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Reviewing the Role and Effectiveness of Wind-Assisted Ship Propulsion Technology in the Maritime Industry's Decarbonization efforts

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by

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Executive Summary

This thesis explores the role and effectiveness of WASP technology in decarbonizing the maritime industry, which contributes about 3 percent of global greenhouse gas emissions. The study evaluates if WASP can enhance decarbonization efficiency and serve as a cost-effective investment tool for shipping companies. Based on a comprehensive literature review and interviews with industry experts, including a Decarbonization Specialist, a Ship Performance Manager, and a Founder and Managing Director of a shipping company, the study provides insights into the operational, financial, and regulatory aspects of WASP technologies.

Findings indicate that WASP technologies can achieve significant fuel savings, translating into substantial reductions in GHG emissions. This helps companies comply with regulations like the CII. Despite high initial installation costs and complexities, long payback periods, and variable wind efficiency, the long-term benefits justify the investment. These benefits include fuel savings, operational savings, and compliance with increasingly strict environmental regulations. As technology advances and production scales up, costs are expected to decrease, enhancing financial viability.

The study recommends early investment in WASP technologies and implementing flexible financial models like leasing or rental agreements to reduce upfront costs. WASP should be part of a broader decarbonization strategy, including alternative fuels, advanced hull designs, and operational optimizations. Continued collaboration among industry stakeholders, technology providers, and regulatory bodies is essential for technological improvements and confidence in WASP investments.

Effective regulatory frameworks are crucial for promoting WASP adoption. Policies like the EU ETS and compliance credits can offset initial costs and provide financial incentives. Well-designed regulations are needed to create a level playing field and encourage widespread adoption.

In conclusion, WASP technologies offer a promising solution for reducing the maritime industry's carbon footprint. Strategic integration of these technologies, supported by regulatory incentives and industry collaboration, can significantly enhance environmental and economic performance. Investing in WASP aligns with global decarbonization goals and positions companies to thrive in a future focused on sustainability. This report underscores the transformative potential of WASP technologies, making it an essential reading for stakeholders committed to a greener future.

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List of Abbreviations

BIMCO: Baltic and International Maritime Council

CAPEX: Capital Expenditures

CEO: Chief Executive Officer

CII: Carbon Intensity Indicator

CO2: Carbon Dioxide

DCS: Data Collection System

EEDI: Energy Efficiency Design Index

EEXI: Energy Efficiency Existing Ship Index

ESG: Environmental, Social ang Governance

EUA: EU Allowance

EU ETS: European Union Emissions Trading System

GHG: Greenhouse Gas

GT: Gross Tonnage

HFO: Heavy Fuel Oil

IAPP: International Air Pollution Plan

IMO: International Maritime Organization

LNG: Liquid Natural Gas

MRV: Monitoring, Reporting, and Verification

MT: Metric Ton

NGO: Non-Governmental Organization

OPEX: Operating Expenditures

ROI: Return on Investment

RoPax: Roll-on / Roll-off Passenger

Ro-Ro: Roll-on / Roll-off

SEEMP: Ship Energy Efficiency Management Plan

VGP: Vessel General Permit

WASP: Wind-Assisted Ship Propulsion

W.A.V.E: Wind, Activity, Vessel optimization, Eco-Fuel

1. Introduction

Within the intricate web of global trade, a pressing challenge unfolds – Greenhouse gas emissions. This problem concerns the whole planet due to its negative effects on the environment and climate change.

The shipping industry remains vital today as it is responsible for almost 90 percent of global trade and has an enormous impact on the global economy. (ShipFinex 2023) In 2021, the volume of goods transported by sea was approximately 11 billion metric tons, compared to 4 billion metric tons in 1990. (Porwal 2023) In 2022, the international shipping industry alone accounted for approximately 3 percent of the world's greenhouse gas emissions. (Sinay SAS 2023) These values show how essential this industry is to the world population.

The current challenge for this industry is to find a way to sustain operations and facilitate expansion, concurrently reducing carbon emissions and achieving greater carbon neutrality over time, all while maintaining profitability.

Motivated by the imperative to address the pressing challenges posed by carbon emissions in the maritime industry, I embarked on an exploration fueled by comprehensive research and immersion in diverse articles on the subject, as the importance of mitigating carbon emissions in this sector has become evident. I strongly believe that investigating potential solutions is necessary in this industry. The decrease in carbon emissions is and will be a priority in this industry.

There are benefits and challenges with wind-assisted ship propulsion (WASP) systems. The main benefits are the fact that wind is free and predictable, that it is a sustainable source of energy, that these systems have a great impact on energy efficiency, no extended crew is needed, and systems can be retrofitted or tailored to new buildings for greater efficiency. (DNV AS 2023a)

On the other hand, the challenges are that operational experience with these new technologies is still developing, and they are not suitable for all ship segments due to the need for deck space (more complicated for container ships). Also, benefits are not equal across ships, fast-moving ships might see limited gains from wind power. On some routes, conditions may not be reliable enough, while in some ports, bridges and other structures may impact the installation of the systems. (DNV AS 2023a)

Nowadays, a lot of effort is being put into the decarbonization of this industry, from shipping companies to international organizations creating new regulations and norms to incentivize it. There are short-term, mid-term, and long-term solutions that could serve the decarbonization cause. Short-term measures would be speed optimization or reduction for energy efficiency improvement, mid-term solutions would involve alternative fuels, and long-term measures would concentrate on the development of new technologies such as engine technologies, wind propulsion technologies, operational systems, and carbon-neutral and fossil-free fuels. (Rauca, Batrinca 2023) (Tadros, Ventura, Soares 2023) (Bouman et al. 2017)

This research aims to thoroughly understand the role of WASP technology in the maritime industry's decarbonization efforts and to evaluate its effectiveness. A key objective is to explore not only the benefits but also the barriers hindering the widespread adoption of WASP technology. The study will include an analysis of tangible measures, such as emission reductions and fuel savings, to quantify the positive impacts of WASP technology. This approach will offer strategic insights for businesses in the shipping sector, aiding them in implementing sustainable and economically viable initiatives. The Carbon Intensity Indicator (CII) being new makes it more interesting because the first annual reporting will be made in 2023 with the first ratings given in 2024. (Washington 2022)

My research is therefore focused on reviewing the role and effectiveness of WASP technology in the maritime industry's decarbonization efforts. It examines the impact of WASP both in the short-term and long-term, analyzing the challenges and potential synergies involved. The study also explores strategic investment planning in the shipping industry, particularly how regulations such as the CII, EEXI, and the EU ETS influence the adoption of WASP technology. To gather comprehensive insights, interviews with industry experts will be conducted, providing valuable information on operational, financial, and regulatory aspects. This research aims to shed light on how WASP technology can contribute to meeting strict environmental regulations and achieving sustainable maritime operations.

To what extent does the implementation of wind-assisted ship propulsion technology not only improve the decarbonization efficiency of ships but also prove to be a cost-effective investment tool in strategic planning for sustainable and economical initiatives for shipping companies? What are the main barriers preventing shipping companies from investing in wind-assisted ship propulsion technology?

2. Literature review

2.1 Regulations

The shipping industry plays a crucial role in global trade, but its operations contribute significantly to greenhouse gas emissions. To address this issue, regulations have been and are being put in place.

The International Maritime Organization (IMO), a United Nations specialized agency responsible for safe, secure and efficient shipping and the prevention of pollution from ships has developed a new measure allowing the comparison of a ship's emissions to the benefits it provides to society called the CII (Carbon Intensity Indicator) that will provide a rating system to grade ships (cargo and passenger vessels) on how much air pollution they are responsible for. (Nautilus Shipping 2023) (IMO 2019)

Regulations, such as the CII, act as powerful drivers for change. They create rules that make sure everyone involved takes responsibility for how their actions affect the environment. These rules also give a standard way to compare and get a better understanding of how well the players are doing. In the maritime industry, where it's tough to balance profit-making and eco-friendliness, strong regulations are like essential signs that show the way toward a future where being green and making a profit go hand in hand.

In addition to the Carbon Intensity Indicator (CII), several other crucial regulations shape the landscape of environmental responsibility in the maritime industry, including the Energy Efficiency Existing Ship Index (EEXI), Energy Efficiency Design Index (EEDI), and the European Union Emissions Trading System (EU ETS). (IMO 2019) This study will comprehensively examine and analyze the impact of these key regulations on the maritime industry's journey toward environmental sustainability.

