), building a basis for such simulations by detecting and quantifying the rapid changes in Arctic ice conditions and their potential influence on navigability. Stephenson et al. (2013) then used climate projections to estimate the point in time and area in which the Northwest Passage or the Transpolar Sea Route might open, indicating a timeline for usability. In 2015, Stephenson and Smith integrated sea-ice forecasts from various CMIP5 climate models, with a least-cost

path algorithm to identify the optimal routes and accessibility under RCP 4.5 and 8.5, linking historical observations with future projections. In that, they modeled the conditions for various vessel ice classes, similar to the study by Zhang et al. (2023), which applied the same methodology, but focused on the NSR and TSR and used CMIP6 models, while also applying the POLARIS risk-indexing system to quantify navigational risk. Wang et al. (2024) used FIO-ESM v2.1, a high-resolution simulation developed by the First Institute of Oceanography (FIO) in China and projected navigability for four different vessel configurations, using the ATAM. These models highlight uncertainties, given by the variability across the used climate models, and identify conditions for which Arctic navigation might become feasible by comparing emission and vessel usage scenarios.

### **Optimization and Economic Modelling Techniques**

Another type of methods used for assessing the economic feasibility are optimization and economic modelling techniques, mainly addressing the profitability and market uptake. Many studies define cost-benefit and route optimization frameworks comparing the emerging routes with the traditional corridors, such as the Suez Canal. Here, the main factors used are distance, fuel, time, capacity constraints and ice-related expenses such as icebreaker fees, insurance premiums for high-risk shipping operations and vessel modification expenses. To manage the uncertainties that these studies cannot quantify, such as the mentioned insurance premiums that are likely to be higher due to increased risks, many analyses use scenario planning. A study conducted by Wu et al. (2024) compares the cost competitiveness of the NEP to the Suez Canal, using a scenario-based economic model including several cost drivers, while Bennett et al. (2020) focus on the TSR and deploy an integrative framework, combining climate modelling with a scenario analysis of logistical, geopolitical and socioeconomic factors and thus provide a more holistic assessment on the effects of the route opening for long-term decision-making. Li et al. (2023) take a more detailed approach and employ high-resolution, operationally detailed models in their comparison of a trans-Arctic route to the Suez Canal route, using realistic voyage cost calculations based on current operational data. While these studies agree on the potential benefits of shorter and ice-free routes, they highlight vessel capability as a critical factor for taking full advantage. Song et al. (2023) additionally highlight short-term dynamic factors such as fog and other weather phenomena in the Arctic with the potential to

disrupt shipping in the Arctic, likely offsetting some of the anticipated savings due to delays or re-routings.

## **Key Findings**

These studies comprise three key findings: firstly, in line with the research presented in previous sections, the physical feasibility of navigating through the Arctic is increasing, but it remains seasonally limited for the foreseeable future. In terms of the NSR and potentially even the TSR, the climate-driven models project them to be accessible in a reliable matter by mid-century (Melia, Haines and Hawkins 2016; Stephenson et al. 2013). For the NWP the estimations depend very much on the models and exhibit a higher uncertainty (Stephenson, Smith and Agnew 2013). The ideal scenario of full year navigation with conventional vessels is unlikely in the near future, which implies the next finding: feasibility is highly driven by vessel capability and support infrastructure. The navigable season is seen to extend a lot for all vessel types, even those with lower ice-breaking capability, with projected windows of 3-4 months by midcentury for ice-capable ships and up to 120 days for heavy icebreakers (Stephenson et al. 2013). Additionally, the cost-benefit analyses mostly show low margins for the Arctic routes. The shorter distances reduce fuel consumption and time; however, these savings are often offset by icebreaker fees, smaller vessels and risk premiums (Wu et al. 2024). In line with that, commodities with lower schedule sensitivity are identified as the most suitable cargo for these routes given the uncertainties of the routes (Bennett et al. 2020).

## **Strengths and Limitations**

Each of the approaches has its strengths and limitations. Climate-focused simulations are useful for estimations of the physical risks and their implications on navigable periods and general conditions, but they often assume shipping will occur once the routes are open and fail to factor in all the relevant economic decision factors. Economic optimization models on the other hand incorporate these factors and are thus able to evaluate profitability and the implications for trade and supply chains. They are however highly dependent on assumptions of these factors and might overlook immediate hazards. As could be seen from the literature, none of the methods

provides a complete answer and thus should be used complementary in an integrated framework, to cover the various perspectives on the topic.

## **2.5 Identified Research Gaps**

Taking these learnings and given the current situation of the avoidance of the Red Sea due to Houthi attacks, it becomes apparent that shipping companies like Hapag-Lloyd should critically assess the potentials of these emerging routes to uphold competitiveness and to exploit all available opportunities for diversification of routes, in an effort to stabilize the supply chains and keep operations economic. While many of the studies study the topic from one of the presented approaches, there are few that have developed an integrated framework as demanded above. Such integrated model will be critical to realistically evaluate the feasibility of the route for a specific shipping company such as Hapag-Lloyd. Moreover, most models rely on assumptions rather than real operational data, particularly in the context of container shipping. By incorporating company specific schedule and vessel information, this thesis offers a more tailored and actionable evaluation. As a result, the findings provide more relevant and intuitive insights for Hapag-Lloyd's strategic decision-making than generic Arctic navigability research.

## **3 Methodology**

### **3.1 Research Design and Approach**

For the assessment of the Arctic routes' economic viability, this thesis will compare a variety of scenarios, capturing the uncertainties regarding the key influential variables. The scope of the analysis comprises:

Considering the next 20 years as the timeframe, climate data was retrieved for the years 2015-2044 – ten years back for trend analysis and twenty years ahead as future projections. While routing decisions are made rather short term, strategic investments – such as fleet renewal – are made with a longer-term perspective. Therefore, anchoring the analysis in the typical lifespan of a vessel of just over 20 years (Shimotsuura 2024) reflects the timeframe relevant for decisions being made today.

Two emission scenarios, taking into account the uncertainty around the extent of climate change. Following the current practice in climate science, SSP1-2.6 (sustainable development, low radiative forcing) and SSP5-8.5 (fossil-fueled development, high radiative forcing) are chosen as baseline scenarios (ClimateData.ca n.d.), representing a best- and a worst-case scenario respectively.

Two vessel types, Open Water – OW – and Polar Class 6 – PC6 – vessels. Despite OW vessels being the main vessel type in most ship owners' fleets on the routes in focus (Stephenson, Smith and Agnew 2013), such as Hapag-Lloyd's, both OW and PC6 vessels are included in the scenario analysis to identify whether the availability of an ice-class ship influences the route viability. PC6 vessels are chosen following most related studies, as they possess only medium icebreaking capabilities and are thus less-investment heavy than high ice-class ships (Stephenson, Smith and Agnew 2013).

Two PC6 capacity levels, reflecting the uncertainty around the exact capacity of a PC6 vessel, given the limited use of such ships to date. As reference for the highest assumed capacity the cargo volume of the previously mentioned "Venta Maersk" – belonging to a comparable ice class (IMO 2002) – is used. For the lowest assumed capacity specifications from a PC6 vessel design are referenced (Remontowa Marine Design & Consulting n.d.). These volumes are in accordance with the associated literature (Bennett et al. 2020).

Two traditional route options for each of the Hapag-Lloyd Asia-Europe routes, mirroring the situation determining the routing decisions: in the absence of rebel attacks in the Red Sea the Suez Canal Route will be utilized, in the case of a continuing or re-escalating Red Sea Crisis the vessels will continue to navigate around the Cape of Good Hope. These two traditional routes serve as the baseline for comparison with the Arctic routes.

As it constitutes the core business, the scope will comprise only Hapag-Lloyd's liner shipping business, so the "regularly scheduled services between ports along a trade route". Within that, the focus will be on containerized shipping, as it makes up 50% of the total value of goods transported by sea (World Shipping Council 2021). Also, on container ships, cargo of many owners is placed, unlike in bulk cargo, where there is usually one owner, which means there are many stakeholders with interest in diversification of shipping modes and routes to ensure reliable and stable supply chains (UNCTAD 2024a).

The assessment of economic viability consists of two main questions:

*Are the routes navigable?*

and

*Is it financially viable to switch to these routes?*

To answer the question of route accessibility, in a first step the sea ice thickness and sea ice concentration in the Arctic under both SSPs are simulated, being the key influential factors. To quantify the navigational risk of a given area for shipping operations, the IMO's POLARIS framework is applied, following common practice of the relevant literature. It consists of assigning a risk value based on the area's sea ice thickness, while then computing an overall risk score for the given area by taking into account the sea ice concentration (IMO 2016). This process is described in more detail in chapter 3.3. To identify the available routes per season, the resulting Risk Index Outcomes serve as inputs for a pathfinding algorithm, yielding the route with the lowest associated risk for each timestep within the considered time horizon.

To then answer the question of economic viability, the emerging routes are compared to the traditional Suez Canal and Cape of Good Hope route in terms of their costs, determined by the distance travelled, the operational speed, the vessel capacity as well as the fuel consumption and price.

## 3.2 Data Collection

### Climate Data

As indicated, the relevant variables for assessing Arctic navigability when using the POLARIS framework are sea ice concentration and sea ice thickness. As the CMIP6 models are found to produce better projections terms of these variables compared to the previous CMIP versions, CMIP6 data will be used in this thesis. The specific model selected is the “ACCESS-CM2” model based on the paper by Zhang, Haapala and Uotila (2024), judging it to provide plausible estimates for the relevant variables. Due to scope limitations only data from this one model is utilized. The data for both variables, with sea ice concentration given by the “siconc” variable and sea ice thickness by the “sithick” variable, is obtained from the Copernicus Climate Data Store at monthly resolution for both SSPs for the years 2015 to 2044. Further, the sea-ice area percentage on ocean grid, given by the “areacello” variable, is used as a helper variable in the pathfinding algorithm, also obtained from the “ACCESS-CM2” model for both SSPs at fixed resolution. The model outputs these variables over a gridded domain of the world with each discrete grid cell corresponding to a latitude-longitude pair (Copernicus Climate Change Service 2021).

### Shipping Data

The information on the routes and deployed vessels (see Appendix A) are obtained from the shipping database “Alphaliner” (AXSMarine n.d.). For each service, detailed information such as the port rotation and its duration are listed, as well as the deployed vessels. The vessel specifics are later enriched with information from the Hapag-Lloyd website (2024c) for the fuel consumption estimation.

The detailed schedules (see Appendix B) of the services of interest, including departure and arrival dates per vessel, are obtained from the Maersk “Vessel Schedules” tool (Maersk n.d.).

For the traditional corridors, the distances (see Appendix C) of the routes are obtained from “VesselFinder” (VesselFinder n.d.), a renowned vessel tracking service provider. For the Arctic routes, the distances of the Arctic segment are calculated by the least-cost path algorithm.

The fuel price used in this analysis corresponds to the market rate as of April 15, 2025 (Ship & Bunker n.d.; Appendix D). As most container vessels today operate on “Very Low Sulphur Fuel Oil” – “VLSFO” – following the IMO’s sulphur cap for marine fuels (Einemo 2021), this fuel type serves as the basis for the cost calculations in this thesis.

The vessel capacities are based on the specifications provided in the Alphaliner route data for OW vessels (AXSMarine n.d.) and given by the “Venta Maersk” specifications (Port of Hamburg n.d.) and the Remontowa (n.d.) design parameters for the two respective PC6 capacity levels.

### 3.3 Analytical Framework

Following the research approach outlined earlier, in the first step the navigability of the Arctic is assessed following below workflow:

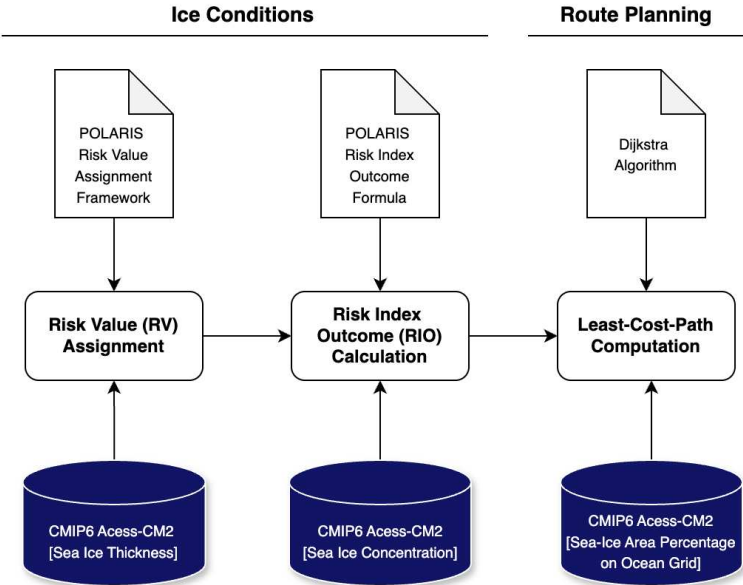


Figure 8: Workflow of Navigability Assessment (Own Illustration)

## Ice Conditions

Firstly, so-called “Risk Values” – “RVs” – are assigned to each grid cell based on the corresponding value of sea ice thickness. The assignment is carried out according to the classification shown in Figure 9.

Polar Ship Category	ICE CLASS	ICE FREE	Winter Risk Values (RVs)										
			NEW ICE 0-10 cm	GREY ICE 10-15 cm	GREY WHITE ICE 15-30 cm	THIN FIRST YEAR 1ST STAGE 30-50 cm	THIN FIRST YEAR 2ND STAGE 50-70 cm	MEDIUM FIRST YEAR 1ST STAGE 70-95 cm	MEDIUM FIRST YEAR 2ND STAGE 95-120 cm	THICK FIRST YEAR 120-200 cm	SECOND YEAR 200-250 cm	LIGHT MULTI YEAR 250-300 cm	HEAVY MULTI YEAR 300+ cm
A	PC1	3	3	3	3	2	2	2	2	2	2	1	1
	PC2	3	3	3	3	2	2	2	2	2	1	1	0
	PC3	3	3	3	3	2	2	2	2	2	1	0	-1
	PC4	3	3	3	3	2	2	2	2	1	0	-1	-2
	PC5	3	3	3	3	2	2	2	1	0	-1	-2	-2
B	PC6	2	2	2	2	1	1	0	0	-1	-2	-3	-3
	PC7	2	2	2	2	1	1	0	0	-2	-3	-3	-3
C	IAA	3	2	2	2	2	1	0	0	-2	-3	-4	-4
	IA	3	2	2	2	1	0	-1	-2	-3	-4	-5	-5
	IB	3	2	2	1	0	-1	-2	-3	-4	-5	-6	-6
	IC	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8
	No Ice Class	3	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-8

Figure 9: Risk Value Assignment Framework (PAME n.d.)

Based on the RVs, limitations for operations are assessed by calculating the so-called “Risk Index Outcome” – “RIO” – given by:

$$RIO = (C_1 \cdot RV_1) + (C_2 \cdot RV_2) + (C_3 \cdot RV_3) + \dots (C_n \cdot RV_n)$$

Where  $C_1 \dots C_n$  are the concentrations of ice types within the ice regime (here: grid cell) and  $RV_1 \dots RV_n$  are the corresponding Risk Index Values for each ice type

As no detailed data on sea ice concentration per ice type is available, but only a single sea ice concentration value per grid cell, the formula reduces to:

$$RIO = C \cdot RV$$

To translate the RIO into implications for operations, below thresholds are used:

$RIO_{SHIP}$	Ice classes PC1-PC7	Ice classes below PC 7 and ships not assigned an ice class
$RIO \geq 0$	Normal operation	Normal operation
$-10 \leq RIO < 0$	Elevated operational risk*	Operation subject to special consideration**
$RIO < -10$	Operation subject to special consideration**	Operation subject to special consideration**

Figure 10: Evaluation of RIO for Operations (IMO 2016)

As the IMO states that voyages labelled as “Elevated Operational Risk” and “Operation subject to Special Consideration” should be avoided, this thesis will regard all routes navigating grid cells with  $RIO < 0$  as non-navigable.

## **Route Planning**

Based on the derived RIO values a Dijkstra shortest-path algorithm is deployed, identifying the least-cost route, in this context corresponding to the route with the lowest operational risk. The start and end points are defined as  $(66.5^{\circ}N, 0.0)$  and  $(66.5^{\circ}N, 168.0^{\circ}W)$ , marking the entrances to the Arctic circle via the Fram Strait and Bering Strait respectively and thus connecting the Atlantic and the Pacific Ocean. For simplification, it is assumed that the vessels travel from Ningbo to Rotterdam, representing the furthest entry and exit points in Asia and Europa respectively along the currently serviced routes. The distances from these ports to the start and end points of the Arctic path segment are as indicated calculated with the “VesselFinder Route Planner” (VesselFinder n.d.; Appendix C). For the Arctic path segment the algorithm computes the route by selecting grid cells with the lowest cumulative cost – in this case the highest summed RIO. Following the navigability limitations defined before, only routes with a RIO of  $\geq 0$  in all visited grid cells are considered viable. The path between the two points is then translated into nautical miles and added to the open-water distances to calculate the total route length.

## **Cost Analysis**

To now assess the cost of each route option, these respective distances are combined with the associated fuel costs, being the only cost-driver considered in this thesis. To derive the fuel costs, the speed, the fuel consumption of a given vessel and the fuel price are required.

The speed of the vessels is calculated as follows

$$Speed \left( \frac{\text{nautical miles}}{\text{hours}} \right) = \frac{\text{Distance (nautical miles)}}{\text{Time Travelled (hours)}}$$

using the schedule times as obtained from the Maersk Vessel Schedule tool for the actual time travelled by the operating vessels on the Cape of Good Hope route. As the Gemini Cooperation

due to its recent formation has not yet navigated the Suez Canal Network, no historical speeds can be retrieved and therefore the average speed on the Cape of Good Hope route is inferred to the Suez Canal route. For the Arctic routes the operating speed of the lower capacity vessel is also applied to the higher capacity vessel in absence of a speed specification. As this speed is slightly lower than on the traditional routes, it is reasonable to assume that they both operate at this speed under Arctic conditions.

This speed is used to compute the total travel time for a given route:

$$Total\ Travel\ Time\ (hours) = \frac{Distance\ (nautical\ miles)}{Speed\ (\frac{nautical\ miles}{hour})}$$

The overall costs of a given route are then determined by:

$$Route\ Costs\ (USD) = Total\ Travel\ Time\ (hours) \cdot Fuel\ Consumption\ (\frac{tons}{hour}) \cdot Fuel\ Price\ (\frac{USD}{ton})$$

Where the fuel consumption is obtained according to the calculation based on the vessel specifics as shown in Appendix E.

For better comparability, the route costs are normalized to the vessel capacity on each respective route. As TEU – Twenty-Foot Equivalent Unit – is the commonly used capacity measure in container shipping, it serves as the basis for this normalization.

$$Costs\ per\ TEU\ (\frac{USD}{TEU}) = \frac{Route\ Costs\ (USD)}{Capacity\ (TEU)}$$

### 3.4 Limitations and Assumptions

#### Data and Information Limitations

Due to data availability and scope limitations, this thesis will focus on Hapag-Lloyd only. Since the service portfolio is representative of those of other major shipping companies, findings of this thesis can however be inferred to the broader shipping industry. Another limitation is the lack of historical data on the Gemini Cooperation network. Due to time restrictions, only data retrieved from the Maersk Vessel Schedule source up until 24<sup>th</sup> of March 2025 could be used in this analysis. Therefore, since the services were operated from February onwards, the only

truly historical data available is the data between the beginning of February up until the 24<sup>th</sup> of March. The remaining data comprises the planned schedule up until July and thus no analysis on historical route duration and delays could be included in this thesis. For the same reason, the vessels included in the analysis are restricted to those that were operating the network in the timeframe that was visible on the Maersk Vessel Schedule tool. However, it is reasonable to assume that vessels additionally deployed on these routes would not differ significantly in size or speed to those already in use. Unknown is also the actual fuel consumption of the used vessels, as well as of the PC6 vessels. Therefore, educated guesses were taken about the consumption, based on calculations using the available vessel specifics. As however Hapag-Lloyd possesses this information, integrating actual consumption figures into the analysis to enhance accuracy would be straightforward. Additionally, due to scope constraints the operating speed on the traditional routes is inferred from the currently used Cape of Good Hope route, despite the likelihood that the Suez Canal route would require lower speeds due to the canal width and be subject to speed limitations in the Red Sea and the Mediterranean Sea. Similar inference is performed for the Arctic routes, as previously described, which should be validated when considered in a real-world decision-making process. Also, as detailed information on freight rates is difficult to obtain and the focus is put on the cost and not the profitability of the routes, they are excluded from this analysis.

### **Limitations in Methodology**

Due to limitations in scope and scope and computational capacity, only two SSPs are considered and only one climate model exploited for projections. This limits the assessment of potential inter-model variability, which might influence the robustness of results. Thus, the results should be critically reviewed and interpreted with caution and in subsequent analyses compared to the outputs from other climate data models. Further and due to the same constraints, the sea ice information used for the ten years preceding today are derived solely from model projections and are not validated with historical observations, such as satellite data which would enhance the credibility of results. Also, the fuel consumption and price are the only cost drivers assumed in this analysis, being considered the main cost component in related studies (Li et al. 2023). Other operating cost components are regarded as route-independent. Crew salaries are assumed to be incurred on hourly basis and maintenance and repair costs are considered similar across all routes. This simplification is reasonable, as the variation in these costs is expected to be

marginal compared to the differences in total fuel consumption, which is primarily driven by distance, speed and the vessel characteristics. This thesis also disregards differences in port call fees. However, it is reasonable to assume that the Arctic ports will as of now charge higher fees due to the limited availability in the area. Also, insurance premiums, likely being higher due to the associated risk with navigating the Arctic are assumed to balance out with the increased premiums due to longer distances on the traditional routes (UNCTAD 2024b). As detailed information could not be obtained due to scope constraints, these differences are thus considered marginal. Further, a study by Hu et al. (2024) showed that the ATAM model, employing similar sea ice thickness thresholds in assigning Risk Values to POLARIS, tends to underestimate Arctic accessibility. This is assumed to result from outdated model parameters. This again highlights the importance of validating the model outputs against historical observations to ensure reliability.

## 4 Analysis and Results

### Current Routes

In focus are the westbound legs of the Gemini Cooperation Asia-Europe services with the Hapag-Lloyd internal names “NE1” and “NE2”, as Hapag-Lloyd operates on these as a vessel provider. They follow the routes illustrated in Figure 11 and 12 below.



Figure 11: Hapag-Lloyd Service NE1 (westbound in black) (Hapag-Lloyd 2024a)



Figure 12: Hapag-Lloyd Service NE2 (westbound in black) (Hapag-Lloyd 2024a)

The maps show the routing around the Cape of Good Hope. The port calls differ slightly in the Suez Canal network, however only on the eastbound leg that is not in focus of this thesis.

# 4.1 Current Routing Challenges and Arctic Accessibility

## Route Distances

As can be seen in Figure 13, the currently used Cape of Good Hope routes are significantly longer than those navigating the Suez Canal, with an average increase in nautical miles of 33%.

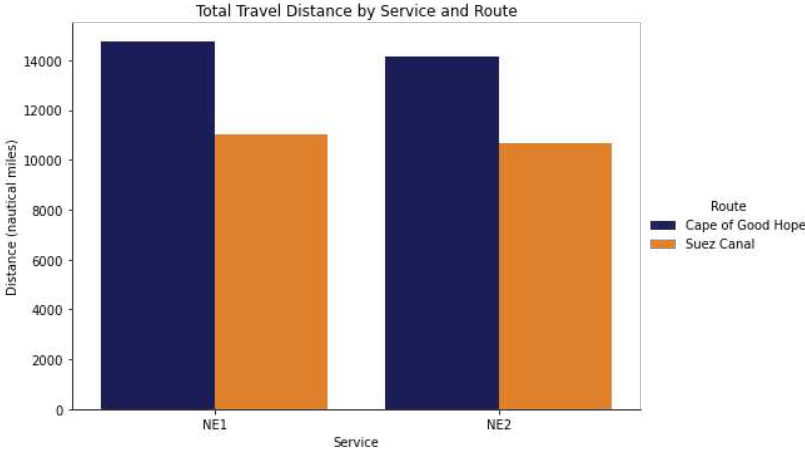


Figure 13: Mean Distance per Service and Route (Own Illustration)

Since the ship speed calculated from the Cape of Good Hope schedules and distances – 15.45 and 16.17  $\frac{\text{nautical miles}}{\text{hour}}$  on average on NE1 and NE2 respectively – aligns with the overall observed average container ship speed (Statista 2021) and speeds used in related studies (Melia, Haines and Hawkins 2016), this speed is also assumed for the Suez Canal routes. Thus, the time travelled on the Cape of Good Hope routes is also around 33% higher than on the Suez Canal routes. Considering the ongoing inaccessibility of the Suez Canal and the associated increase in operational costs, the exploration of shorter route alternatives become increasingly important.

## Sea Ice Thickness and Concentration

The area of interest for the analysis is highlighted by the yellow-colored region in Figure 14, as the sea ice conditions within the waters of this zone are the critical determinant of route accessibility.

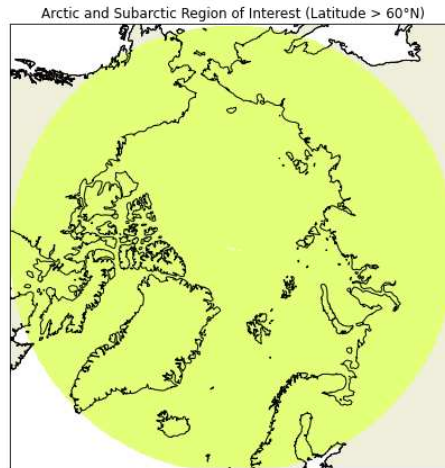


Figure 14: Defined Area of Interest for Accessibility Analysis (Own Illustration)

As shown in Figures 15 and 16, both sea ice concentration and sea ice thickness in both best- and worst-case scenarios exhibit a pronounced downward trend – consistent with findings in the literature despite being based on different climate models (Zhang et al. 2023; Wang et al. 2024).

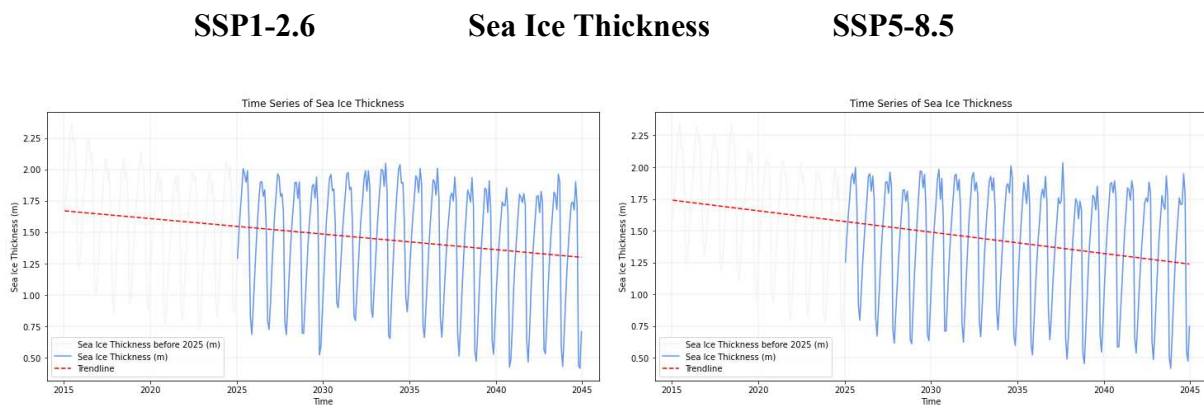


Figure 15: Sea Ice Thickness Values and Trend (2015-2044) (Own Illustration)

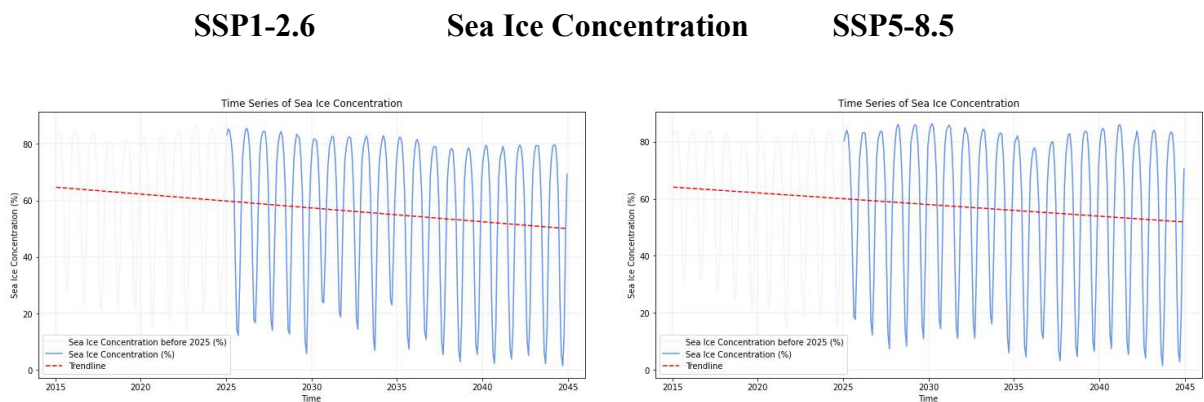


Figure 16: Sea Ice Concentration Values and Trend (2015-2044) (Own Illustration)

This is further supported by the seasonal graphs (see Figure 17 and 18), exhibiting the same downward trend, illustrated by the colour shift from blue (2015) to red (2044), while maintaining a very similar – however in the SSP5-8.5 slightly more pronounced – seasonal cycle.

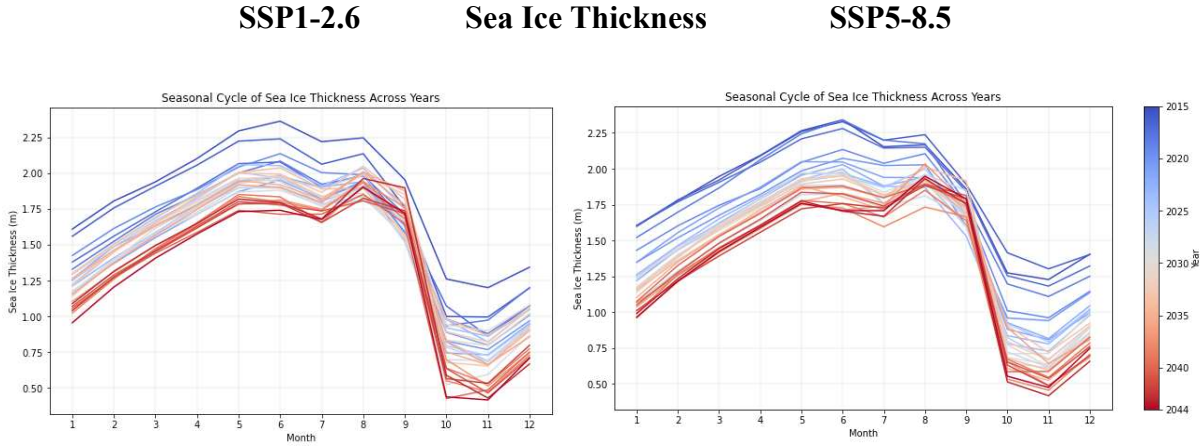


Figure 17: Seasonal Graph of Sea Ice Thickness (2015-2044) (Own Illustration)

The shown sea ice thickness peaks in early summer align with the process of ice thickening throughout the cold months, followed by the melting season during which the ice thins before refreezing again (U.S. Environmental Protection Agency 2025).