National regulations complement the standards set by the IMO, serving to address localized environmental concerns within individual countries. These regulations vary in their strictness, with some nations imposing more rigorous requirements than those outlined by the IMO. This variation poses a challenge for shipping companies operating internationally, as they must navigate and adhere to the diverse regulatory frameworks of each country they operate in. (Mirlo 2023)

Consequently, this can result in increased operational costs and administrative burdens. For instance, regulations like the European Union's Monitoring, Reporting, and Verification (MRV) regulation, the United States' Vessel General Permit (VGP), and

China's National Marine Environmental Protection Law exemplify such mandates. These regulations mandate that shipping companies monitor, report, and verify their emissions, particularly focusing on Carbon dioxide (CO2) emissions, while also encouraging the adoption of sustainable practices to mitigate environmental impact. Through these measures, national regulations contribute to a comprehensive approach to environmental responsibility within the shipping industry. (Mirlo 2023)

2.1.1 International Maritime Organization (IMO) Regulations

The International Maritime Organization (IMO) is responsible for the introduction of regulations for decarbonization in the maritime industry, putting in place a strategy on reduction of GHG emissions from ships. The 2023 IMO strategy on reduction of GHG emissions from ships illustrates all the organizations goals, visions and overall strategy to battle pollution in this industry. (IMO GHG Strategy 2023)

The 2023 IMO GHG strategy outlines four levels of ambition for decarbonizing international shipping. Firstly, it aims to improve energy efficiency in new ships by reviewing and potentially strengthening design requirements. Secondly, it targets a 40% reduction in average CO2 emissions per transport work by 2030 compared to 2008. Thirdly, it calls for at least 5% (with a striving goal of 10%) of international shipping’s energy to come from zero or near-zero emission sources by 2030. Finally, it seeks to peak GHG emissions as soon as possible and achieve net-zero by or around 2050, ultimately aiming for a complete phase-out aligned with the Paris Agreement’s temperature goals. (IMO GHG Strategy 2023)

It establishes indicative checkpoints serving as stepping stones towards net-zero emissions. By 2030, the strategy ambitiously aims to reduce total annual GHG emissions from international shipping by at least 20%, striving for a more aggressive 30% reduction compared to 2008 levels. This ambition further intensifies by 2040, targeting a minimum of 70%, striving for an even more impactful 80% reduction when compared to the 2008 baseline. These incremental yet significant targets serve as crucial milestones on the path towards achieving net-zero emissions in the maritime industry. (IMO GHG Strategy 2023)

Building upon the exploration of wind-assisted ship propulsion technology, this section dives into the regulatory context. Regulations such as the Carbon Intensity Indicator, the Energy Efficiency Existing Ship Index (EEXI), and EU ETS create both pressure and opportunities for shipping companies to reduce emissions. We will analyze how these regulations interact with WASP technology, assessing its potential as a compliance strategy and a cost-effective investment.

2.1.1.1 The Carbon Intensity Indicator (CII)

As the maritime industry navigates the critical path towards decarbonization, the Carbon Intensity Indicator (CII) emerges as a game-changer. Launched in 2023, this unique regulatory tool transcends mere emissions tracking, instead measuring a ship's "pollution capability" while considering the societal benefit of cargo transport. (Nautilus Shipping 2023)

The CII system takes a retrospective approach, judging ships based on their emissions from the previous year. This means the first ratings, issued in 2024, will assess a ship's environmental impact throughout 2023. (CLARKSONS PLC 2024)

This measure impacts all cargo, RoPax (roll-on/roll-off passenger) and cruise vessels above 5000 gross tonnage and trading internationally. By March 31st of each year, ships must report their annual CII performance to their flag administration or authorized representative. (Lloyd's Register Group Services Limited 2024a)

The goal is to increase the carbon reduction factor yearly to force constant progress and lower emissions. If progress isn't made from one year to another, a vessel might get downgraded and face penalties, even though there is currently no direct penalty linked to the CII rating to ensure the implementation effect. (Nautilus Shipping 2023) (Sun et al. 2023)

The CII will provide a rating system that will grade ships based on how much air pollution they are responsible for, allowing to identify more efficient vessels from lesser ones. The ratings will be from A (Major Superior performance level) to E (Inferior performance level), with C and above being considered as acceptable levels. This system will allow to create incentives for the best-performing ships and encourage the others to reach a higher ranking. (Nautilus Shipping 2023)

The ratings will be classified as such: (Nautilus Shipping 2023)

- **A** – Major superior performance level
- **B** – Minor superior performance level
- **C** – Moderate performance level
- **D** – Minor inferior performance level
- **E** – Inferior performance level

Effective 2024, ships must calculate and report their CII alongside the previous year's aggregated Data Collection System (DCS) data to the designated verifier. Any correction factors and voyage adjustments should also be included. The deadline for both DCS and CII remains unchanged, falling on March 31st annually. The ship's attained annual CII and its corresponding environmental rating (A to E) will be displayed on the DCS Statement of Compliance (SoC) and must be kept onboard for five years. (DNV AS 2023b)

For vessels receiving a D rating for three consecutive years or a single E rating, updating the Ship Energy Efficiency Management Plan (SEEMP) Part III with a corrective action plan becomes mandatory before receiving the SoC. This plan should analyze the reasons behind the failure to achieve the required CII and propose a revised implementation strategy. (DNV AS 2023b)

The Ship Energy Efficiency Management Plan (SEEMP) is a structured, practical tool for helping shipowners manage their environmental performance and improve operational efficiency that was introduced by the IMO in 2013, and further enhanced in 2023. (DNV AS 2023c)

The simplified attained annual CII calculation formula is as follows:

Figure 1 – Simplified CII calculation (DNV AS 2023b)

2.1.1.2 *The Energy Efficiency Existing Ship Index (EEXI)*

The Energy Efficiency Existing Ship Index (EEXI) entered the scene in 2023. This technical measure targets existing international cargo and passenger vessels exceeding 400 GT, demanding they achieve a specific EEXI value by their next International Air Pollution Prevention (IAPP) survey renewal. It evaluates a ship's CO2 emissions per unit of cargo transported, ensuring minimum energy efficiency standards. While existing IAPP certificates have been around since 2009, the EEXI value marks a critical new requirement. (CLARKSONS PLC 2024)

It is a one-time certification targeting design parameters for existing ships such as bulk carriers, gas carriers, tankers, containerships, cargo vessels, LNG carriers, and cruise vessels. (Mister Sustainability 2024)

The EEXI is a measure of a ship's energy efficiency, benchmarked against the Energy Efficiency Design Index (EEDI) standard. Ships exceeding 400 gross tonnages must calculate their EEXI, aligning it with specific ship types and size thresholds. This calculation ensures that each ship's energy efficiency is at least at the minimum level set by the EEDI baseline. (IMO 2019)

Essentially, EEXI functions as a "report card" for existing ships, comparing their real-world energy efficiency against a predetermined baseline. This baseline mirrors the required EEDI for newly built vessels in 2023, ensuring a consistent standard across both new and existing fleets. (Bayraktar, Yuksel 2023)

To determine compliance, each ship's "attained EEXI" is calculated and compared to the "required EEXI" value. This comparison incorporates a "reduction factor," expressed as a percentage relative to the baseline EEDI, allowing for adjustments based on specific ship types and size groups. Crucially, for vessels exceeding 400 GT, this process must be undertaken using established values categorized by ship type and size. Ultimately, the EEXI framework ensures compliance by requiring each ship's attained EEXI to be lower than its corresponding required EEXI. (Bayraktar, Yuksel 2023)

Here are the original and simplified formulas for the EEXI calculation:

Figure 2 - EEXI formula (Bureau Veritas 2024)

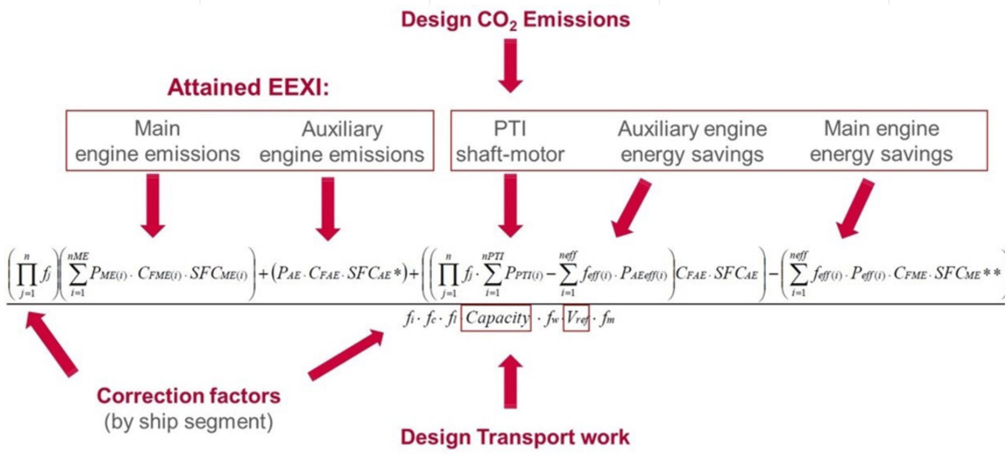


Figure 3 – EEXI simplified formula (Mister Sustainability 2024)

$$\text{EEXI} = \frac{CO_2 \text{ Emissions [gram]}}{\text{Transportation Work [ton * mile]}}$$

EEXI represents a significant step towards a greener maritime future, pushing existing ships to improve their energy efficiency and reduce carbon emissions. While challenges exist, the regulation serves as a crucial driver for innovation and investment in cleaner technologies, such as wind-assisted ship propulsion technology, paving the way for a more sustainable maritime industry.

2.1.2 Other relevant regulations

2.1.2.1 The European Union Emissions Trading System (EU ETS)

The EU Emissions Trading System (ETS) is a regulatory mechanism designed to reduce greenhouse gas emissions by implementing a cap-and-trade framework. This system imposes a limit, known as a cap, on GHG emissions within specific sectors of the economy. Annually, a finite number of EU Allowances (EUAs) are allocated for trading within the market. This allocation diminishes each year to align with the European Union's objective of reaching a 55% reduction in GHG emissions by 2030 compared to 1990, ultimately aiming for net zero emissions by 2050. Each EU allowance grants companies the privilege to emit GHG emissions equivalent to one metric ton of CO2, as per its global warming potential. (DNV AS 2024) (European Union 2024a)

Starting January 2024, the EU Emissions Trading System (EU ETS) will include CO2 emissions from large ships (over 5,000 gross tonnage) visiting EU ports, irrespective of their flag. The EU ETS applies to 50% of emissions from voyages starting or ending outside the EU, and 100% of emissions within EU ports and between EU ports. Initially covering CO2, it will also include methane and nitrous oxide emissions from 2026. This system, part of the EU's climate objectives, encourages energy efficiency and low-carbon solutions in maritime transport. Shipping companies must buy and surrender allowances for their emissions, with a phased approach from 2025 to 2027 for complete compliance. The system's effectiveness is monitored, with adjustments considered in line with developments at the International Maritime Organisation (IMO). (European Union 2024b)

By 2030, approximately 20 million allowances, valued at around EUR 1,6 billion at EUR 80 per allowance, are expected to be utilized. Failure by shipping companies to surrender allowances incurs a penalty of EUR 100 per ton of CO2 equivalent, adjusted for inflation. They remain liable for the surrender of the required allowances. These penalized companies are publicly disclosed. EU Member States are mandated to establish penalties that are effective, proportionate, and dissuasive. (European Union 2024c)

In anticipation of stricter emissions caps and rising prices for emissions allowances, shipping companies are likely to invest in innovative technologies, such as wind power, and clean fuels to mitigate increasing costs associated with greenhouse gas emissions. By minimizing compliance expenses, companies can enhance competitiveness and promote sustainable development. Participation in the EU ETS grants companies the flexibility to manage additional costs by either improving energy efficiency or purchasing emissions allowances from others. (Christodoulou, Cullinane 2023)

The implementation of the EU ETS in the maritime industry will benefit proactive companies by allowing them to sell surplus emissions allowances to less environmentally conscious companies, generating additional revenue. For businesses like ship owners or ship operators, it is crucial to consider that the return on investment and payback period are as important as the decrease in carbon emissions. (BAR Technologies Ltd 2023)

Initially, the costs of emission reduction measures implemented by shipping companies will likely match their additional CO2 expenses, as companies aim to minimize overall compliance costs efficiently. However, in the long run, the EU ETS could encourage investments in energy-efficient new vessels, increasing demand and reducing production costs. This would lower prices for new vessels and decrease capital costs for shipowners, incentivizing further investments crucial for decarbonizing the maritime industry. (Christodoulou, Cullinane 2023)

2.1.3 Impact of regulations on the shipping industry

To evaluate the impact of regulations on the shipping industry, it is important to understand who the main stakeholders of this industry are and how these regulations affect them. The key stakeholders of this industry are ship owners, ship operators, charterers, chartering brokers, flag states, coastal states, insurance companies, banks and private investors, classification companies, shipyards, demolition yards, ports and terminals, and traders. (ThinkCompass Software 2024) (Hardiyanto, Pitana, Handani 2020)

This industry is considered to be the most regulated compared to other industries. Shipowners are required to adhere to all regulations issued by the International Maritime Organization (IMO), making them the primary entities affected by changes in these regulations. This is largely because shipowners are responsible for covering most of the expenses related to implementing these regulatory changes on their vessels. These regulations impose additional implementation costs for shipowners and operators for compliance. (Hardiyanto, Pitana, Handani 2020)

Examining how regulations impact the shipping industry requires considering various perspectives. Financially, there are costs and potential profits to assess. From a customer viewpoint, ensuring satisfaction post-regulation is essential. Internally, attention must be given to procedures like training and planning. Lastly, in terms of learning and growth, the resources needed for compliance, such as technology and staff knowledge, must be considered. These perspectives offer a comprehensive understanding of the impact of regulations on the shipping industry. (Karahalios, Yang, Wang 2014)

Jeremy Nixon, CEO of the worldwide container shipping corporation Ocean Network Express, highlighted at a conference in January 2022 the substantial financial commitment required by the global container shipping sector to align with IMO objectives. He projected an investment need of approximately $1.5 trillion over the next two to three decades. (Shih 2022)

Regulations on the shipping industry lead to significant financial investments and higher operational costs. They affect vessel resale values and require detailed contractual adjustments, such as the BIMCO CII Clause. While these regulations can disrupt global trade, they also drive technological innovation, improve efficiency, reduce emissions, and promote sustainability.

The introduction of the CII has led to the development of new clauses in charter parties to manage compliance responsibilities. For instance, the BIMCO CII Clause aims to balance responsibilities between shipowners and charterers, ensuring that operational practices do not adversely affect the vessel’s CII rating. This has created a need for careful drafting of contracts to include terms that address operational speeds, routes, and other factors that can influence a ship's carbon intensity rating. (Austin, Adamson, Hyne 2022)

By clearly defining the responsibilities and expectations of both parties, the BIMCO CII Clause helps prevent disputes and ensures that both shipowners and charterers work collaboratively to maintain compliance with CII standards. (Austin, Adamson, Hyne 2022)

The regulations have also influenced the resale market for vessels. Ships with better CII ratings are perceived as more valuable due to lower risk of regulatory non-compliance and potentially lower operational costs. This dynamic is reshaping investment and asset management strategies within the shipping industry. (The Maritime Executive 2023)

These regulations bring substantial financial consequences for shipping companies, mainly through the necessity of compliance. The integration of innovative technologies, such as wind-assisted ship propulsion, leads to increased operational expenses. Investments in research and development within the industry to discover newer and more effective methods for minimizing environmental harm will rise. Furthermore, such regulations can disrupt global trade and supply chain dynamics. The introduction of new technologies and processes, or changes in shipping routes, may cause delays and operational disruptions. Consequently, shipping costs and pricing could rise, as the expenses associated with regulatory compliance are typically transferred to consumers. (Mirlo 2023)

However, these regulations also offer advantages to both the shipping industry and the environment by diminishing the ecological impact of maritime operations and stimulating greater sustainability and resilience within the sector. The drive towards adopting innovative technologies and processes can not only enhance operational efficiency and reduce emissions but also encourage innovation and investment within the industry. (Mirlo 2023)

Regulations in the shipping industry significantly impact Environmental, Social, and Governance (ESG) reporting. These regulations necessitate comprehensive reporting on sustainability practices, which increases transparency and accountability. As a result, shipping companies must integrate ESG criteria into their operations to meet regulatory requirements, thereby enhancing their environmental performance, improving social conditions for their workforce, and ensuring robust governance practices. This integration not only aids in compliance but also strengthens stakeholder trust, attracts sustainable investments, and promotes long-term business resilience. (Moschaki 2023)

2.2 Wind-assisted ship propulsion

2.2.1 Background and evolution of wind-assisted ship propulsion

Throughout history, sailing played a vital role in the advancement of civilizations and trade, with records of sailing vessels tracing back to around the 6th millennium BC. It served as the dominant method of maritime propulsion until the emergence of engines, offering increased power and consistent speeds, ultimately leading to its decline. (Khan et al. 2021)

Wind-assisted ship propulsion has a long history dating back centuries, hitting its peak around the 1840s with the rise of clipper ships. These ships were much better than early steamships, which were seen as slow and not very efficient because they needed a lot of space for their engines and fuel. But with the invention of better engines like the triple expansion engine and later the diesel engine, and with more demand for bigger ships, sailing ships became outdated. (Lloyd’s Register Group Limited. 2015)

There was a renewed interest in wind-assisted ship propulsion in the 1980s because of the oil crisis in the 1970s. But just as this technology was starting to look good, fuel prices stabilized, and the development of wind-assisted propulsion slowed down. Fast forward to today, and things are changing. More and more organizations are trying to reduce their carbon footprint and use less fossil fuels. They're seeing benefits beyond just saving money. And in this new world, wind-assisted propulsion is becoming one of the best ways to use renewable energy in shipping. (Lloyd’s Register Group Limited. 2015)

A combination of economic and environmental factors renews the interest in wind-assisted technologies today. As the demand for cleaner fuels grows, fuel prices are likely to rise, making investments in energy-saving devices more attractive. This scenario shows that wind-assisted ship propulsion technologies can be cost-efficient solutions with their potential for fuel savings. (Bordogna 2020)

Given that fuel costs constitute between 60 and 70 percent of vessels' operating costs, reducing fuel consumption is a logical strategy from a business and environmental standpoint. (Holsvik, Williksen, Adland 2020)

This technology works by using devices like wingsails, square rig sail systems, towing kites, and Flettner rotors to catch the wind and move the ship forward. By combining wind power with traditional engine power, ships can use less fuel, save money, and emit fewer greenhouse gases. Wind-assisted propulsion doesn't just help ships keep their speed with less engine power; it can also make them go faster without using more fuel, which could mean shorter trips and more profit. (Lloyd’s Register Group Limited. 2015)

Even though steam and diesel engines ruled the seas for a long time, sailing ships were fast and reliable. Today, modern wind-assisted technologies offer different ways to use wind power effectively, showing that wind-assisted ship propulsion could be a great solution for making shipping more environmentally friendly and sustainable. (Lloyd’s Register Group Limited. 2015)