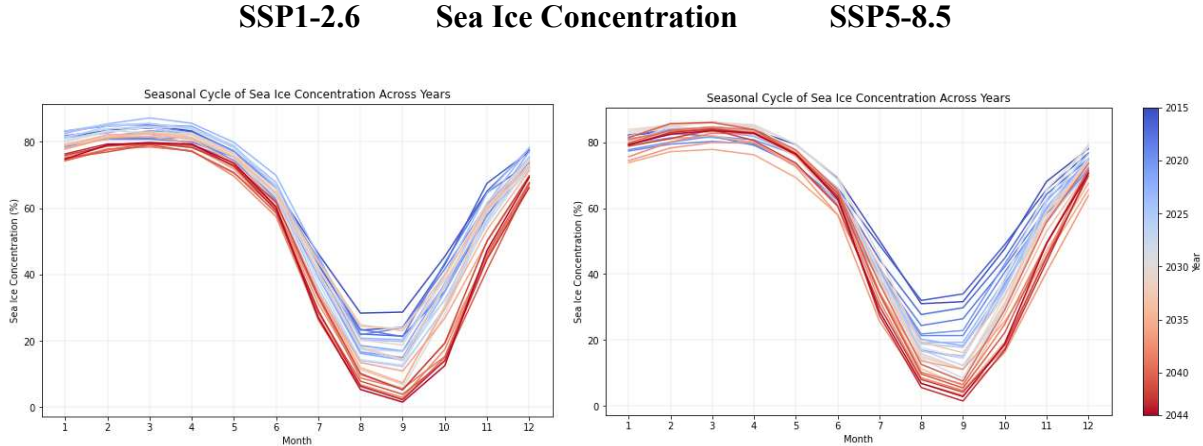


Figure 18: Seasonal Graph of Sea Ice Concentration (2015-2044) (Own Illustration)

This is supported by the sea ice concentration graphs: high values between January and April again align with the Arctic’s cold season while reaching a minimum in late summer (Lindsey and Scott 2022). Note that the sea ice thickness values reach their minimum later in the year, as thin ice melts faster than thick multi-year ice, exposing water faster and thus reducing the sea ice concentration earlier (Hansen et al. 2015).

## Arctic Accessibility

In accordance with the POLARIS mapping framework as outlined in chapter 3, the sea ice thickness values have been translated into Risk Values (RVs) for both Open Water (OW) and Polar Class 6 (PC6) vessels. In combination with the sea ice concentration, the Risk Index Outcomes (RIO) were subsequently computed for each grid cell, providing a more meaningful indication on the area’s accessibility. Consistent with the observed decline in sea ice thickness and concentration, the resulting RIO values exhibit an upward trend for both vessel types, indicating a progressively diminishing level of overall operational risk. Note that the shown curves display spatially averaged RIO values and thus do not provide detailed information on the local variability of risk within the region at this point.

### SSP1-2.6 Monthly Risk Index Outcomes SSP5-8.5

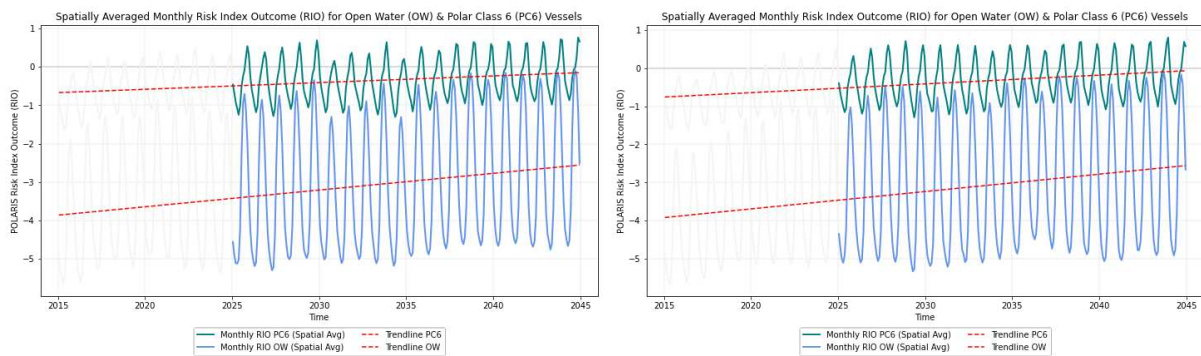


Figure 19: Spatially Averaged Risk Index Outcomes (2015-2044) (Own Illustration)

As shown in Figure 19, under both SSPs only PC6 vessels exhibit months with average RIO values above zero – thus surpassing the accessibility threshold for “Normal Operation” as defined by the POLARIS framework. This enhanced transit potential of PC6 vessels compared to OW vessels aligns with findings from the relevant literature (Melia, Haines and Hawkins 2016; Stephenson et al. 2013; Zhang et al. 2023). The observation suggests that navigation with OW vessels will not be feasible at any point in time within the next two decades; however, the subsequent path computation will further assess in spatial detail whether any navigable areas exist under the defined navigability conditions. Moreover, the graphs indicate that the persisting seasonality as seen earlier continues to challenge the operational feasibility of Arctic navigation throughout the whole assessed time horizon, as several months each year are expected to remain below the navigability threshold.

As the graphs show only spatially averaged values, they do not provide sufficient information on the area’s accessibility but only display the overall trend. To finally assess the accessibility of the region per given point in time in detail, the Dijkstra least-cost-path algorithm is deployed, yielding the route with the least risk through the Arctic waters while optimizing for distance. Following the viability criterion – allowing navigation only in grid cells with a RIO  $\geq 0$  – the algorithm identified a total of 35 and 38 viable paths within the next twenty years (240 monthly time steps) under SSP1-2.6 and SSP5-8.5 respectively. The results thus indicate only minor differences between the two scenarios. Also, all viable paths were restricted to PC6 vessels. These findings align with the results from the Monthly Risk Index Outcomes graphs (see Figure 19), confirming that no viable paths exist for OW vessels within the assessed timeframe. When looking at the monthly distributions of viable paths (see Figure 20 below), it becomes clear that also PC6 vessels – despite their ability to navigate through the Arctic – can only operate at most without restrictions during the months of October through December. The seasonally limited accessibility is consistent with previous findings (Li et al. 2023; Melia, Haines and Hawkins 2016; Stephenson et al. 2013).

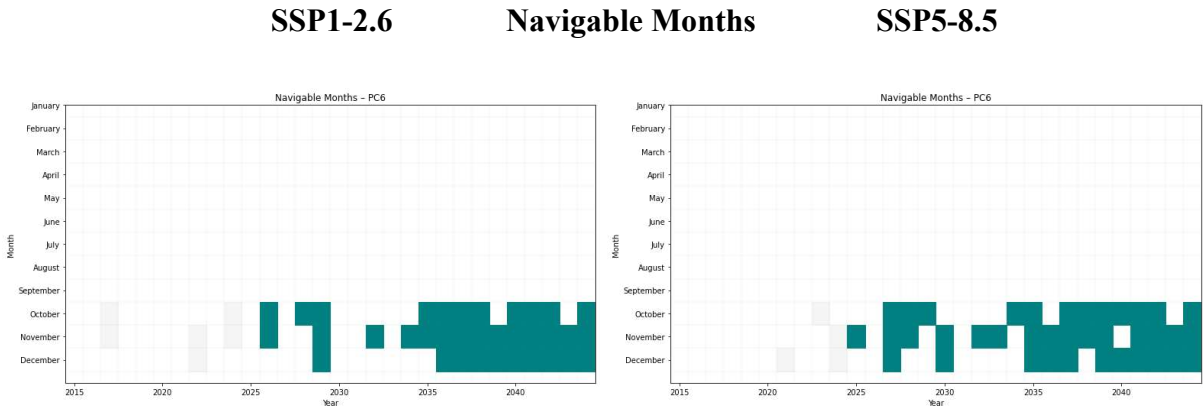


Figure 20: Navigable Months between 2015 and 2044 (Own Illustration)

Despite the increasing density of years with at least one navigable month across time, the exact timing and duration of the navigable period stay volatile until 2044. The navigable months overlap with those identified in the literature – however the cited studies found longer navigable periods for PC6 and even identified navigable windows for OW vessels within the timeframe until 2044. These discrepancies are assumed to result from differences in climate model selection or accessibility thresholds. Moreover, at a monthly resolution it is difficult to capture intra-month volatility or make statements about navigability within individual months with precision.

While the navigable periods remain constrained and volatile, the potential benefits of the routes also strongly depend on the distance travelled. When comparing the navigable months under both SSPs, the results show that the October paths are consistently shorter than those in November and December across all years and under both SSPs. The October routes tend to cut more directly through the central Arctic, passing closer to the North Pole similar to the TSR, whereas the December paths follow a trajectory close to the Russian coastline, aligning with the traditional Northern Sea Route – NSR. This variation in routing efficiency due to seasonal inaccessibility of particular areas is consistent with findings in the literature (Stephenson et al. 2013). In Figure 21 and 22 the illustrations from 2044 are shown, exemplifying the patterns observed within the analyzed timeframe (see Appendix F and G for more details).

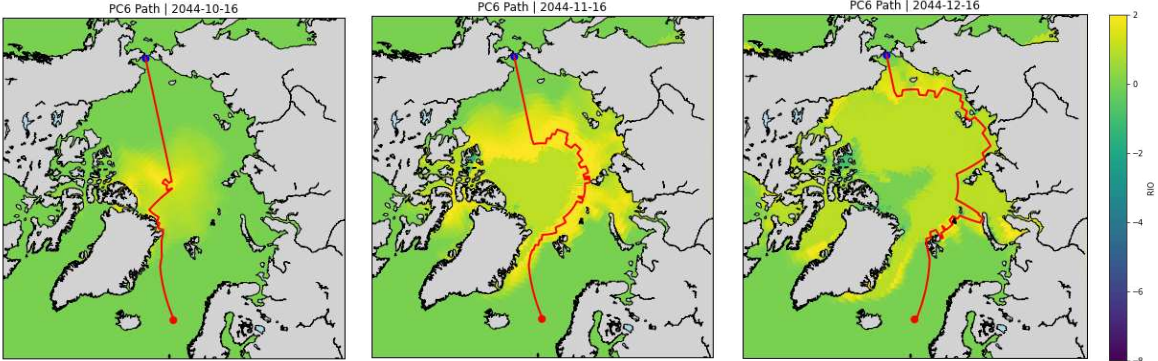


Figure 21: Viable Routes in 2044 under SSP1-2.6 (Own Illustration)

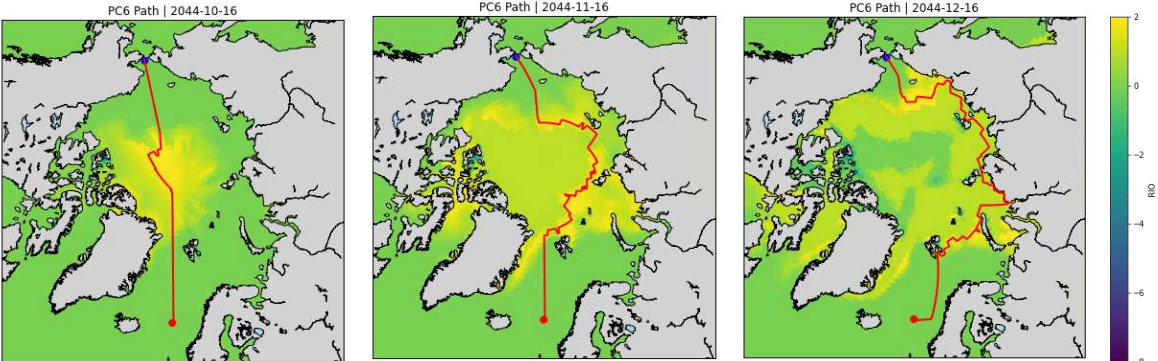


Figure 22: Viable Routes in 2044 under SSP5-8.5 (Own Illustration)

To assess the full viability of these routes, their length and the extent to which it can be translated into cost and time efficiencies compared to the traditional shipping routes are evaluated in the following. At this stage, the main takeaway is that Hapag-Lloyd is projected to not be able to navigate the Arctic in the next two decades using its existing fleet. To determine whether investments into Polar Class vessels would be strategically beneficial, the potential cost savings and operational benefits must be examined.

## 4.2 Comparative Analysis of Shipping Routes

### Distance

Averaging over the distances of the viable paths computed by the Dijkstra algorithm, it can be observed that the Arctic routes can offer distance savings of on average 37% compared to the Cape of Good Hope route and 17% compared to the Suez Canal route. These savings are slightly more pronounced under SSP5-8.5 and tend to be marginally higher for the NE1 service. The literature reports even larger potential distance savings, with Li et al. (2023) citing reductions of up to 40% when compared to the Suez Canal route. This is due to the case study design, which assumes direct transit from Rotterdam to Shanghai without intermediate port calls.

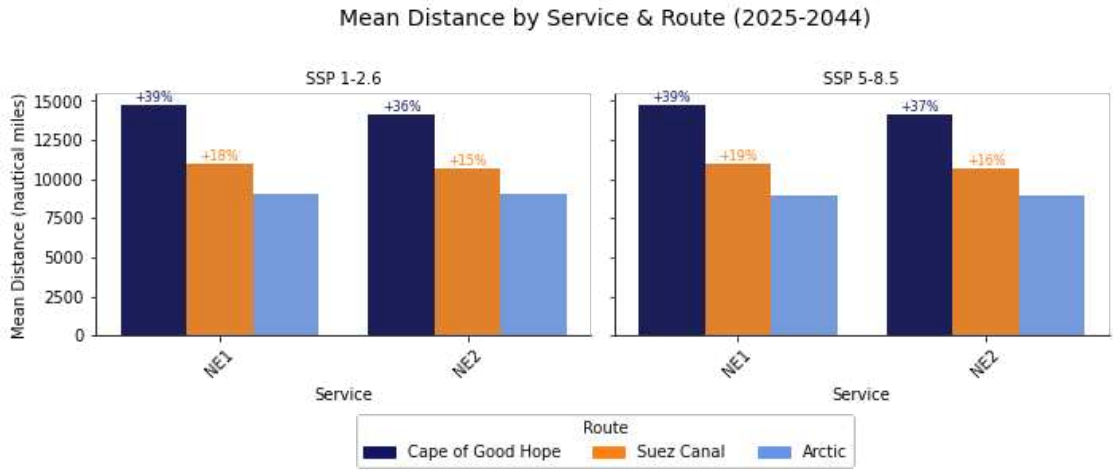


Figure 23: Distance Comparison between Arctic and Traditional Routes (Own Illustration)

Considering a speed of  $15.3 \frac{\text{nautical miles}}{\text{hour}}$  for both PC6 vessels, this translates to an average time saving of 13.59 days compared to the Cape of Good Hope route and 4.11 days compared to the Suez Canal route. In this analysis, an average transit time of 28.62 days was calculated for the Suez Canal route and 24.51 days – with a minimum of 19.88 days – for the Arctic route. Related studies have reported even greater reductions in travel time, reducing the Suez Canal routing time – typically estimated at around 30 days, matching the results of this analysis – to 17-22 days according to Melia, Haines and Hawkins (2016), around 13-18 days as found by Bennett et al. (2020), and even to on average 13 days according to Zhang et al. (2023) when using the Arctic route. These findings suggest that this analysis underestimates both the distance and time savings on the Arctic route, possibly due to conservative sea ice projections and speed estimations with regards to the PC6 vessels.