Wind-assisted ship propulsion technologies present several opportunities for the shipping industry. They have the potential to significantly reduce CO2 emissions and air pollution from both current and future fleets, especially when coupled with alternative fuels and other energy-saving methods. Additionally, these technologies can help bridge the price gap between fossil-fueled and zero-emission ships, although the relatively higher cost of clean fuels may remain a challenge. Moreover, by speeding up full decarbonization within the shipping sector, wind propulsion systems can reduce the required investments and time commitments. Notably, they have demonstrated the ability to substantially decrease marine fuel consumption, offering potential fuel savings of up to 30%, depending on the vessel type and environmental conditions. (Advanced Wing Systems 2021)

The economics of wind propulsion in the maritime industry present compelling advantages. Firstly, the energy cost is essentially fixed at zero, offering significant potential savings. Moreover, this technology is readily available today and can be applied across various types of vessels in the fleet. With a robust pipeline of technological advancements and ongoing projects, the outlook for wind propulsion remains promising. Additionally, the predictability of weather routing and forecasts contributes to the reliability and effectiveness of this technology in optimizing vessel performance and fuel efficiency. (International Windship Association 2023a)

Over 150 prominent companies, experts, and supporters have declared the Decade of Wind Propulsion 2021-2030, demonstrating a collective commitment from this expanding technology sector within commercial shipping to advance the decarbonization of both existing fleets and future vessels, aiming to Deliver, Optimize, and Facilitate this vital transition. (International Windship Association 2023a)

The upcoming decade marks a crucial period for realizing the potential of wind propulsion within the shipping industry, known as the 'Decade to Deliver.' Projections from EU research suggest a significant uptake of wind propulsion installations by 2030, potentially reaching 10,700 installations covering half of the bulker market and 65% of tankers. This widespread adoption is expected to result in a substantial reduction of emissions, estimated at 7.5Mt of CO2, and the creation of numerous job opportunities. The UK Clean Maritime Plan further underscores the growth potential of wind propulsion technologies, forecasting a £2 billion segment by the 2050s, with an estimated 37-40,000 installations representing 40-45% market penetration. Notably, the small vessel market, including fisheries and ferries, presents additional opportunities for wind propulsion adoption. Overall, with full market rollout, wind propulsion has the potential to meet a significant portion of the fleet's energy needs and contribute to reducing global greenhouse gas emissions by up to 1%. (International Windship Association 2023a)

Providers of wind propulsion technology and various stakeholders involved in its development are committed to enhancing existing systems through ongoing optimization efforts. A robust pipeline of research and development projects, as well as innovative concepts, ensures continuous advancement in this field. The International Windship Association is actively developing a 'Wind Propulsion Accelerator Programme' to bolster these endeavors. This initiative will include a dedicated test fleet, an incubator program to nurture wind technology, and a supportive framework to bring these solutions to market. The optimization strategy encompasses hybrid systems that seamlessly integrate wind propulsion into vessel energy management. Additionally, efforts are directed toward refining ship design, implementing advanced weather routing techniques, and addressing other critical aspects to maximize the efficacy of wind propulsion technologies. (International Windship Association 2023a)

Wind propulsion serves as a vital component in accelerating the adoption of alternative low-carbon and zero-emissions fuels in the shipping industry. Through a hybrid approach termed W.A.V.E. (Wind, Activity, Vessel optimization, Eco-fuel), combining wind propulsion with operational and vessel optimization measures, industry objectives can be met at reduced costs. Wind propulsion alone contributes around 20-30% of the required energy, while operational and vessel optimization measures offer additional reductions. Integrating eco-friendly fuels becomes more feasible with decreased reliance on expensive eco-fuel bunkering, and the streamlined approach also offers benefits such as reduced storage space and increased vessel range. (International Windship Association 2023a)

2.2.2 Wind-assisted ship propulsion technologies

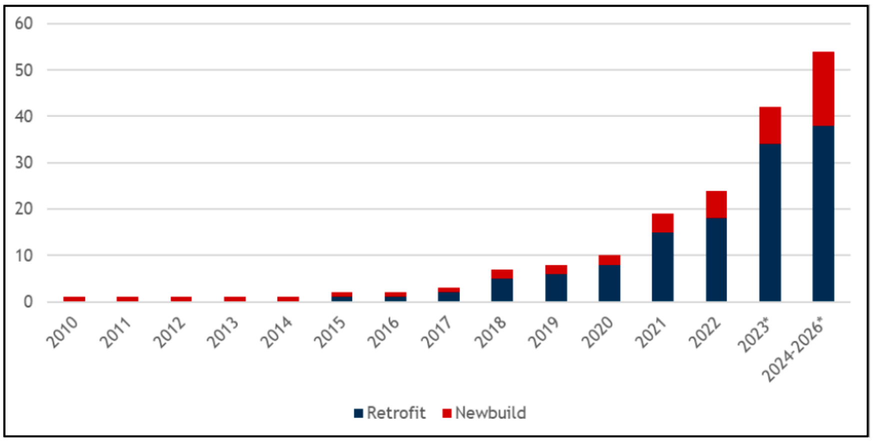
Wind-assisted ship propulsion refers to a set of technologies that utilize wind energy to propel a vessel alongside its engine, serving as auxiliary propulsion. This process, known as 'motorsailing', involves combining wind-assisted devices with the ship's engine to reduce the required propulsion power for a given speed.

There are two primary modes of operation: one maintains ship speed with lower engine power, resulting in decreased fuel consumption, costs, and CO2 emissions, while the other increases ship speed with the same engine power, potentially reducing voyage times and enhancing ship profitability. (Advanced Wing Systems 2021)

These technologies are divided into seven main categories, each fully automated for ease of use, safety, and efficiency. (International Windship Association 2023b)

These systems include traditional sail designs and modern variations like dynarig, categorized as Soft Sail. Another category, Hard Sail, utilizes wingsails, foils, and JAMDA style rigs, with some equipped with solar panels for supplementary power generation. Flettner Rotor or Rotor Sails consist of rotating cylinders driven by low-power motors, leveraging the Magnus effect to create thrust. Suction Wings, such as Ventifoil and Turbosail, incorporate non-rotating wings with vents and internal fans to maximize propulsion through boundary layer suction. Dynamic or passive kites are deployed from the vessel's bow to aid propulsion or generate a blend of thrust and electrical energy. Turbines, adapted for marine use, produce electrical energy or a combination of electrical energy and thrust. Lastly, Hull Form involves redesigning ship hulls to harness wind power for thrust generation. (International Windship Association 2023b)

Figure 4 - Number of ships (*planned to be) equipped with a wind propulsion system (European Maritime Safety Agency 2023)



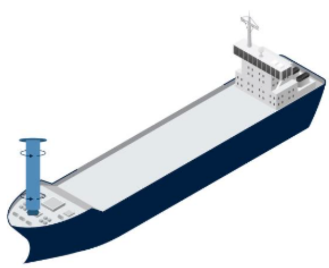
The graph displayed above clearly illustrates an increasing trend in the number of ships, including both retrofits and newbuilds, planned to be equipped with wind propulsion systems. This noticeable rise not only highlights a growing interest in these technologies but also reflects a rising trust within the maritime industry. The data depicted affirms the industry's commitment to embracing these sustainable propulsion methods, marking a positive step towards a more environmentally friendly maritime industry.

2.2.2.1 Rotor sails

Rotor sails, also referred to as Flettner rotors, are cylindrical structures equipped with small electric engines mounted vertically on a ship's deck. These rotors spin actively, generating a pressure differential known as the 'Magnus effect' when coupled with wind, thereby producing forward thrust. Ideally, rotor sails perform best when encountering a crosswind (at 90° or 270° angles) to maximize their lift potential. However, their effectiveness diminishes when sailing directly into headwinds or with tailwinds due to increased drag. Additionally, the rotational motion of rotor sails may cause some vibrations and noise, necessitating control measures. Present rotor sails typically range from 18 to 35 meters in height, with diameters reaching up to 5 meters. (European Maritime Safety Agency 2023)

Anemoi Marine Technologies Ltd is enhancing the shipping industry's sustainability with its innovative rotor sail technology. As a spin-off from Blue Planet Shipping Ltd, Anemoi has partnered with major firms like Vale and Cargill. (Lloyd’s Register Group Services Limited 2024b)

Figure 5 - Rotor Sail technology schematic (European Maritime Safety Agency 2023)

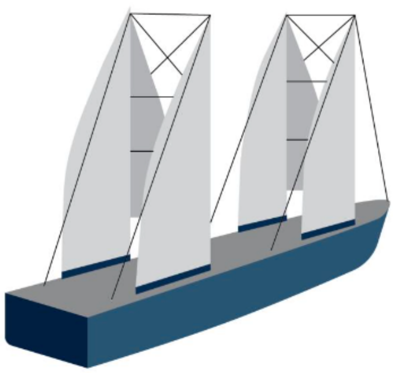


2.2.2.2 Soft sails

Soft sails, resembling traditional sails, offer flexibility and can be designed with wing-shaped configurations to optimize thrust. Some modern soft sails even incorporate masts that serve as cranes for loading and unloading purposes, enhancing their utility. An alternative approach involves inflatable soft sails, featuring wing-shaped designs and inflatable capabilities, supported by telescopic masts. Automation enables seamless setting, reefing, and synchronization of inflation/deflation and mast extension/retraction. Prototype testing, including a 100 square meter version on a sailing boat, and ongoing trials on a Ro-Ro cargo carrier demonstrate promising performance, with the system touted to be lighter and more effective upwind compared to conventional soft sails. However, recent observations suggest that hard sails may outperform soft sails in fuel consumption reduction, with only a few larger commercial vessels currently employing soft-sail technology, down from previous figures. Notably, one technology provider shifted focus from soft to hard sails based on efficiency findings. (European Maritime Safety Agency 2023)