**Total Costs**

Distance and speed translate into the total cost of each route, given the fuel price of  $523 \frac{USD}{ton}$  (Ship & Bunker n.d.) and the respective vessel’s fuel consumption:

Vessel	Fuel Consumption ( $\frac{tons}{hour}$ )
OW (Average on NE1)	3.59
OW (Average on NE2)	4.25
PC6 (Highest Assumed Capacity)	1.27
PC6 (Lowest Assumed Capacity)	1.1

Table 1: Fuel Consumption per Service and Vessel (Own Calculations)

In terms of absolute cost savings, navigating the Arctic instead of the Suez Canal with the Low-Capacity PC6 vessel results in average savings of 998,597 USD on NE1 and 1,131,214 USD on Service NE2. With the High-Capacity PC6 vessel, the savings remain substantial, averaging 946,258 USD on NE1 and 1,078,875 USD on NE2. In comparison to the Cape of Good Hope route, the savings are even more pronounced. The Low-Capacity PC6 vessel offers an average amount of savings of 1,453,832 USD on NE1 and 1,603,525 USD on NE2. When using the High-Capacity PC6 vessel, on average 1,401,493 USD on NE1 and 1,551,186 USD on NE2 could potentially be saved when navigating the Arctic.

These figures translate into savings of 75-83% when using the Low-Capacity PC6 vessel and 71-80% when using the High-Capacity PC6 vessels. The related literature does not report savings of this extent but estimates around 17-33% (Li et al. 2023). This discrepancy likely results from differences in the distance computation and vessel specifications and assumptions, in particular regarding the capacity and efficiency of Polar Class vessels. Additionally, the results show slightly higher savings under SSP5-8.5; this trend is not explored in the literature but is intuitive considering the change in sea ice conditions and risk, enabling shorter and less risky Arctic passages.

### Cost per TEU

The Arctic routes appear very favorable across both scenarios, services and PC6 capacity levels in terms of absolute cost savings. However, as the cargo capacity of PC6 vessels differs from that of vessels currently deployed on the traditional routes, a direct cost comparison is misleading. For a fairer assessment, the costs are therefore normalized to reflect the cost per TEU, using the capacity levels for the OW and PC6 vessels as shown in Table 2.

Vessel	Given in TEU
OW (Average Capacity on NE1)	21,854
OW (Average Capacity on NE2)	18,800
PC6 (Highest Assumed Capacity)	3,600
PC6 (Lowest Assumed Capacity)	606

Table 2: Capacity Levels in TEU (AXSMarine n.d.; Port of Hamburg n.d.; Remontowa Marine Design & Consulting n.d.)

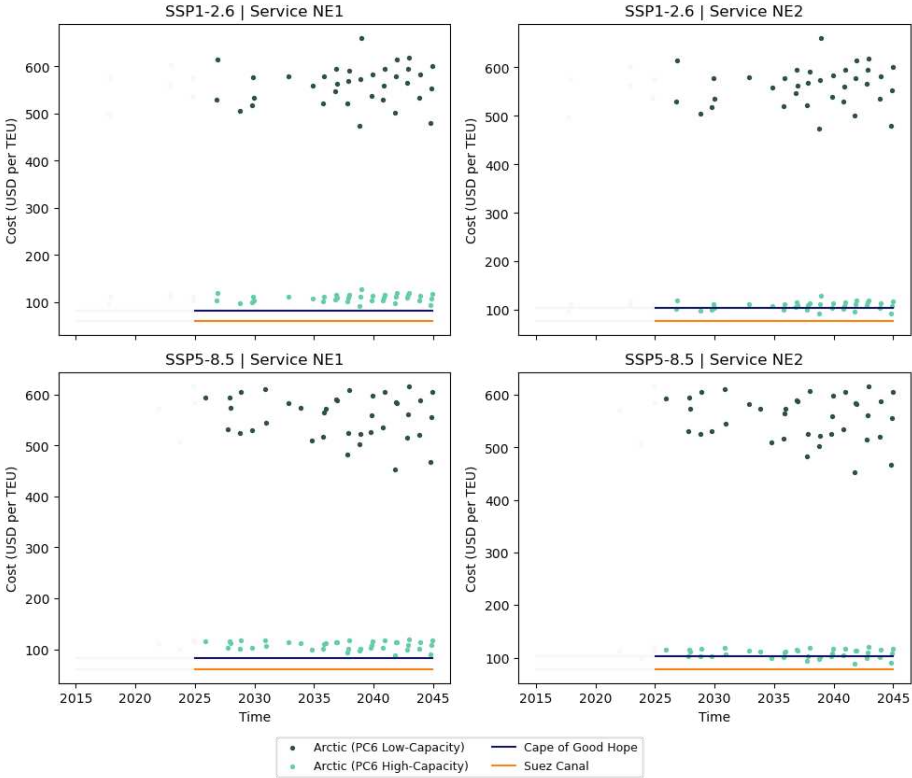


Figure 24: Cost per TEU per Route, Service, SSP and PC6 Vessel Capacity Level (Own Illustration)

When evaluating the cost per TEU, the results paint a different picture: due to their smaller vessel sizes, navigating Arctic routes with PC6 vessels appears now less favorable compared to shipping on the traditional routes than when looking at the total costs. However, in certain months within roughly a decade of today, the Arctic routes become cost-competitive on the NE2 service under both SSPs when using PC6 vessels with a capacity comparable to the “Venta Maersk” – given by “PC6 High-Capacity” data points in Figure 24. In contrast, the smaller PC6 vessel is not competitive under any scenarios and in neither service nor year. These findings are consistent with related studies, such as Wu et al. (2024), which similarly highlight the limited economic viability of the smaller Polar Class vessels in Arctic navigation.

### **TEU per Year**

Given that the navigable period in the projections from the used climate model and POLARIS is limited to a maximum of three navigable months per year until 2044, the potential benefits of rerouting through the Arctic are significantly reduced. In fact – under these constraints and considering one transit through the Arctic per month – a maximum of 10,800 TEU can be transported annually with the High-Capacity PC6 vessels and only 1,818 TEU with a Low-Capacity PC6 vessel. On average, this translates to a fraction of 0.7-4.1% of the NE1 cargo volume and 0.8-4.8% NE2 volume on the traditional routes, highlighting the limited contribution of the Arctic rerouting as projected for the next two decades.

## 5 Discussion

### 5.1 Interpretation of Key Findings

In line with the relevant literature, Arctic sea ice thickness and concentration are projected to decline substantially under both the best case – SSP1-2.6 – and the worst case climate scenario – SSP5-8.5 – over the next two decades. Correspondingly, the projections show a clear decrease in navigational risk, suggesting that Arctic navigation will be increasingly feasible within the next twenty years. Also consistent with previous studies, the computed Arctic routes are significantly shorter than both traditional route options, offering average savings of approximately 13.6 days compared to the Cape of Good Hope route and 4.1 days compared to the Suez Canal route. Already in the analyzed timeframe the October routes follow a similar trajectory as the Transpolar Sea Route, due to its characteristics in terms of distance and accessibility considered as the most beneficial Arctic route. However, Hapag-Lloyd’s current liner shipping fleet, consisting exclusively of Open Water vessels, cannot safely navigate the Arctic, as the navigational risk posed for this vessel type does not pass the IMO’s threshold for unrestricted accessibility. These findings reinforce conclusions from the literature, highlighting the criticality of vessel readiness for Arctic shipping operations. To enable Arctic routing, investment in Polar Class vessels would be required. However, these vessels generally have smaller capacities limiting transport volumes, resulting in poor per-TEU economics compared to the routing via the traditional corridors. Consequently, the Arctic routes appear economically unattractive under current conditions, becoming cost-competitive using PC6 vessels only occasionally and only on one of the two services analyzed. Further, they only become competitive when compared to the Cape of Good Hope route, with their advantage disappearing in the event of restored accessibility to the Suez Canal. Once OW vessels become capable of navigating the Arctic safely, the cost per TEU is however expected to become consistently competitive, due to the significantly shorter route distances.

In spite of that, the viability is not only driven by the per-TEU economics but also by the duration and reliability of the navigable period. The strong seasonality of sea ice conditions results in restricted and fluctuating windows during which navigation is possible. These limitations, remaining high even under the worst-case climate scenario, restrict the total annual cargo volume that can be transported and undermines operational planning reliability. With a maximum of three navigable months fewer than 5% of the current NE1 and NE2 services’

throughput can be transported via the Arctic, thereby significantly limiting the strategic impact of these routes. As shown in Figure 25 however, under both SSPs the percentage of viable Arctic routes for PC6 vessels increases over time even in the short analyzed timeframe, with at least 16.7% of routes projected to be viable in every year in the decade spanning 2035 to 2044. Taken together with the observed trend in sea ice conditions, these findings indicate a further extension of the navigable period.

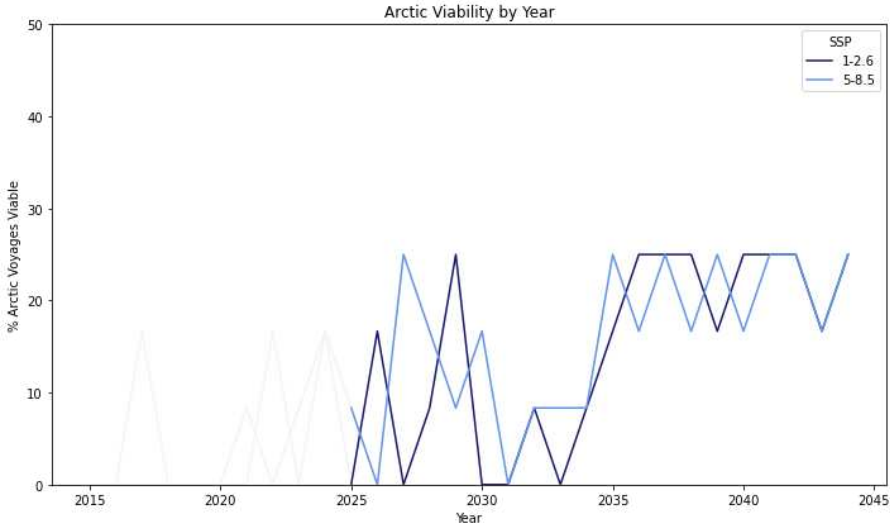


Figure 25: Navigation Viability for PC6 vessels (Own Illustration)

Additionally, recent scientific research suggests that the CMIP6 ice projections may underestimate the speed of Arctic sea ice loss due to inadequate representation of tipping points, indicating that longer and more reliable navigable windows could emerge earlier than currently estimated (Shen et al. 2023) – a development that could alter the assessment of viability by improving accessibility and planning reliability and potentially enabling the deployment of larger vessels earlier, thus increasing transport capacity.

A key takeaway from the analysis, aligning with the reviewed literature is that the cost trade-offs between Arctic and traditional routes are marginal, and their viability is highly sensitive to climatic and economic uncertainties. The findings of this thesis reinforce the conclusion that while Arctic routes offer potential benefits under certain conditions, their overall strategic value remains constrained in the near to medium term. Taken together, the limited and volatile navigable windows, at most marginal per-TEU economics and fleet constraints imply that Arctic routing remains non-viable for Hapag-Lloyd under current and projected conditions.

## **5.2 Implications for Stakeholders**

As the services of Hapag-Lloyd can be considered representative of other market stakeholder's service offerings, the findings can be inferred to the broader shipping industry. Given a similar fleet composition, it is thus generally also judged not viable to adopt the Arctic routes for other major carriers as it remains mostly inaccessible. Moreover, an investment in dedicated PC6 vessels appears economically unjustifiable, as the associated costs are disproportionately high – according to existing research being up to three times more expensive to build than vessels without an ice class (Solakivi, Kiiski and Ojala 2018) – despite offering only a fraction of the capacity, thus leading to poor per-TEU economics. Further, the deployment periods, remaining constrained for the foreseeable future, and resulting idle times during non-navigable periods offset the potential benefits and undermine the economic rationale for investments under current conditions. However, in case of access to PC6 vessels, seasonal deployment could be considered – demanding however continuous monitoring due to the volatility in sea ice conditions.

While Arctic waters increasingly open up for economic opportunities due to climate change, the accessibility of the region is also shaped by regulatory and geopolitical factors. Considering that the physical accessibility is projected to remain constrained, it might be valuable for coastal states and other regulatory instances in the Arctic to enhance the attractiveness of the area in terms of infrastructure, ease of operations and fees. Considering the environmental factors, robust environmental safeguards and emergency response frameworks should be established before the area becomes fully accessible for standard vessels.

To follow the demands of the UNCTAD, to work on “achieving more robust, reliable and resilient maritime chokepoints” (2024b), all stakeholders should invest efforts into the exploration and feasibility assessment of Arctic navigation, in line with environmental and regulatory considerations.

## **5.3 Managerial and Strategic Recommendations**

Based on the results, the current outlook is not stable enough for Hapag-Lloyd to integrate the Arctic routes into their liner shipping operations in the near future. However, if the Arctic routes are viewed as alternative options in the event of major disruptions along the traditional

corridors, they may serve as a flexible supplement to existing trade lanes. Given that rerouting decisions can be made on short notice, Hapag-Lloyd could adopt a monitoring-based approach to be able to reroute suitable cargo to complement the trade on the traditional routes when risks and cost align. Such a strategy would however require access to a PC6 vessel. An investment in PC6 vessels, considering the high investment costs and few possible use cases, would contradict the strategy of Hapag-Lloyd to enhance their cost-competitiveness. However, since Maersk, being the key strategic partner of Hapag-Lloyd in the Gemini Cooperation, owns the “Venta Maersk”, a vessel of ice class comparable to PC6, it might be advantageous to monitor the developments and consider deploying the vessel – if available to the operations of the Gemini Cooperation – once the conditions are favorable. In parallel, given the changes in sea ice conditions, a consistent monitoring should be set up to identify the point in time at which operations become sufficiently and reliably viable. Given the still relatively low share of viable routes and the observed decline in navigational risk for OW vessels, it may be favorable to postpone Arctic operations until these vessels are able to safely access the region. At that point, regular operations might become cost-effective and strategically more valuable than today.

#### **5.4 Discussions of Limitations and Alternative Perspectives**

As most results are supported by the literature, the data foundation and methodology seem to be sound. However, there are certain limitations affecting the robustness of results. Most notably, projections from only a single climate model are considered, presenting only one possible scenario of future sea ice conditions. The range of potential variability and uncertainty, captured by other models with different parameters and assumptions, is therefore overlooked. Since the navigable periods found in the analysis only partially align with those reported in the literature, incorporating additional models would be valuable to validate and strengthen the results, especially in terms of timing, duration and the feasibility of the navigable windows.

Also, the temporal resolution of the projections restricts insights into intra-monthly variability in sea ice conditions and thus navigational risk. This could challenge the oversimplified classification of certain months as navigable, potentially overlooking that portions of months currently considered non-navigable also offer navigable conditions. In the results of this thesis however, the resolution aligns reasonably well with the transit time, implying that only one voyage per month is feasible. This slightly underestimates the number of transits possible on

the Arctic routes; however, for the narrow navigable window this difference amounts to less than one additional transit and can therefore be considered negligible.

Given also that studies showed that projections are commonly underestimating the pace at which the Arctic sea ice conditions are changing and that the ATAM, being similar to the applied POLARIS framework likely uses outdated model parameters, not only the data limitations but also the methodology applied might have further underestimated Arctic accessibility and thus favorability.

Since no significant differences between the two extreme SSPs could be detected in this analysis, it would most likely not be meaningful to include more SSPs for the same timeframe, as the climate effects for this relatively short time horizon are not diverging much.

Regarding the vessel data limitations, several key variables, such as exact speed figures for either corridor or the fuel consumption of the deployed vessels are important for a realistic assessment of the economic viability of the routes, once deemed navigable. While data on these variables was approximated in this analysis, most of them can be filled with Hapag-Lloyd's internal data. It should be noted that the assumptions made likely favor the Suez Canal route, potentially underestimating the relative attractiveness of the Arctic. Also, the inclusion of historical schedule data may shift the outcome in favor of the Arctic, as reports show that the Asia-Europe trade suffers from issues in on-time performance (see Chapter 1).

One key limitation to a comprehensive assessment of economic viability is the exclusion of revenue considerations across the different routes. The sole perspective on costs overlooks potential profitability drivers – revenues might exceed the costs by achieving higher freight rates paid for time-sensitive or niche cargo on the faster Arctic routes. Additionally, time savings also indirectly translate into revenue, as they enable more transits in the same operational timeframe, increasing cargo throughput. Also, the cargo volume and transportation demand arising from port calls along the route is disregarded. The Arctic route might offer connectivity with valuable ports and regions in the Arctic coastal states and therefore lucrative opportunities and business cases. Thus, this perspective should be incorporated into further assessments.

## **6 Conclusion and Recommendations**

### **6.1 Summary of Research Findings**

As the traditional maritime corridors face disruptions from geopolitical tensions, increasing congestion and climate-related constraints, the search for viable alternative routes has become a strategic priority for global shipping companies. Climate change is reshaping the maritime environment and the rapidly warming Arctic offers increasingly viable alternatives to the traditional routes, as the sea ice reduces and opens the area for navigation. However, the vessel and thus size restrictions, as well as the volatility in navigational risk pose operational hurdles and limit the economic viability of Arctic navigation in liner shipping operations for the next two decades. To present itself as a true alternative to the established shipping corridors, the amount of ice must further reduce significantly to allow traditional container vessels to access the region and unlock its full economic potential. Under current and projected conditions under both the best- and worst-case climate scenario and even with access to vessels with ice-breaking capabilities, no more than 5% of Hapag-Lloyd's current NE1 and NE2 cargo volume could be shifted to the Arctic passages annually and even then, cost-competitiveness is only observed in comparison to the Cape of Good Hope Route. Once the Suez Canal regains full accessibility, these relative benefits vanish. However, given the ongoing instability in the Suez Canal region, the growth in global trade volumes and the favorable trends in Arctic sea ice conditions, the conditions should be continuously monitored and re-evaluated for Hapag-Lloyd to be able to exploit benefits once the viability improves.

In conclusion, Arctic routes are found to be no viable alternatives to the Suez Canal and Cape of Good Hope routes for Hapag-Lloyd's NE1 and NE2 services over the next two decades – given the current fleet composition, cost structures and navigability risk.

### **6.2 Critical Review**

The key strength of this thesis is the availability of real service schedules and vessel data from Hapag-Lloyd, allowing for well-grounded calculations and estimations and providing valuable and practice-oriented insights to Hapag-Lloyd's strategic decision-making process. This empirical foundation strengthens the relevance and applicability of the findings.

However, the robustness of results would benefit from the incorporation of additional climate models and historical data to validate the assumptions and findings. Furthermore, the current analysis adopts a purely cost-based perspective, assuming that cost competitiveness alone would drive routing decisions. In practice however, profitability drivers should be included to support a more comprehensive economic assessment. Moreover, the assumption that carriers will always choose the lowest-cost option disregards the influence of environmental concerns and regulatory frameworks, which, depending on the strategic positioning, could outweigh the economic benefits and lead to continued preference for the traditional corridors.

In summary, while the methodological framework is strong and adaptable, the accuracy and strategic usefulness of results would benefit from adding these additional factors in future analyses.

### **6.3 Directions for Future Research**

Given that related studies have produced diverging results in terms of Arctic accessibility, future research should incorporate multiple climate models. This variety in projections would help to verify the findings of this study and improve the robustness of assessments under the prevailing uncertainty. To account for the revenue dimension, one approach for future work could be to explore the freight rate dynamics and demand shifts under the availability of the Arctic routes. Additionally, following research of Bennett et al. (2020), examining the suitability of different cargo types for trade through the Arctic could uncover commercially feasible business cases for carriers. Building on this, the assumption of a direct transit from Asia to Europe without loading and unloading at intermediate ports can be revisited. Research suggests that intermediate Arctic ports and transshipment strategies become attractive in an ice-class shipping context (Bennett et al. 2020). This is especially interesting for Hapag-Lloyd, as they focus on the new Hub and Spoke concept already with the Gemini Cooperation and could therefore open opportunities for new service designs and trade optimization. It may also be worthwhile to assess the viability of the Arctic routes for other shipping companies, as its viability heavily depends on the fleet capabilities, service network and the company's strategy. For some industry players, Arctic navigation may be more relevant or feasible than for Hapag-Lloyd. Finally, as an alternative to investing into entirely new Polar Class vessels, a cost-benefit

analysis could be conducted for retrofitting existing vessels to equip them with icebreaking capabilities and how this affects the assessment of viability of the Arctic routes.

As the Arctic experiences rapidly changing climate, geopolitical and economic conditions, making it a region of growing interest, future research should be conducted to navigate this complexity and support informed decision-making for sustainable and economically viable Arctic shipping operations.

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# Appendices

## Appendix A: Routes and Deployed Vessels

Source: AXSMarine. n.d. “Maritime Tools and Resources | Alphaliner.” Accessed March 22, 2025. <https://public.axsmarine.com/alphaliner/all-tools>.

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Alphaliner - Service data										
Gemini Cooperation - Asia-Europe service (AE2 / NE1)										
Participants										
<b>Carrier</b>	<b>Status</b>	<b>Service Branding</b>	<b>Remarks / Info</b>							
Hapag-Lloyd	Vessel provider	NE1								
Maersk A/S	Alliance partner	AE2								
Coverage										
North Europe / Far East										
Type										
CON										
Sailing frequency										
7										
Duration of rotation										
98										
Proforma fleet										
14 ships (from 19,870 - 23,664 teu)										
Weekly capacity (teu)										
7909										
Port rotation										
Ningbo (incl Zhoushan), Shanghai, Tanjung Pelepas, Tanger Med, Wilhelmshaven, Bremerhaven, Rotterdam, Salalah, Singapore, Ningbo (incl Zhoushan)										
Comments										
Comments - Service Chronology										
> Service organized in February 2025 as part of the new 'Gemini Cooperation' alliance, set up by Maersk and Hapag-Lloyd (See news1 / news2).										
© Alphaliner										
Ships deployed										
Vessel name	Type	Flag	DWT	TEU	TEU 14	Speed	Gear	Operator	Open date	
MANILA EXPRESS	cc/m	DEU	229348	23664	13550	18,5	No	Hapag-Lloyd	(own)	
TIHAMA	cc/m	DEU	199744	19870	0	21	No	Hapag-Lloyd	(own)	
BARZAN	cc/m	DEU	199744	19870	0	21	No	Hapag-Lloyd	(own)	
BANGKOK EXPRESS	cc/m	DEU	229348	23664	13550	18,5	No	Hapag-Lloyd	(own)	
DAMIETTA EXPRESS	cc/m	DEU	229348	23664	13550	18,5	No	Hapag-Lloyd	(own)	
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Alphaliner - Service data										
Gemini Cooperation - Asia-Europe service (AE1 / NE2)										
Participants										
<b>Carrier</b>	<b>Status</b>	<b>Service Branding</b>	<b>Remarks / Info</b>							
Hapag-Lloyd	Vessel provider	NE2								
Maersk A/S	Vessel provider	AE1								
Coverage										
North Europe / Far East										
Type										
CON										
Sailing frequency										
7										
Duration of rotation										
91										
Proforma fleet										
13 ships (from 5,560 - 20,568 teu)										
Weekly capacity (teu)										
7425										
Port rotation										
Shanghai, Yantian (Shenzhen), Tanjung Pelepas, Rotterdam, Hamburg, London Gateway Port, Tanger Med, Singapore, Shanghai										
Comments										
Comments - Service Chronology										
> Service organized in February 2025 as part of the new 'Gemini Cooperation' alliance, set up by Maersk and Hapag-Lloyd (See news1 / news2 / news3).										
© Alphaliner										
Ships deployed										
Vessel name	Type	Flag	DWT	TEU	TEU 14	Speed	Gear	Operator	Open date	
MUMBAI MAERSK	cc/m	DNK	190326	20568	0	22	No	Maersk A/S	(own)	
MAERSK MONTE PASCOAL	cc/l	SGP	71475	5560	4100	23,3	No	Maersk A/S	(own)	
MILAN MAERSK	cc/m	DNK	190326	20568	0	22	No	Maersk A/S	(own)	
AL ZUBARA	cc/m	DEU	199744	19870	0	21	No	Hapag-Lloyd	(own)	
MAJESTIC MAERSK	cc/m	DNK	213971	19076	0	22,5	No	Maersk A/S	(own)	
GUDRUN MAERSK	cc/v	DNK	115700	10888	0	24	No	Maersk A/S	(own)	
All information above is given as guidance only and in good faith without guarantee © Alphaliner 1999-2025										

# Appendix B: Detailed Schedules

Source: Maersk. n.d. “Vessel Schedules.” Accessed March 24, 2025.

<https://www.maersk.com/schedules/vesselSchedules>.

Q11	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Vessel Name	TEU (Nominal)	Built	IMO Number	Call Sign	Class	Flag	Rotation	Port	Terminal	Arrival Date	Voyage Number	Departure Date	Service	Hapag	Route	
1 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Shanghai	1 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-02-25 14:50:00	509W   509W	2025-02-27 00:35:00	NE2		Cape of Good Hope	
2 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Yantian	1 Yantian	Yanlian Intl. Container Terminal	2025-03-03 13:16:00	509W   509W	2025-03-04 20:31:00	NE2		Cape of Good Hope	
3 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Tanjung Pelepas	1 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-03-10 04:00:00	509W   509W	2025-03-10 19:09:00	NE2		Cape of Good Hope	
4 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Rotterdam	1 Rotterdam	APM 2 Terminal Maasvlakte II	2025-04-07 12:00:00	509W   515E	2025-04-09 04:00:00	NE2		Cape of Good Hope	
5 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Hamburg	1 Hamburg	Eurogate Container Terminal Hamburg	2025-04-10 23:00:00	509W   515E	2025-04-12 15:00:00	NE2		Cape of Good Hope	
6 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 London Gateway	1 London Gateway	London Gateway Terminal	2025-04-15 13:00:00	509W   515E	2025-04-16 23:00:00	NE2		Cape of Good Hope	
7 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Port Tanger Med	1 Port Tanger Med	Port Tanger Med Terminal	2025-04-21 08:00:00	515E   515E	2025-04-22 02:00:00	NE2		Cape of Good Hope	
8 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Port Tanger Med	1 Port Tanger Med	Port Tanger Alliance Terminal	2025-04-22 08:30:00	515E   515E	2025-04-23 06:30:00	NE2		Cape of Good Hope	
9 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Singapore	1 Singapore	PSA Singapore Terminal	2025-05-20 07:00:00	515E   515E	2025-05-22 03:00:00	NE2		Cape of Good Hope	
10 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Shanghai	1 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-05-27 20:00:00	515E   522W	2025-05-29 14:00:00	NE2		Cape of Good Hope	
11 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	2 Shanghai	2 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-06-02 01:00:00	515E   522W	2025-06-03 16:30:00	NE2		Cape of Good Hope	
12 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	2 Yantian	2 Yantian	Yanlian Intl. Container Terminal	2025-06-08 03:00:00	522W   522W	2025-06-09 12:00:00	NE2		Cape of Good Hope	
13 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	2 Tanjung Pelepas	2 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-07-07 12:00:00	522W   528E	2025-07-09 04:00:00	NE2		Cape of Good Hope	
14 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	2 Rotterdam	2 Rotterdam	APM 2 Terminal Maasvlakte II	2025-07-10 23:00:00	522W   528E	2025-07-12 15:00:00	NE2		Cape of Good Hope	
15 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	2 Hamburg	2 Hamburg	Eurogate Container Terminal Hamburg	2025-07-15 13:00:00	522W   528E	2025-07-16 23:00:00	NE2		Cape of Good Hope	
16 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	2 London Gateway	2 London Gateway	London Gateway Terminal	2025-07-21 08:00:00	528E   528E	2025-07-22 02:00:00	NE2		Cape of Good Hope	
17 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	2 Port Tanger Med	2 Port Tanger Med	Port Tanger Alliance Terminal	2025-07-22 08:30:00	528E   528E	2025-07-23 06:30:00	NE2		Cape of Good Hope	
18 AL ZUBARA	18800	2015	9708875	DDXA2	DNV	Germany (DE)	1 Ningbo	1 Ningbo	Ningbo Meishan Terminal	2025-03-15 09:56:00	005E   512W	2025-03-16 21:02:00	NE1		Cape of Good Hope	
19 AL ZUBARA	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Shanghai	1 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-03-18 19:13:00	512W   512W	2025-03-20 04:31:00	NE1		Cape of Good Hope	
20 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Tanjung Pelepas	1 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-03-25 15:00:00	512W   512W	2025-03-28 06:00:00	NE1		Cape of Good Hope	
21 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Port Tanger Med	1 Port Tanger Med	Port Tanger Alliance Terminal	2025-04-22 16:00:00	512W   512W	2025-04-24 08:30:00	NE1		Cape of Good Hope	
22 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Port Tanger Med	1 Port Tanger Med	TC3 Tanger Alliance Terminal	2025-04-23 14:30:00	512W   518E	2025-05-02 22:00:00	NE1		Cape of Good Hope	
23 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Wilhelmshaven	1 Wilhelmshaven	Wilhelmshaven Eurogate CT	2025-05-04 19:30:00	512W   518E	2025-05-06 21:30:00	NE1		Cape of Good Hope	
24 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Bremerhaven	1 Bremerhaven	NTB North Sea Terminal Bremerhaven	2025-05-08 15:00:00	512W   518E	2025-05-09 15:00:00	NE1		Cape of Good Hope	
25 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Rotterdam	1 Rotterdam	APM 2 Terminal Maasvlakte II	2025-06-04 20:00:00	518E   518E	2025-06-06 02:00:00	NE1		Cape of Good Hope	
26 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Salalah	1 Salalah	Salalah Terminal	2025-06-14 13:30:00	518E   518E	2025-06-15 18:30:00	NE1		Cape of Good Hope	
27 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Singapore	1 Singapore	PSA Singapore Terminal	2025-06-21 03:30:00	518E   526W	2025-06-23 02:30:00	NE1		Cape of Good Hope	
28 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Ningbo	1 Ningbo	Ningbo Meishan Terminal	2025-06-24 17:00:00	518E   526W	2025-06-26 11:00:00	NE1		Cape of Good Hope	
29 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	2 Shanghai	2 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-07-02 20:00:00	526W   526W	2025-07-03 03:00:00	NE1		Cape of Good Hope	
30 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	2 Tanjung Pelepas	2 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-07-29 16:00:00	526W   526W	2025-07-30 08:00:00	NE1		Cape of Good Hope	
31 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	2 Port Tanger Med	2 Port Tanger Med	Port Tanger Alliance Terminal	2025-07-30 14:30:00	511W   511W	2025-07-31 08:30:00	NE1		Cape of Good Hope	
32 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Ningbo	1 Ningbo	Ningbo Meishan Terminal	2025-09-08 07:40:00	511W   511W	2025-09-09 15:38:00	NE1		Cape of Good Hope	
33 MANILA EXPRESS	23664	2023	9540120	DCAU2	DNV	Germany (DE)	1 Shanghai	1 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-03-12 12:53:00	511W   511W	2025-03-14 04:15:00	NE1		Cape of Good Hope	
34 MANILA EXPRESS	18800	2015	9736107	DGLM	DNV	Germany (DE)	1 Tanjung Pelepas	1 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-03-19 13:35:00	511W   511W	2025-03-21 07:31:00	NE1		Cape of Good Hope	
35 THAMA	18800	2015	9736107	DGLM	DNV	Germany (DE)	1 Port Tanger Med	1 Port Tanger Med	Port Tanger Alliance Terminal	2025-04-15 16:00:00	511W   511W	2025-04-16 08:00:00	NE1		Cape of Good Hope	
36 THAMA	18800	2015	9736107	DGLM	DNV	Germany (DE)	1 Port Tanger Med	1 Port Tanger Med	TC3 Tanger Alliance Terminal	2025-04-16 14:30:00	511W   511W	2025-04-17 08:30:00	NE1		Cape of Good Hope	