Introduced in 2021, Michelin's WISAMO sail is an innovative, inflatable, and retractable wing sail designed for both commercial and recreational vessels. Approved by DNV and compliant with the WAPS ST-0511 standard, it enhances navigation and bridge clearance. After initial tests on a yacht, the WISAMO system is now installed on the MN Pelican, a 155-meter ro-ro cargo ship, to evaluate its efficiency on commercial routes between Poole, Great Britain, and Bilbao, Spain. (Autermann 2023)

Figure 6 - Soft sails technology schematic (European Maritime Safety Agency 2023)

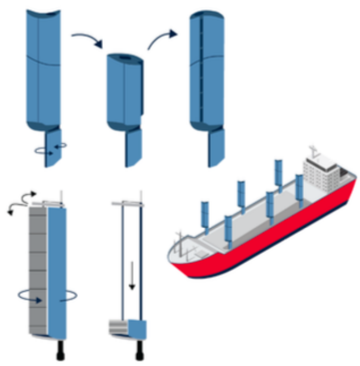


2.2.2.3 Hard sails

Hard sails, resembling traditional soft sails in function, utilize aerodynamic principles to generate lift and drag forces through wind interaction. However, unlike soft sails, hard sails possess a rigid structure crafted from lightweight and durable materials like carbon fiber. Typically, these sails can be adjusted and automated to align with wind directions for optimized propulsion. Predominantly wing-shaped, they are often termed as wing sails due to their design resemblance to airplane wings, leveraging aerodynamic principles akin to aircraft. This design provides increased lift and a higher lift-to-drag ratio compared to conventional sails. Hard sails come in various sizes, ranging from 12 meters in height for smaller cargo vessels to 50 meters for larger bulk carriers, resulting in sail areas ranging from around 30 to 1,000 square meters. Some hard sails are even equipped with solar panels to increase power generation. (European Maritime Safety Agency 2023)

A collaboration between Cargill, BAR Technologies, Mitsubishi Corporation and Yara Marine Technologies has the potential to decarbonize cargo vessels by up to 30 percent, with wind-assisted propulsion technology. Pyxis Ocean, a Mitsubishi Corporation vessel chartered by Cargill is one of the first vessels to use this technology with the help of two WindWings, which are 37.5 meter high sails that can harness the power of the wind. Across typical global shipping routes, WindWings have the potential to reduce fuel consumption by 1.5 tonnes per WindWing each day, with even greater savings achievable on transoceanic journeys. This equates to significant cost reductions for vessel owners, particularly with heavy fuel oil (HFO) priced around $800 per tonne. Such savings are poised to become increasingly valuable as the industry transitions to future fuels, which are expected to carry a higher price tag. (Cargill, Incorporated 2023)

Figure 7 - Hard-sail technology schematic (European Maritime Safety Agency 2023)

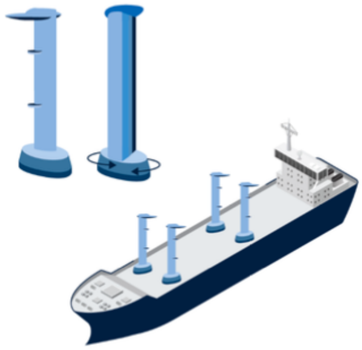


2.2.2.4 Suction wings

Suction wings, vertical wing-shaped structures affixed to the deck, contrast with rotor sails as they lack rotating outer parts for thrust generation. However, they feature orientable wings, capable of automatic rotation to align with wind direction. These wings incorporate vents and internal fans, utilizing boundary-layer suction to produce thrust, complementing the thrust generated by their wing shape. Optimal thrust is achieved at side winds, while it is minimal at head and tail winds. Typically ranging from 10 to 36 meters in height, ships commonly deploy two or four wings, although single-wing installations are also observed. Some suppliers offer smaller suction wings (10 meters tall) as containerized units, enhancing flexibility in placement and transportation. (European Maritime Safety Agency 2023)

Econowind, a Dutch firm specializing in WASP systems, offers several products including the innovative Containerized eConowind unit. This system, designed to fit within a standard 40 ft sea container, allows for quick installation and removal, making it adaptable for various ship types like cargo vessels and tankers. (Econowind 2023)

Figure 8 - Suction-wing technology schematic (European Maritime Safety Agency 2023)

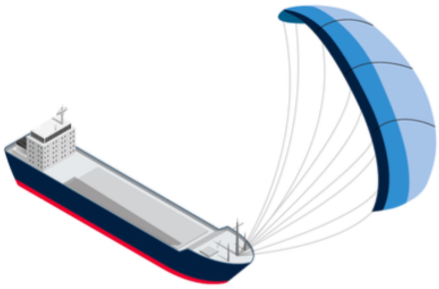


2.2.2.5 Kites

Kites deployed at a ship's bow harness lift and drag to generate propulsion, with automated systems facilitating launch and retraction based on wind conditions. Unlike other technologies, kites capitalize on higher wind speeds at greater altitudes, altough at a trade-off between altitude and propulsion due to increased elevation angles. Kites are categorized as passive or dynamic: passive kites track wind direction, while dynamic ones move swiftly to enhance lift, potentially flying in a figure-eight pattern. Although dynamic kites efficiently generate thrust downwind, their effectiveness diminishes as wind angles decrease, a drawback less prevalent in passive kites. Available in sizes ranging from 10 to 40 square meters for leisure and fishing boats, larger ships can deploy kites up to 1,000 square meters, with development underway for sizes up to 5,000 square meters. To mitigate ship emissions without onboard installation, kite-propelled tugs are under development to tow ships, utilizing kite thrust for propulsion, potentially powering transoceanic transport entirely. (European Maritime Safety Agency 2023)

Founded in 2016, Airseas introduces the Seawing system, leveraging aeronautical expertise to enhance maritime propulsion. This system features a 1000 square meter kite that ascends up to 300 meters to utilize stronger winds, optimizing ship efficiency. Designed for rapid 24-hour installation on various large vessels, Seawing aims to reduce fuel consumption and emissions by 20%. (AIRSEAS, SAS 2023)

Figure 9 - Kite technology schematic (European Maritime Safety Agency 2023)



2.2.2.6 Hull and wind turbines

The vessel's hull can adopt a symmetrical aerofoil shape, capable of generating lift and propelling the ship forward. However, this innovation is exclusive to newly constructed ships and is currently demonstrated in a design tailored for Ro-Ro vessels, as illustrated in MEPC79-INF.21. (European Maritime Safety Agency 2023)

Wind turbines designed for maritime use, like those found on land, can be installed on ships to produce onboard electricity. This electricity can power propulsion systems or meet the energy needs of other ship systems like lighting and pumps. Although research into ship-based wind turbines has been extensive, no large-scale prototypes have been developed, and startups from the 2010-2015 period have ceased operations. However, a recent concept proposes a horizontal wind turbine housed within a 40-foot container with open sides to capture wind effectively. This container, containing the turbine, can be lifted onto a ship and placed on top of a conventional cargo container. According to the technology provider, SideWind (2023), the turbine's operational wind speed range is 1.5-40 meters per second (m/s), capable of producing over 700 kW with 20 turbines at a side-wind speed of 20 m/s. (European Maritime Safety Agency 2023)

2.2.3 Comparative Table – Existing WASP technologies

The comparative table (Appendix 4) provides a comprehensive overview of existing WASP technologies. It presents key information to facilitate a better understanding and comparison of these technologies.

The table details the specific types of wind-assisted propulsion technology, along with the providers who offer these technologies and the commercial names of each WASP product. It also lists the entities that have invested in the development or deployment of these technologies.

Information on the types and sizes of vessels that can utilize each WASP technology is provided, specifying whether the technology is suitable for new vessel constructions, retrofitting existing vessels, or both. Additionally, the table includes technical specifications such as the height, diameter, and weight of the WASP units.

Financial aspects are covered with data on the capital expenditure (CAPEX) required for each unit of the technology and the operational expenditure (OPEX) for maintaining each unit. The costs associated with training crew and personnel to operate the technology are also included.

The table outlines the specific challenges associated with each WASP technology, as well as the benefits offered by each. Finally, it provides data on the potential fuel savings and emissions reductions achieved through the use of each WASP technology.

This table aims to provide stakeholders with valuable insights into the comparative advantages and limitations of various WASP technologies, aiding in informed decision-making for the adoption of sustainable propulsion solutions in the maritime industry.

3. Methods

This section explores the motivations behind focusing the literature review on key areas such as the drive for decarbonization in the shipping industry, the regulatory framework designed to reduce greenhouse gas emissions, and an exploration of the historical development and variety of WASP technologies. This comprehensive review aims to contextualize the global situation, highlighting the pressing need for decarbonization, the challenges and advantages it presents, and the potential solutions available through innovative technologies.

Building on this foundation, the study progresses by gathering primary data through interviews with key stakeholders in the shipping industry. The first notable conversation is with a decarbonization specialist from a renowned commodity trading firm in Geneva, which has made considerable investments in WASP technology. This dialogue aims to shed light on the investment rationale from an insider's perspective, examining cost-effectiveness and the technology's role in achieving regulatory compliance.

The second interview involves a detailed discussion with a Ship Performance Manager at an international marine shipping classification, ship design, energy transition advisory, compliance, and consultancy services provider. This conversation delves into the technical specifics of WASP technologies, focusing on their integration, operational impacts, and efficiency improvements in real-world maritime settings.

The third interview features the founder and managing director of a Geneva-based company providing services to the International Trading and Shipping industry. This discussion provides insights into the broader market trends and the strategic importance of WASP technology for companies involved in international trade and shipping, emphasizing its potential to enhance competitiveness and sustainability in the sector.

Acknowledging the difficulties in primary data collection, it's important to note the hesitance among companies to share financially sensitive information. Despite these obstacles, the research aims to gather a comprehensive collection of data strong enough to analyze WASP technology's cost-effectiveness as an investment for decarbonization.

The findings and analysis presented will offer a broad perspective and general recommendations, recognizing that the conclusions drawn may not universally apply to all potential investors. This approach ensures a balanced examination, providing valuable insights into the viability and impact of investing in wind-assisted ship propulsion technologies within the shipping industry's evolving regulatory and environmental context.

4. Results and Discussion

4.1 Interview summaries

4.1.1 Interview 1: Decarbonization Specialist at a Commodity Trading Company

Role and Responsibility: The decarbonization specialist was specifically hired to help the company reduce its carbon footprint. His role was created to support projects aimed at reducing emissions and improving sustainability in their maritime operations. He is responsible for overseeing initiatives like the integration of wind-assisted ship propulsion technologies, ensuring they align with the company's environmental goals.

Technological Investments and Integration: The commodity trading company based in Geneva has invested in Bound4Blue's eSails technology to capitalize on the benefits of wind-assisted ship propulsion. Publicly announcing this investment, they aim to install the eSails on a long-term chartered juice carrier that regularly shuttles between Brazil and Belgium. This specific route is ideal for accurate measurement of benefits and precise projections due to its predictability. In dry bulk shipping, this consistency is rare, as most routes are variable and unpredictable.

Installation and Challenges: Installation of the eSails is planned for early 2025, delayed from the original schedule due to structural challenges. Ensuring the deck's load-bearing capacity and building robust foundations are crucial to absorbing the forces generated by the sails.

Additionally, piping and cabling need to be repositioned to accommodate the installation. Though significant challenges remain, careful planning should mitigate potential problems.

Expected Operational Benefits: Through projections and historical weather data, the company anticipates exceeding 10% in fuel savings with the e-sails technology. This will be verified through rigorous measurement using the performance-monitoring tools already installed onboard, enabling a clear before and after comparison.

Reducing emissions and meeting strict EU ETS regulations is a significant objective. The company expects this project to generate compliance credits, enhancing its cost-effectiveness.

Costs and Return on Investment: WASP technologies have a relatively long payback period, between 5-10 years, compared to simpler retrofitting solutions like paint upgrades.

However, the company believes that the long-term benefits justify the investment because wind energy is renewable and free once installed, reducing operational costs over the long term.

The technology has an approximate lifespan equal to the vessel itself. If necessary, the system can be removed and installed on another ship. The juice carrier's long-term charter ensures sustained returns and strengthens the investment rationale.

Future Outlook and Barriers: The decarbonization specialist perceives WASP as a medium-term solution. While there are significant barriers in terms of financial investment and operational adjustments, evolving environmental regulations will likely accelerate adoption. Integrating WASP with greener fuels will become essential to maximize efficiency.

4.1.2 Interview 2: Ship Performance Manager in Maritime Performance Services

Role and Involvement in Wind-assisted ship propulsion: The Ship Performance Manager in Maritime Performance Services holds a significant role in guiding fleets, banks, charters, NGOs, and energy efficiency providers. His work focuses on enhancing ship performance, ensuring regulatory compliance, and supporting the transition toward decarbonization. This role also involves in-depth consultancy on wind-assisted propulsion technologies to help clients determine the best strategies for improving efficiency and reducing environmental impact.

Technology Overview and Industry Trends: Among the different wind-assisted technologies, Flettner rotors are the most prevalent, followed by suction sails, rigid sails, and kites. Suction sails are gaining popularity due to their relatively low cost and simpler mechanical design. Despite being more efficient, rigid sails are less suitable for widespread adoption because of their higher complexity and cost. Kites are cheaper but face significant challenges with recovery and deployment.

The company gained extensive insights from the Maersk Pelican project, which delivered transparent data that set a benchmark for wind-assisted ship propulsion projects.

Operational Challenges and Benefits: Wind-assisted ship propulsion faces significant challenges due to the variable nature of wind conditions, impacting efficiency across different regions and seasons. For instance, fuel savings on the Maersk Pelican varied dramatically from 2% to 12% depending on the season, even on the same route. Such variability makes it difficult to attract broad stakeholder investment.

Retrofitting costs are also high, particularly for older ships requiring foundational modifications. However, if wind-assisted ship propulsion technologies are integrated into new builds, they can offer considerable fuel savings. These technologies will become increasingly critical as the costs of fossil fuels rise and regulatory requirements grow stricter.

Industry Collaboration and Support: Collaborating closely with WASP technology manufacturers, the company helps clients identify suitable technologies by simulating specific vessels and routes. They also participate in the Wind Industry Joint Program, working alongside 25 companies to resolve issues surrounding installation, operations, and safety.

Costs and Return on Investment: The payback period for WASP technologies generally falls between 7 and 10 years. Suction sails are relatively affordable compared to rigid sails, which can be three to four times more expensive. While Flettner rotors are efficient, they are mechanically complex and costly.

Foundation bases, particularly collapsible or rail systems, often double the cost of the system itself. Although prices are currently high, market maturation and improved production processes are expected to lower costs over time.

Despite the relatively long payback periods and higher initial investment, WASP systems can offer substantial fuel savings, reducing fuel consumption by up to 12-15% under optimal conditions. This potential, coupled with stricter environmental regulations, is driving more companies to explore these technologies. Additionally, market trends suggest that the costs will decrease over time as manufacturers refine their processes, achieve economies of scale, and improve system integration.

Regulatory Impact and Future Outlook: Regulations like CII, EEXI, and EU ETS motivate companies to invest in WASP technologies. However, they are not the sole drivers, as many first-movers see the strategic long-term value in these technologies. Combining wind-assisted propulsion with future green fuels like hydrogen or ammonia will further maximize fuel efficiency.

4.1.3 Interview 3: Founder and Managing Director of a Geneva based company - International Trading and Shipping Industry

Regulatory Impact: The shipping industry seeks a level playing field with regulations like the CII and the EU ETS. While these regulations aim to standardize costs across similar businesses, they are often poorly designed. The CII incentivizes longer voyages, and the EU ETS only applies to cargo entering and leaving Europe, creating inconsistencies. Although regulations are affecting the industry, they are not changing rapidly enough to meet decarbonization needs. Shipowners initially bear the costs, but these are eventually passed down to consumers, impacting all parties along the value chain.

Technological Investments and Integration: WASP technologies, such as sails, are part of the solution to decarbonization but are currently too expensive and not effective enough in reducing fuel consumption. As volumes increase, costs may decrease, making these technologies more viable. They are seen as a medium-term solution and part of a broader strategy involving multiple technologies to reduce emissions.

Installation and Challenges: Installing WASP technologies presents logistical challenges, especially for retrofitting existing vessels. Shipyard space is scarce, complicating the widespread adoption of these technologies. Current solutions are viewed as short-term unless significant advancements are made.

Expected Operational Benefits: WASP technologies offer benefits like efficiency, cost reduction, and reduced fuel use, leading to lower emissions. However, their high installation costs and long payback periods make them less attractive. Combining various technologies could achieve significant emission reductions, making this a step in the right direction.

Future Outlook and Barriers: The future of WASP technology is seen as a part of the solution, but not the sole solution. The cost-effectiveness of these technologies today is questionable, with a payback period exceeding 20 years. A combination of different fuels, hull designs, and other technologies will be necessary for cost-effective decarbonization. Certification and trusted measures are crucial for ensuring the effectiveness of these solutions.

4.1.3.1 Conclusion

In summary, the interviews illustrate the challenges and opportunities associated with wind-assisted propulsion technologies. Despite the unpredictability of wind conditions and high upfront costs, the long-term fuel savings and regulatory compliance benefits are clear. Industry collaboration, continued technological refinement, and regulatory incentives will be crucial in driving the adoption of these technologies for decarbonizing the shipping industry.

Despite the challenges, the Ship Performance Manager sees opportunities for reducing the upfront costs through a rental or leasing model. This approach would allow shipowners to use wind-assisted systems on specific routes with favorable wind conditions. The systems could be installed temporarily, then removed when not needed, optimizing fuel savings and providing flexibility to fleet operators.

Additionally, the founder and managing director of a Geneva-based company highlights the strategic importance of wind-assisted propulsion technologies. He believes these technologies can boost competitiveness and sustainability in the shipping sector. His perspective emphasizes the need for a combined approach using multiple technologies and strong regulatory support to make wind-assisted ship propulsion a viable solution for decarbonizing the shipping industry.