Q11	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
41	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	1	Wilhelmshaven	Wilhelmshaven Eurogate CT	2025-04-22 14:00:00	511W   517E	2025-04-25 22:00:00	NE1	Cape of Good Hope	
42	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	1	Bremerhaven	NTB North Sea Terminal Bremerhaven	2025-04-27 19:30:00	511W   517E	2025-04-29 21:30:00	NE1	Cape of Good Hope	
43	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	1	Rotterdam	APM 2 Terminal Maasvlakte II	2025-05-01 15:00:00	511W   517E	2025-05-02 15:00:00	NE1	Cape of Good Hope	
44	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	1	Salalah	Salalah Terminal	2025-05-28 20:00:00	517E   517E	2025-05-30 02:00:00	NE1	Cape of Good Hope	
45	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	1	Singapore	PSA Singapore Terminal	2025-06-07 13:30:00	517E   517E	2025-06-08 18:30:00	NE1	Cape of Good Hope	
46	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	1	Ningbo	Ningbo Meishan Terminal	2025-06-14 03:30:00	517E   517E	2025-06-16 02:30:00	NE1	Cape of Good Hope	
47	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	Shanghai		YANGSHAN SGH GUANDONG TERMINAL	2025-06-17 20:00:00	517E   517E	2025-06-19 14:00:00	NE1	Cape of Good Hope	
48	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	Shanghai		YANGSHAN SGH GUANDONG TERMINAL	2025-06-24 20:00:00	526W   526W	2025-06-26 14:00:00	NE1	Cape of Good Hope	
49	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	Yantian		YanTian Intl. Container Terminal	2025-06-30 01:00:00	526W   526W	2025-07-01 16:30:00	NE1	Cape of Good Hope	
50	TIHAMA	18800	2015	9736107	DGLM		Germany (DE)	Tanjung Pelepas		Peabuhan Tanjung Pelepas Terminal	2025-07-06 03:00:00	526W   526W	2025-07-07 12:00:00	NE1	Cape of Good Hope	
51	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Ningbo	Ningbo Meishan Terminal	2025-03-02 02:00:00	510W   510W	2025-03-03 17:30:00	NE1	Cape of Good Hope	
52	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-03-05 03:48:00	510W   510W	2025-03-06 13:27:00	NE1	Cape of Good Hope	
53	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Tanjung Pelepas	Peabuhan Tanjung Pelepas Terminal	2025-03-12 19:26:00	510W   510W	2025-03-14 07:01:00	NE1	Cape of Good Hope	
54	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Port Tanjung Mediterranean	Port Tanjung Mediterranean	2025-04-08 16:00:00	510W   510W	2025-04-09 08:00:00	NE1	Cape of Good Hope	
55	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Port Tanjung Mediterranean	TC3 Tanger Alliance Terminal	2025-04-09 14:30:00	510W   510W	2025-04-10 08:30:00	NE1	Cape of Good Hope	
56	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Wilhelmshaven	Wilhelmshaven Eurogate CT	2025-04-15 14:00:00	516E   516E	2025-04-18 22:00:00	NE1	Cape of Good Hope	
57	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Bremerhaven	NTB North Sea Terminal Bremerhaven	2025-04-21 01:00:00	510W   516E	2025-04-23 03:00:00	NE1	Cape of Good Hope	
58	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Rotterdam	APM 2 Terminal Maasvlakte II	2025-04-24 15:00:00	510W   516E	2025-04-25 15:00:00	NE1	Cape of Good Hope	
59	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Salalah	Salalah Terminal	2025-05-21 13:30:00	516E   516E	2025-05-23 02:00:00	NE1	Cape of Good Hope	
60	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Singapore	PSA Singapore Terminal	2025-05-31 13:30:00	516E   516E	2025-06-01 18:30:00	NE1	Cape of Good Hope	
61	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	1	Ningbo	Ningbo Meishan Terminal	2025-06-07 03:30:00	516E   516E	2025-06-09 02:30:00	NE1	Cape of Good Hope	
62	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	Shanghai		YANGSHAN SGH GUANDONG TERMINAL	2025-06-10 20:00:00	516E   524W	2025-06-12 14:00:00	NE1	Cape of Good Hope	
63	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	Yantian		YanTian Intl. Container Terminal	2025-06-16 01:00:00	524W   524W	2025-06-17 16:30:00	NE1	Cape of Good Hope	
64	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	Tanjung Pelepas		Peabuhan Tanjung Pelepas Terminal	2025-06-22 03:00:00	524W   524W	2025-06-23 12:00:00	NE1	Cape of Good Hope	
65	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	Rotterdam		APM 2 Terminal Maasvlakte II	2025-07-21 12:00:00	524W   530E	2025-07-23 04:00:00	NE1	Cape of Good Hope	
66	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	Hamburg		Eurogate Container Terminal Hamburg	2025-07-24 23:00:00	524W   530E	2025-07-26 15:00:00	NE1	Cape of Good Hope	
67	BARZAN	18800	2014	9708851	DDAS2		Germany (DE)	London Gateway		London Gateway Terminal	2025-07-29 13:00:00	524W   530E	2025-07-30 23:00:00	NE1	Cape of Good Hope	
68	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Ningbo	Ningbo Meishan Terminal	2025-02-21 23:21:00	509W   509W	2025-02-23 18:51:00	NE1	Cape of Good Hope	
69	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-02-25 13:39:00	509W   509W	2025-02-26 20:21:00	NE1	Cape of Good Hope	
70	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Tanjung Pelepas	Peabuhan Tanjung Pelepas Terminal	2025-03-05 21:28:00	509W   509W	2025-03-07 04:47:00	NE1	Cape of Good Hope	
71	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Port Tanjung Mediterranean	Port Tanjung Mediterranean	2025-04-01 16:00:00	509W   509W	2025-04-02 08:00:00	NE1	Cape of Good Hope	
72	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Port Tanjung Mediterranean	TC3 Tanger Alliance Terminal	2025-04-02 14:30:00	509W   509W	2025-04-03 08:30:00	NE1	Cape of Good Hope	
73	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Wilhelmshaven	Wilhelmshaven Eurogate CT	2025-04-08 14:00:00	509W   515E	2025-04-11 22:00:00	NE1	Cape of Good Hope	
74	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Bremerhaven	NTB North Sea Terminal Bremerhaven	2025-04-13 19:30:00	509W   515E	2025-04-15 21:30:00	NE1	Cape of Good Hope	
75	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Rotterdam	APM 2 Terminal Maasvlakte II	2025-04-17 15:00:00	509W   515E	2025-04-18 15:00:00	NE1	Cape of Good Hope	
76	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Salalah	Salalah Terminal	2025-05-14 20:00:00	515E   515E	2025-05-16 02:00:00	NE1	Cape of Good Hope	
77	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Singapore	PSA Singapore Terminal	2025-05-24 13:30:00	515E   515E	2025-05-25 18:30:00	NE1	Cape of Good Hope	
78	BANGKOK EXPRESS	23664		9943889	DDIT2			1	Ningbo	Ningbo Meishan Terminal	2025-05-31 03:30:00	515E   523W	2025-06-02 02:30:00	NE1	Cape of Good Hope	
79	BANGKOK EXPRESS	23664		9943889	DDIT2			2	Ningbo	Ningbo Meishan Terminal	2025-05-31 03:30:00	515E   523W	2025-06-02 02:30:00	NE1	Cape of Good Hope	
80	BANGKOK EXPRESS	23664		9943889	DDIT2			2	Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-06-03 17:00:00	515E   523W	2025-06-05 11:00:00	NE1	Cape of Good Hope	

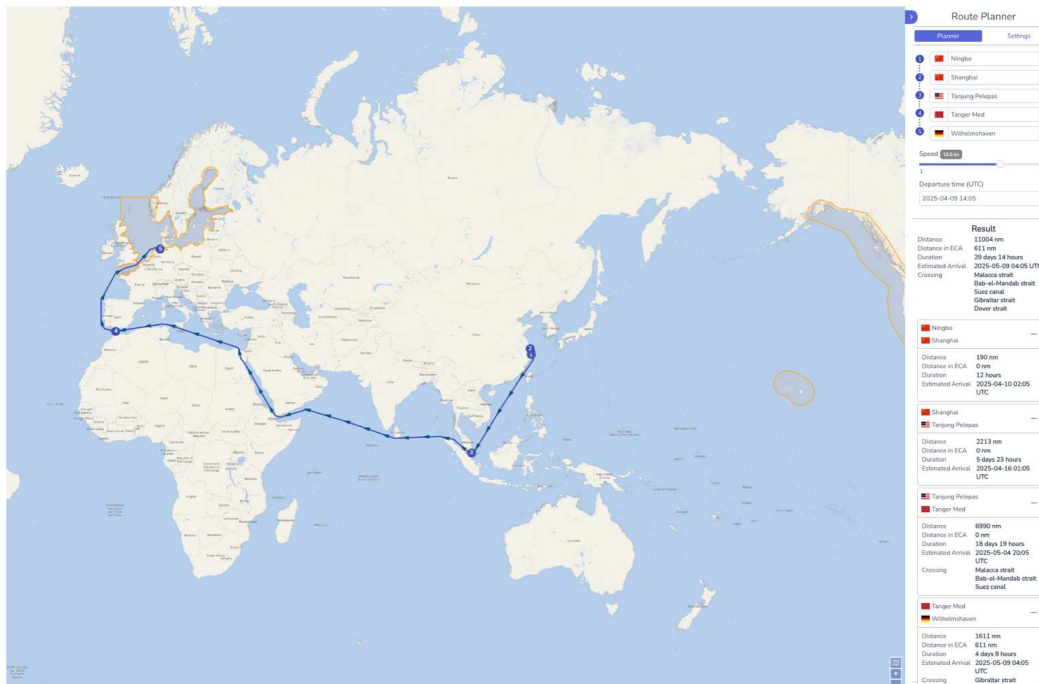
Q11	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
81	BANGKOK EXPRESS	23664	2023	9943889 DDIT2				2 Tanjung Pelepas	2 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-06-11 20:00:00	523W   523W	2025-06-12 23:00:00	NE1	Cape of Good Hope	
82	BANGKOK EXPRESS	23664	2023	9943889 DDIT2				2 Port Tangier Meditterraanee	2 Port Tangier Meditterraanee	Port Tangier Meditterraanee	2025-07-08 16:00:00	523W   523W	2025-07-09 08:00:00	NE1	Cape of Good Hope	
83	BANGKOK EXPRESS	23664	2023	9943889 DDIT2				2 Wilhelmsshaven	2 Wilhelmsshaven	Wilhelmsshaven Eurogate CT	2025-07-09 14:30:00	523W   523W	2025-07-10 08:30:00	NE1	Cape of Good Hope	
84	BANGKOK EXPRESS	23664	2023	9943889 DDIT2				2 Bremerhaven	2 Bremerhaven	NTB North Sea Terminal Bremerhaven	2025-07-15 14:00:00	523W   529E	2025-07-18 22:00:00	NE1	Cape of Good Hope	
85	BANGKOK EXPRESS	23664	2023	9943889 DDIT2				2 Rotterdam	2 Rotterdam	APM 2 Terminal Maasvlakte II	2025-07-20 19:30:00	523W   529E	2025-07-22 21:30:00	NE1	Cape of Good Hope	
86	BANGKOK EXPRESS	23664	2023	9943889 DDIT2			Germany (DE)	1 Ningbo	1 Ningbo	NINGBO MEISHAN TERMINAL	2025-07-24 15:00:00	523W   508W	2025-07-25 15:00:00	NE1	Cape of Good Hope	
87	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Shanghai	1 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-02-17 22:41:00	508W   508W	2025-02-18 23:32:00	NE1	Cape of Good Hope	
88	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Tanjung Pelepas	1 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-02-26 15:40:00	508W   508W	2025-02-27 23:34:00	NE1	Cape of Good Hope	
89	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Port Tangier Meditterraanee	1 Port Tangier Meditterraanee	Port Tangier Meditterraanee	2025-03-25 14:00:00	508W   508W	2025-03-26 12:00:00	NE1	Cape of Good Hope	
90	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Port Tangier Meditterraanee	1 Port Tangier Meditterraanee	TC3 Tangier Alliance Terminal	2025-03-26 14:30:00	508W   508W	2025-03-27 08:30:00	NE1	Cape of Good Hope	
91	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Wilhelmsshaven	1 Wilhelmsshaven	Wilhelmsshaven Eurogate CT	2025-04-01 14:00:00	508W   514E	2025-04-04 22:00:00	NE1	Cape of Good Hope	
92	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Bremerhaven	1 Bremerhaven	NTB North Sea Terminal Bremerhaven	2025-04-06 19:30:00	508W   514E	2025-04-08 21:30:00	NE1	Cape of Good Hope	
93	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Rotterdam	1 Rotterdam	APM 2 Terminal Maasvlakte II	2025-04-10 15:00:00	508W   514E	2025-04-11 15:00:00	NE1	Cape of Good Hope	
94	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Salalah	1 Salalah	Salalah Terminal	2025-05-07 20:00:00	514E   514E	2025-05-09 02:00:00	NE1	Cape of Good Hope	
95	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Singapore	1 Singapore	PSA Singapore Terminal	2025-05-17 13:30:00	514E   514E	2025-05-18 18:30:00	NE1	Cape of Good Hope	
96	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	1 Ningbo	1 Ningbo	Ningbo Meishan Terminal	2025-05-24 03:30:00	514E   522W	2025-05-26 02:30:00	NE1	Cape of Good Hope	
97	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	2 Ningbo	2 Ningbo	Ningbo Meishan Terminal	2025-05-24 03:30:00	514E   522W	2025-05-26 02:30:00	NE1	Cape of Good Hope	
98	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	2 Shanghai	2 Shanghai	YANGSHAN SGH GUANDONG TERMINAL	2025-05-27 17:00:00	514E   522W	2025-05-29 11:00:00	NE1	Cape of Good Hope	
99	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	2 Tanjung Pelepas	2 Tanjung Pelepas	Pelabuhan Tanjung Pelepas Terminal	2025-06-04 20:00:00	522W   522W	2025-06-05 23:00:00	NE1	Cape of Good Hope	
100	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	2 Port Tangier Meditterraanee	2 Port Tangier Meditterraanee	Port Tangier Meditterraanee	2025-07-01 16:00:00	522W   522W	2025-07-02 08:00:00	NE1	Cape of Good Hope	
101	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	2 Wilhelmsshaven	2 Wilhelmsshaven	Wilhelmsshaven Eurogate CT	2025-07-02 14:30:00	522W   522W	2025-07-03 08:30:00	NE1	Cape of Good Hope	
102	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	2 Bremerhaven	2 Bremerhaven	NTB North Sea Terminal Bremerhaven	2025-07-08 14:00:00	522W   528E	2025-07-11 22:00:00	NE1	Cape of Good Hope	
103	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)	2 Rotterdam	2 Rotterdam	APM 2 Terminal Maasvlakte II	2025-07-13 19:30:00	522W   528E	2025-07-15 21:30:00	NE1	Cape of Good Hope	
104	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2			Germany (DE)				2025-07-17 15:00:00	522W   528E	2025-07-18 15:00:00	NE1	Cape of Good Hope	
105	DAMIETTA EXPRESS	23664	2023	9543108 DFPD2												
106																
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## Appendix C: Route Distances

Source: VesselFinder. n.d. “Sea Distance Calculator and Route Planner.” Accessed April 9, 2025. <https://route.vesselfinder.com/>.

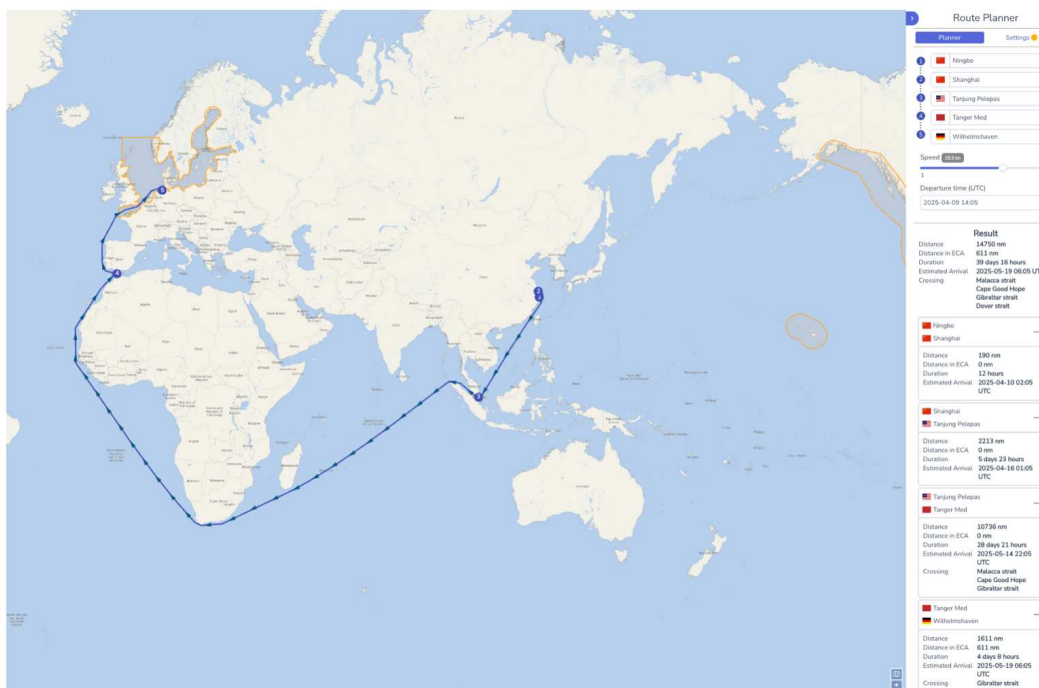
### NE1 via Suez Canal

Ningbo - Wilhelmshaven



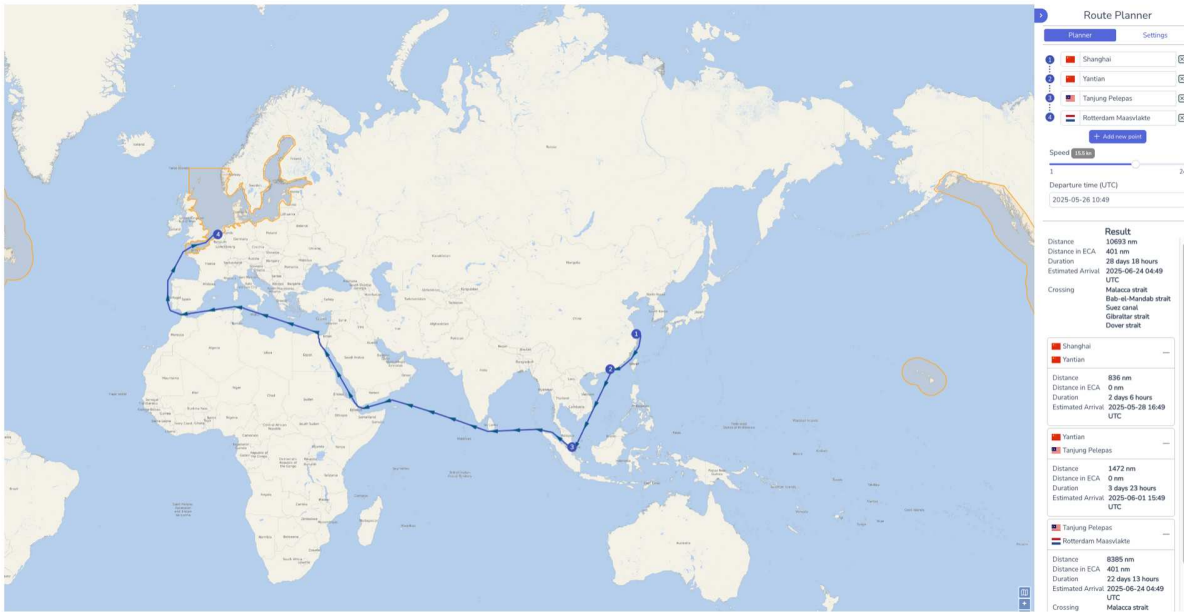
### NE1 via Cape of Good Hope

Ningbo - Wilhelmshaven



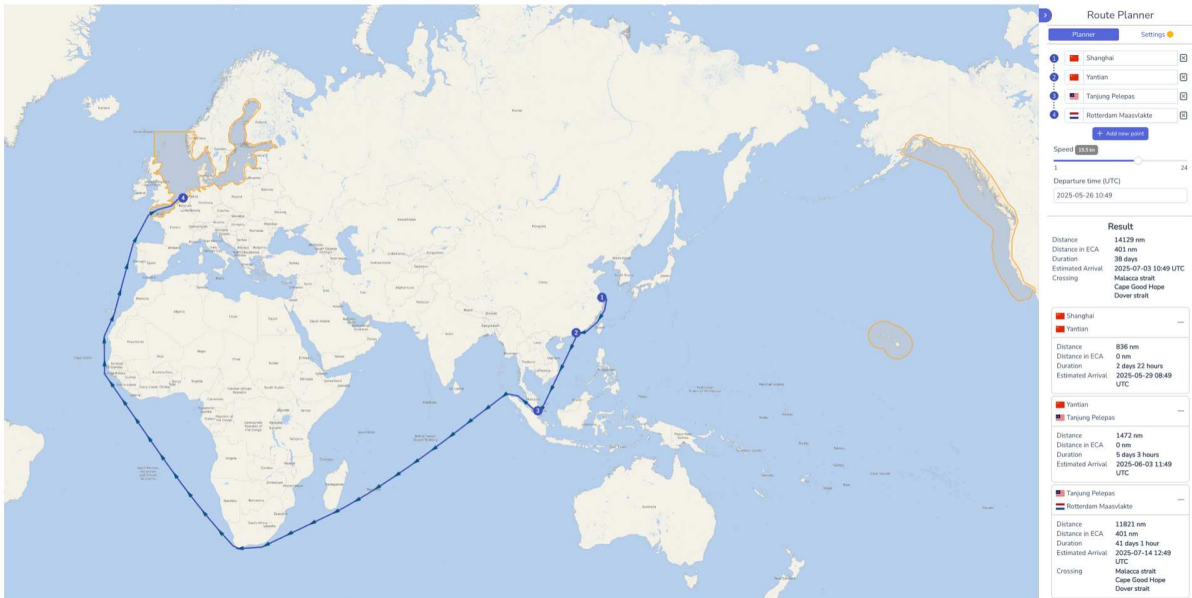
## NE2 via Suez Canal

Shanghai - Rotterdam



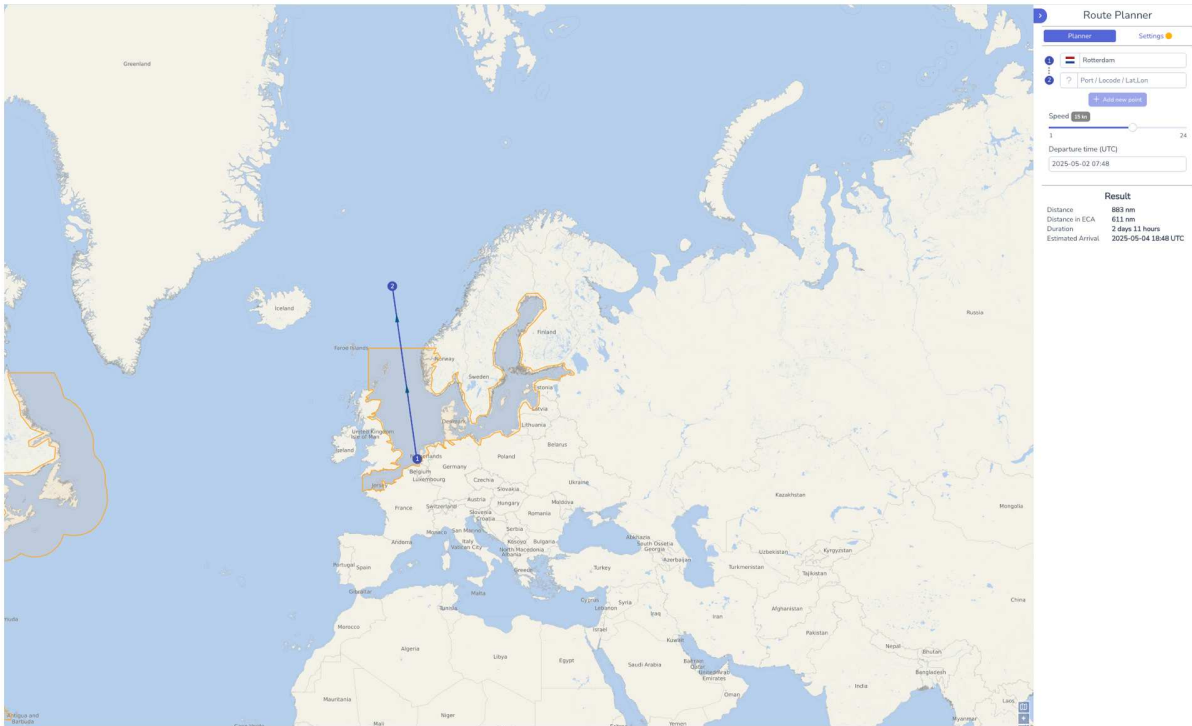
## NE2 via Cape of Good Hope

Shanghai - Hamburg

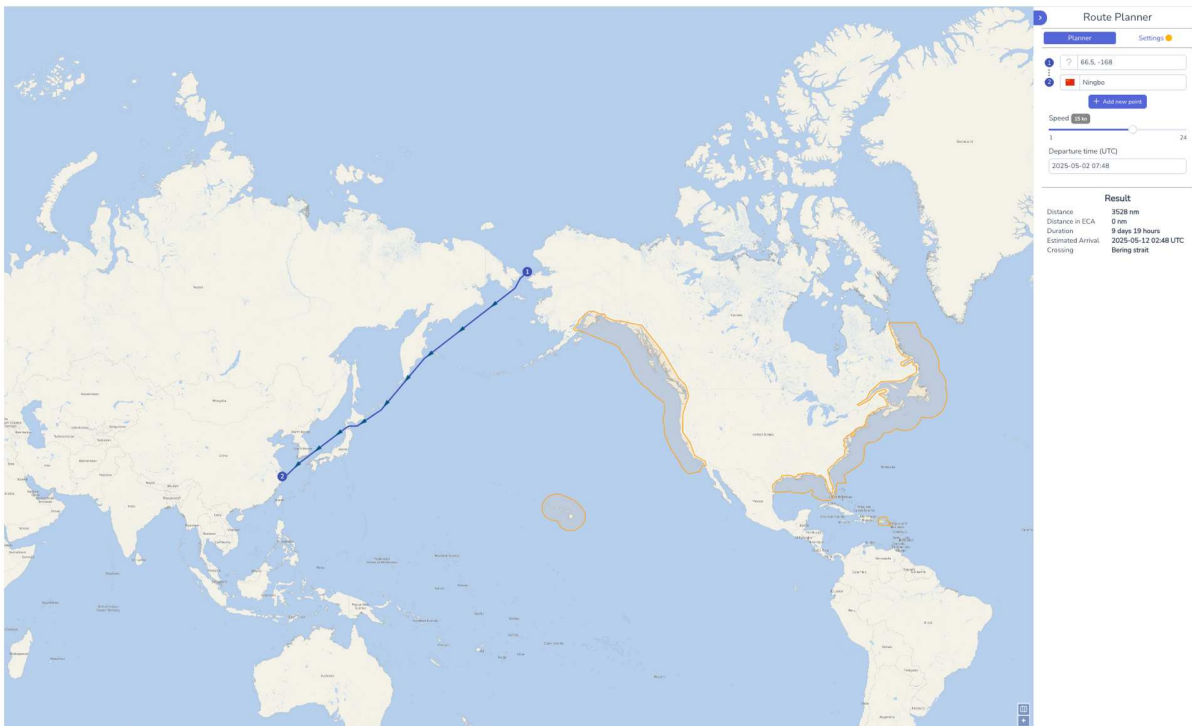


## Arctic Route

Rotterdam - Arctic Circle (66.5°N, 0.0°)



Arctic Circle (66.5°N, 168°W) - Ningbo



	A	B	C	D	E	F	G	H	I	J
1	<b>Service_Hapag</b>	<b>Route</b>	<b>Previous Port</b>	<b>Port</b>	<b>Distance (nautical miles)</b>					
2	NE2	Suez Canal	Shanghai	Yantian	836					
3	NE2	Suez Canal	Yantian	Tanjung Pelepas	1472					
4	NE2	Suez Canal	Tanjung Pelepas	Rotterdam	8385					
5	NE2	Cape of Good Hope	Shanghai	Yantian	836					
6	NE2	Cape of Good Hope	Yantian	Tanjung Pelepas	1472					
7	NE2	Cape of Good Hope	Tanjung Pelepas	Rotterdam	11821					
8	NE1	Suez Canal	Ningbo	Shanghai	190					
9	NE1	Suez Canal	Shanghai	Tanjung Pelepas	2213					
10	NE1	Suez Canal	Tanjung Pelepas	Tanger Med	6990					
11	NE1	Suez Canal	Tanger Med	Wilhelmshaven	1611					
12	NE1	Cape of Good Hope	Ningbo	Shanghai	190					
13	NE1	Cape of Good Hope	Shanghai	Tanjung Pelepas	2213					
14	NE1	Cape of Good Hope	Tanjung Pelepas	Tanger Med	10736					
15	NE1	Cape of Good Hope	Tanger Med	Wilhelmshaven	1611					
16										
17										
18										
19										
20										
21										
22										
23										
24										

## Appendix D: World Bunker Prices

Source: Ship & Bunker. n.d. “Average Bunker Prices.” Accessed April 15, 2025.  
<https://shipandbunker.com/prices/av>.

Prices quoted in USD/metric tonne

The screenshot displays the 'Average Bunker Prices' page on the Ship & Bunker website. The page features a navigation menu with 'home', 'news & features', 'bunker prices', 'eu-ets', and 'bunker intelligence'. The main content area is titled 'Average Bunker Prices' and includes sub-sections for 'Global Average Bunker Prices' and 'Regional Average Bunker Prices'. The 'Global Average Bunker Prices' table lists prices for VLSFO, MGO, IFO380, and BIO across different port averages. The 'Regional Average Bunker Prices' table lists prices for VLSFO, MGO, IFO380, and BIO for Americas, APAC, and EMEA regions. A sidebar on the right contains a 'Click to Learn More' button and a 'Popular News Now' section with a headline about IMO 2028 costs.

Port Name	VLSFO	MGO	IFO380	BIO	
Global 20 Ports Average	523.00 ▲ 2.00	704.00 ▲ 4.00	457.50 ▲ 8.00	-	Apr 14
Global 4 Ports Average	475.50 ▲ 7.00	638.00 ▲ 8.00	421.00 ▲ 11.00	751.50 ▲ 4.50	Apr 14
Global Average Bunker Price	563.50 ▼ 8.50	740.00 ▼ 7.50	468.50 ▲ 2.50	-	Apr 14

Port Name	VLSFO	MGO	IFO380	BIO	
Americas Average	595.50 ▼ 8.50	784.50 ▼ 22.00	492.50 ▼ 3.00	-	Apr 14
APAC Average	572.50 ▲ 1.00	740.50 ▼ 8.50	463.00 ▲ 1.00	-	Apr 14
EMEA Average	527.50 ▲ 4.00	697.50 ▼ 1.00	454.50 ▲ 8.00	-	Apr 14

## Appendix E: Fuel Consumption Calculation Schema

Source: OpenAI. 2025. ChatGPT (May 21 version). <https://chat.openai.com/chat>.