4.2 Discussion

The interviews with a Decarbonization Specialist from a commodity trading company, a Ship Performance Manager in Maritime Performance Services, and the Managing Director of a Geneva-based company in the shipping industry aimed to uncover the challenges, benefits, and trends associated with WASP technology adoption.

The decarbonization specialist focuses on reducing emissions and enhancing sustainability, specifically through integrating WASP into the company's fleet. The ship performance manager oversees fleet efficiency, regulatory compliance, and the transition to greener solutions while advising clients on the cost-effectiveness of WASP technologies. The managing director emphasizes the strategic importance of WASP technologies from a global perspective, highlighting their potential to boost competitiveness and sustainability across the international shipping industry.

Their expertise provided credible insights into the challenges, long-term benefits, and industry trends surrounding WASP technologies. These experts also emphasized cost-effectiveness and strategic investment, highlighting the significant operational savings from renewable wind energy despite the longer payback period.

4.2.1 Operational benefits and challenges

4.2.1.1 Installation Complexities

The decarbonization specialist pointed out structural challenges that caused delays in the installation of eSails on a juice carrier. The load-bearing requirements of the ship's deck had to be carefully assessed, and robust foundations built to absorb the forces generated by the sails. Additionally, piping and cabling needed to be repositioned to accommodate the new technology, further complicating the process and pushing back the installation timeline.

The ship performance manager echoed these challenges, particularly for older vessels being retrofitted with wind-assisted propulsion systems. Many of these ships require foundational modifications to safely integrate the new technology, increasing the complexity and cost of installation. He also emphasized that collapsible or rail systems often double the cost of the installation, adding another layer of financial challenge.

4.2.1.2 Variable Wind Efficiency

The interviewees emphasized the impact of wind variability on fuel savings. The decarbonization specialist explained that accurate projections for savings could be made on the juice carrier's consistent Brazil-Belgium route due to its predictable seasonal weather patterns. This regular route is ideal for measuring the effectiveness of eSails, with an expected fuel savings of over 10%.

The ship performance manager highlighted the Maersk Pelican project to illustrate how wind patterns can significantly impact savings. On the same route, fuel savings ranged from 2% to 12% depending on the season. Such variations underscore the unpredictable nature of wind conditions and their influence on WASP's efficiency. This variability poses challenges in attracting consistent stakeholder investment and securing payback within the anticipated time frame.

4.2.2 Return on Investment (ROI) and Cost-effectiveness

4.2.2.1 Payback period

The decarbonization specialist acknowledged that the relatively long payback period of WASP technologies, typically ranging between 5 to 10 years, could discourage some investors. This longer ROI period is due to the substantial upfront investment required for equipment, installation, and structural modifications, especially in older vessels needing foundational adjustments.

The ship performance manager further explained that this lengthy payback period is due to the high initial costs of installing these systems. He specifically mentioned that foundational bases, such as collapsible or rail systems, often double the cost of the technology itself. Despite these hurdles, he stressed that the adoption of WASP is still strategic given the expected long-term savings.

4.2.2.2 Fuel savings and Lifespan

The interviewees agreed that while the ROI is relatively extended, the projected fuel savings are significant and justify the investment. The decarbonization specialist emphasized that the company anticipates exceeding 10% fuel savings with eSails, leveraging the juice carrier's predictable route. He also noted that performance-monitoring tools on board enable accurate comparisons to measure savings.

The ship performance manager added that Flettner rotors can achieve fuel savings of up to 15% under ideal wind conditions. He highlighted that these technologies have lifespans generally equivalent to the ships themselves, further incentivizing their adoption. WASP systems can also be removed and reused on other vessels if necessary, offering more flexibility.

4.2.2.3 Cost-Effectiveness

The experts underlined the cost-effectiveness of wind energy once WASP systems are installed. Wind energy is free and renewable, providing significant operational cost savings over time compared to fossil fuels. The decarbonization specialist indicated that eSails would generate compliance credits under strict EU ETS regulations, enhancing the project's cost-effectiveness.

The ship performance manager emphasized that adopting a leasing or rental model could further reduce upfront costs. This model allows shipowners to temporarily install WASP technologies on routes with favorable wind conditions. Such flexibility ensures optimal fuel savings while minimizing long-term financial commitments, making these systems more appealing to fleet operators.

4.2.3 Technological Preferences and Trends

While each technology has unique benefits and limitations, operators must balance efficiency with affordability and reliability. The ship performance manager and decarbonization specialist recognized that the future of WASP will depend on refining these technologies to fit the varied needs of the maritime industry.

4.2.3.1 Flettner Rotors

The ship performance manager highlighted that Flettner rotors are the most commonly used WASP technology due to their efficiency. These rotors generate thrust using the Magnus effect, offering significant fuel savings of up to 15% under ideal conditions. However, he acknowledged that these systems are mechanically complex, requiring significant foundational modifications and collapsible bases, which often double the cost.

4.2.3.2 Suction Sails

Suction sails are gaining popularity because of their relatively affordable cost and simpler mechanical design. The ship performance manager noted that they are less complex mechanically, which reduces installation and maintenance costs. However, suction sails may not be as efficient as other technologies, and their effectiveness depends on favorable wind conditions.

4.2.3.3 Rigid Sails and Kites

Rigid sails are efficient but present challenges due to their higher complexity and cost. According to the ship performance manager, their non-collapsible structure requires substantial modifications to accommodate them, which can limit their adoption on older vessels.

Kites offer a cheaper alternative to rigid sails but face significant challenges with deployment and recovery. The ship performance manager emphasized that kites need favorable wind conditions for effective operation, and their logistical issues make them less reliable in certain weather conditions.

4.2.4 Regulatory and Market influence

4.2.4.1 Regulatory Compliance (CII, EEXI, EU ETS):

The decarbonization specialist emphasized that strict environmental regulations are driving the shipping industry's shift towards sustainable solutions. The Carbon Intensity Indicator (CII), Energy Efficiency Existing Ship Index (EEXI), and European Union Emissions Trading System (EU ETS) each impose specific requirements on shipping companies to minimize their carbon footprint.

CII measures the carbon intensity of a vessel's operations and provides annual targets that shipping companies must meet. Failure to comply can result in penalties or reduced operational allowances. The EEXI mandates retrofitting older ships to improve energy efficiency and aligns their performance with newer, more environmentally friendly vessels.

The EU ETS directly impacts companies operating within EU waters, requiring them to purchase carbon credits for their emissions. This regulation encourages the adoption of technologies that can reduce emissions and minimize the need for purchasing credits.

The Founder and Managing Director of the Geneva-based company highlighted the significant impact of regulations like the CII and the EU ETS on the shipping industry. He pointed out that while these regulations aim to standardize costs and promote decarbonization, they often have design flaws. For example, the CII incentivizes longer voyages, and the EU ETS applies inconsistently to cargo entering and leaving Europe.

These regulatory inconsistencies pose challenges but also drive the industry towards sustainable practices, indicating that regulations, despite their imperfections, are essential in promoting environmental responsibility.

4.2.4.2 Rising Fossil Fuel Prices

The interviewees agreed that rising fossil fuel prices are another significant factor influencing the adoption of WASP technologies. As global oil prices remain volatile, reducing fuel consumption directly translates into cost savings.

The ship performance manager pointed out that wind energy is renewable and free once the necessary infrastructure is installed, enabling companies to cut operational costs substantially. With a predictable and increasingly strict regulatory landscape, reducing dependence on fossil fuels through WASP becomes a strategic investment.

Furthermore, as alternative fuels are likely to be more expensive than current options, the return on investment (ROI) and payback period for WASP technologies will become shorter. This means that the financial benefits of adopting WASP will be realized more quickly, making it an even more attractive option for shipping companies looking to reduce costs and meet environmental regulations.

4.2.4.3 Strategic Investment in WASP

The decarbonization specialist views WASP technology as a strategic investment to meet future decarbonization targets, particularly as shipping companies worldwide face mounting pressure to lower emissions. The company aims to generate compliance credits through the EU ETS by installing eSails, further enhancing cost-effectiveness.

Similarly, the ship performance manager sees WASP technologies as crucial in aligning with upcoming regulations. He believes that investing in WASP systems, coupled with greener fuels, will be essential for achieving future decarbonization goals.

Despite the long payback period, the significant long-term savings, compliance credits, and reduced emissions all make WASP technologies an attractive option for companies seeking to stay ahead in a rapidly changing regulatory environment. Investing early also positions them as leaders in sustainable shipping practices, providing a competitive advantage.

According to the founder and managing director of the Geneva-based company, WASP technologies are part of the solution to decarbonization but are currently too expensive and not yet effective enough to significantly reduce fuel consumption. He suggested that as production volumes increase, costs might decrease, making these technologies more viable in the future. Currently, WASP technologies are seen as medium-term solutions and should be part of a broader strategy that includes multiple technologies to reduce emissions.

He recommended that the future of WASP technology should be viewed as part of a combined approach using multiple technologies and strong regulatory support to make wind-assisted ship propulsion a viable solution for decarbonizing the shipping industry. Investing early in these technologies can position companies as leaders in sustainable shipping practices, providing a competitive advantage as regulations become stricter and fossil fuel prices rise. He emphasized that while WASP technologies alone are not the ultimate solution, they are crucial components of a broader strategy to achieve significant emission reductions.