Calculation of a given vessel's fuel consumption, based on company vessel data

Exemplary vessel specifics input (Hapag-Lloyd 2024c; Port of Hamburg .d.; Remontowa n.d.):

### Damietta Express

Specification	Value
Nominal intake (TEU)	23664
Reefer plugs	1500
Deadweight (t)	229348
Gross tonnage	229376
Length (m)	399
Breadth (m)	61
Speed (kn)	20.5
Max. power (kW)	58270
Year built	2024
Port of registry	Hamburg
Flag	Germany
IMO number	9543108
Call sign	DFPD2

Prompt: “Give me a a calculation schema for the fuel consumption calculation based on the vessel specifics and assumed speed of 15.45 knots. Give me also all the assumptions you make.”

Output:

#### Step-by-Step Calculation

##### 1. Estimate Power at Design Speed

$$P_{\text{service}} = 0.85 \times \text{MCR} = 0.85 \times 58,270 = 49,530 \text{ kW}$$

## 2. Scale Power to 15.45 knots

Using the cubic speed–power relationship:

$$\left(\frac{15.45}{20.5}\right)^3 = 0.7537^3 \approx 0.428$$

$$P_{15.45} = 49,530 \times 0.428 = \mathbf{21,210 \text{ kW}}$$

## 3. Estimate Hourly Fuel Consumption

$$\text{Fuel/hour} = 21,210 \times 165 = 3,499,650 \text{ g/h} = \mathbf{3.50 \text{ t/h}}$$

## 4. Estimate Daily Fuel Consumption

$$\text{Fuel/day} = 3.50 \times 24 = \mathbf{84.0 \text{ t/day}}$$

---

### Result

At an assumed speed of **15.45 knots**, the **Damietta Express** is estimated to consume:

- **≈ 3.50 tonnes per hour**
- **≈ 84.0 tonnes per day**

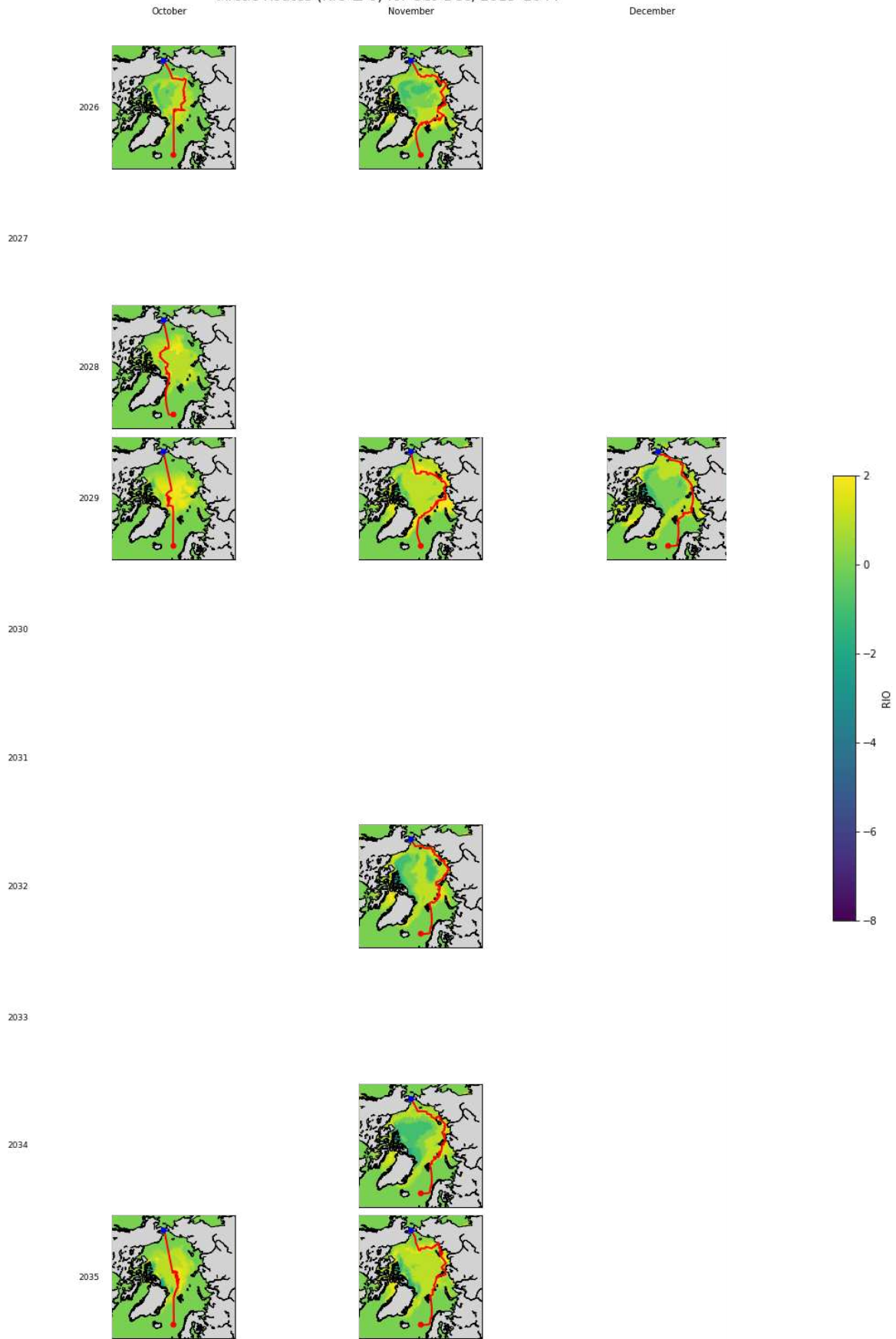
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### Assumptions

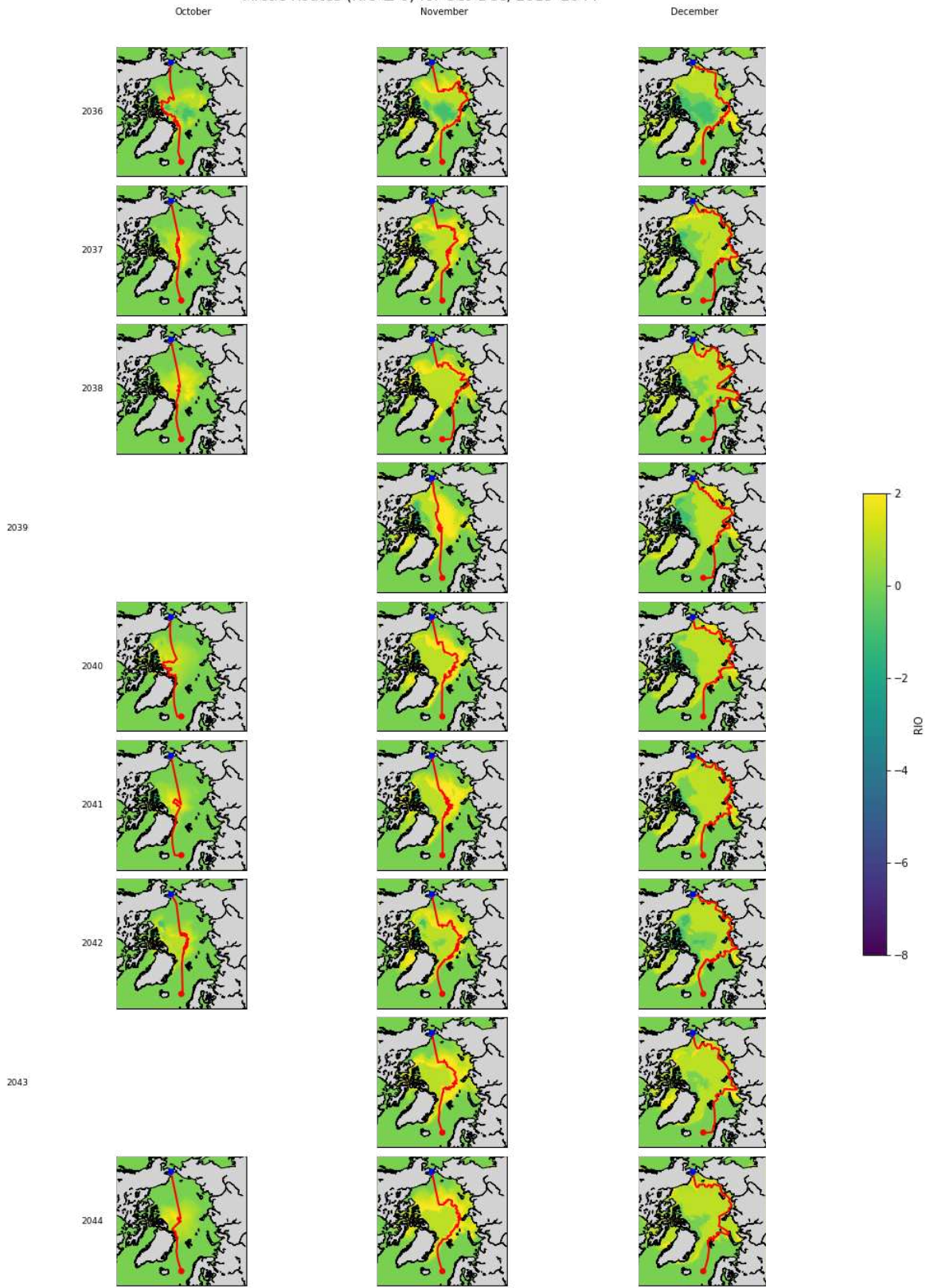
- Engine operates at 85% MCR at design speed
- Power demand scales with the cube of speed
- SFOC = 165 g/kWh (typical for large 2-stroke marine diesel engines)
- Vessel operates in normal weather (no current or wind effects)
- Hull and propeller are clean (no fouling)
- Fuel type: Heavy Fuel Oil (HFO) or VLSFO
- Load condition: average (not ballast or max deadweight)



Arctic Routes (RIO  $\geq 0$ ) for Oct-Dec, 2015-2044

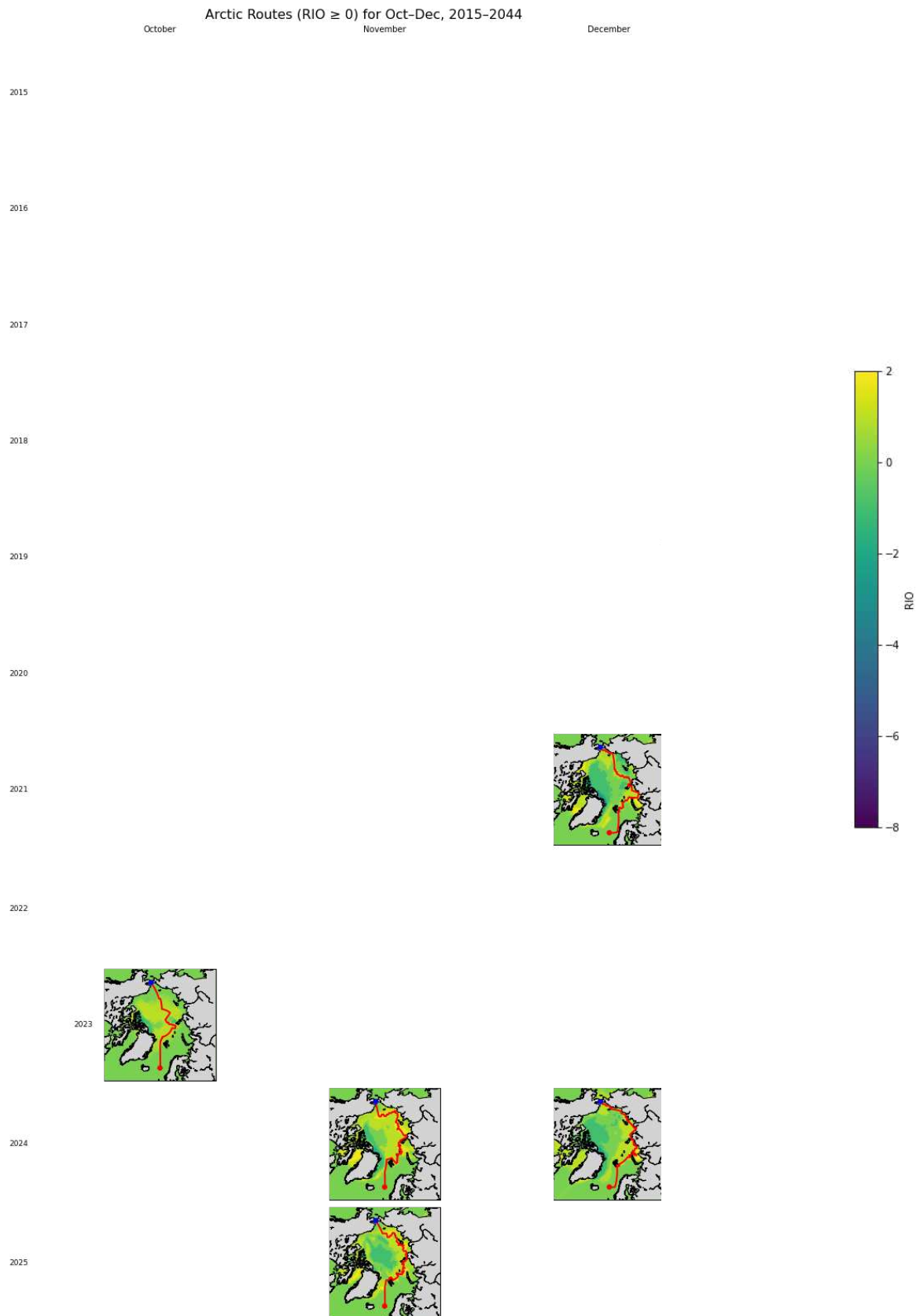


Arctic Routes (RIO  $\geq 0$ ) for Oct-Dec, 2015-2044



# Appendix G: Viable Paths for PC6 (2015-2044) under SSP5-8.5

Source: Own Illustration



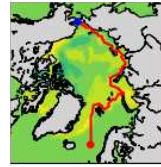
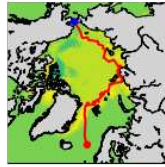
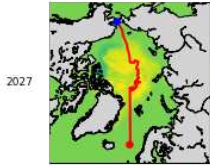
Arctic Routes (RIO  $\geq 0$ ) for Oct-Dec, 2015-2044

October

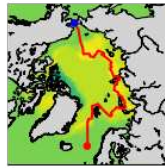
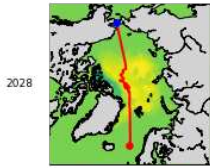
November

December

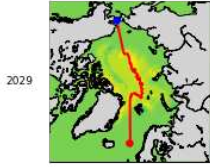
2026



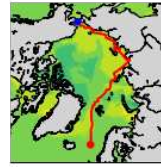
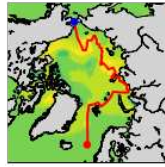
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2028

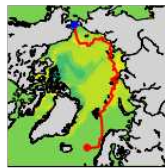
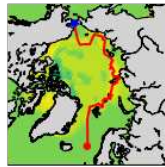


2030

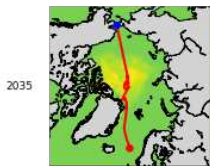
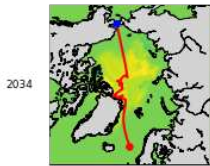


2031

2032



2033



2035