4.2.5 Investment Implications

4.2.5.1 Short-Term implications

Financial Benefits: In the short term, the decarbonization specialist highlighted that compliance credits under strict EU ETS regulations can provide immediate cost savings for shipping companies. Early investments in WASP allow companies to benefit from these credits and potentially reduce costs associated with carbon emissions.

Challenges: However, both the decarbonization specialist and the ship performance manager pointed out that high initial installation costs and foundational modifications can be prohibitive. For older vessels, the retrofitting process is especially challenging due to the need for structural reinforcement.

4.2.5.2 Mid-Term implications

Financial Benefits: Over the mid-term, the decarbonization specialist noted that consistent fuel savings would start to materialize, particularly on predictable routes with favorable wind conditions. With performance-monitoring tools in place, companies can clearly demonstrate fuel efficiency gains from WASP.

Challenges: The ship performance manager cautioned that variability in wind conditions remains a challenge. Fuel savings could range significantly, as shown in the Maersk Pelican project, where savings fluctuated from 2% to 12% depending on the season. This unpredictability might affect investor confidence.

4.2.5.3 Long-Term implications

Financial Benefits: The interviewees agreed that the long-term benefits of WASP make it a strategic investment. The ship performance manager emphasized that fuel savings of up to 15% with Flettner rotors and over 10% with eSails could lead to substantial reductions in operating costs. Wind energy remains renewable and free after installation, further maximizing these savings over time.

Challenges: Despite these significant benefits, the relatively long payback periods of 5-10 years require a commitment from companies to see the full value. However, as environmental regulations become stricter and fossil fuel prices rise, early adopters will be better positioned.

4.2.6 Strategic Recommendations

Investing in WASP: Shipowners and charterers, such as major commodity trading companies, should invest in WASP technologies due to their potential for significant fuel consumption and carbon emission reductions. This investment can lead to lower bunker costs and compliance with environmental regulations, with the savings helping to offset the initial costs of WASP technology.

As alternative fuels are likely to be more expensive, WASP technologies can help reduce their consumption, improving the ROI and shortening the payback period. By integrating WASP with alternative fuels, shipowners can maximize fuel efficiency and operational savings. This dual approach not only strengthens the business case for WASP but also ensures compliance with increasingly strict environmental regulations. Additionally, reduced dependence on fossil fuels through WASP becomes a strategic investment, positioning companies favorably in a market moving towards sustainability.

However, relying solely on WASP to meet regulatory standards and maintain profitability is insufficient, as future regulations will become stricter. WASP should be viewed as a tool for cost-effective decarbonization, but not the ultimate solution. Wind is a free renewable energy source, and combining WASP with alternative fuels, speed reduction, new engines, and other technologies will ensure continuous progress in decarbonization. Shipowners should ensure their existing fleet is WASP-ready and design new builds to accommodate WASP systems.

Based on Wright's Law, which states that for every cumulative doubling of units produced, costs fall by a constant percentage, increased investment in WASP technologies will lead to significant cost reductions and greater accessibility over time. (ARK Investment Management LLC 2021)

As more resources are directed toward the production and implementation of WASP systems, their cost-effectiveness will improve, making these technologies more affordable and attractive for widespread adoption in the maritime industry. This trend will further enhance the economic viability of WASP, encouraging broader use and contributing to long-term sustainability goals.

Leasing & renting Models: The ship performance manager recommended leasing or renting models to provide shipowners with cost-effective access to WASP technologies on specific favorable routes. This allows flexible installation and removal, optimizing savings while reducing long-term commitments.

One of the primary barriers to the adoption of WASP technologies is the high upfront cost. By adopting flexible financial models such as leasing or rental agreements, shipowners and charterers can mitigate these initial expenses. This approach allows shipowners to install WASP systems on a trial basis or for specific routes with favorable wind conditions, thereby optimizing fuel savings without long-term financial commitments.

Partnering with technology providers to explore leasing or rental options is a critical first step. Conducting pilot programs on select routes can help evaluate the performance and savings of WASP technologies, allowing shipowners and charterers to make informed decisions about permanent installations based on real-world data. This strategy not only lowers the financial entry barrier but also provides valuable insights into operational efficiency and cost-effectiveness, leading to increased adoption of WASP technologies, reduced operational costs, and enhanced compliance with environmental regulations.

Technology Selection: The interviewees emphasized that shipping companies should carefully assess their specific routes, fleet conditions, and wind patterns to choose the most suitable WASP technology.

Technology providers: The successful implementation of WASP technologies requires not only system installation but also comprehensive support and training for the ship's crew and maintenance staff. Ensuring staff is capable of operating and maintaining these systems will maximize efficiency.

Offering detailed training programs, providing ongoing technical support, and developing user-friendly manuals and digital resources are essential steps. These measures will improve the performance and reliability of WASP systems, increase shipowner satisfaction, and boost adoption rates.

Policy Incentives: The decarbonization specialist highlighted that regulatory incentives, such as compliance credits, can accelerate WASP adoption by offsetting initial costs.

Collaborative Research: The ship performance manager recommended further collaboration through initiatives like the Wind Industry Joint Program, involving multiple companies to refine technological integration, operations, and safety. Data sharing across the sector can improve accuracy in forecasting benefits and building confidence in WASP investments.

5. Conclusion

This thesis set out to explore the role and effectiveness of WASP technology in the maritime industry's decarbonization efforts, particularly examining whether its implementation can not only improve decarbonization efficiency but also serve as a cost-effective investment tool for strategic planning. The findings from extensive literature review and interviews with industry experts offer comprehensive insights into their potential and limitations.

WASP technologies have demonstrated significant potential in reducing fuel consumption and greenhouse gas emissions, depending on wind conditions and the type of technology used. This translates into substantial reductions in carbon emissions, aligning with the industry's regulatory requirements.

Despite their effectiveness, the adoption of WASP technologies faces operational and financial challenges. High initial installation costs and long payback periods, often ranging from 5 to 10 years, can deter investment. However, the long-term benefits, including significant fuel savings and compliance with strict environmental regulations, justify the initial expenditure. Moreover, costs are expected to decrease as production volumes increase and technology advances, enhancing their financial viability.

A multifaceted approach is essential for the maritime industry to fully leverage WASP technologies. Shipping companies should consider early investments in WASP technologies to capitalize on long-term operational savings and regulatory compliance benefits. This strategic move can position companies as leaders in sustainable shipping practices. Implementing leasing or rental models can mitigate high upfront costs, allowing shipowners to trial these technologies on specific routes with favorable wind conditions.

Additionally, WASP should be part of a broader decarbonization strategy that includes alternative fuels, advanced hull designs, and operational optimizations. This integrated approach can maximize emissions reductions and enhance overall efficiency. Collaboration among industry stakeholders, technology providers, and regulatory bodies is crucial. Sharing data and best practices can drive technological improvements and build confidence in WASP investments.

Regulatory frameworks play a critical role in promoting the adoption of WASP technologies. Regulations such as the EU ETS and compliance credits can offset initial costs and provide financial incentives for early adopters. Effective and well-designed regulations are necessary to create a level playing field and encourage widespread adoption.

In conclusion, WASP technologies represent a promising avenue for the maritime industry's transition toward greater sustainability and carbon neutrality. While current challenges exist, the strategic integration of these technologies, supported by regulatory incentives and industry collaboration, can significantly enhance shipping operations' environmental and economic performance. Investing in WASP technologies not only aligns with global decarbonization goals but also positions companies to thrive in a future where sustainability is of the greatest importance.

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Appendix 1 – Interview of decarbonization specialist at a commodity trading company in Geneva (17.04.2024)

Interview Protocol

Code	Question
	Thank you for taking the time to give me an interview. I appreciate it.
QP01	*Can you explain the types of wind-assisted propulsion technologies your company has invested in?* *To get an overview / their own ships?*
QP02	*How do these technologies integrate with existing ship designs?* *Main challenges and benefits*
QP03	*What has been the observed impact of wind-assisted propulsion technologies on fuel consumption and carbon emissions?* *Satisfaction level and efficiency of wind*
QP04	*Are there any operational or maintenance challenges associated with these technologies?* *Main challenges (ports, loading & unloading, etc)*
QP05	*How does the initial investment in wind-assisted propulsion compare to traditional propulsion methods in terms of cost?* *Is it expensive?*
QP06	*What are the projected savings in fuel costs over the lifetime of a ship using wind-assisted propulsion?* *Is it cost-effective and what is the "expected" payback period?*
QP07	*Why invest in wind-assisted propulsion and not another alternative?* *Is it cheaper, easier to implement?*
QP08	*Can you discuss any subsidies, incentives, or regulatory benefits for adopting wind-assisted propulsion technologies?* *CII / EU ETS / EEXI* *Reputational reasons*
QP09	*Why invest in a vessel that is not yours? Can you take back the WASP technology you put on the ship?* *Long-term time chartering?* *Savings in bunker costs?*
QP10	*How do you see the future of wind-assisted propulsion in the shipping industry?* *Is it a Short-term, Mid-term, or Long-term solution?*
QP11	*What are the main barriers to the widespread adoption of wind-assisted propulsion technologies?* *Industry challenges and potential areas of resistance. Difficult for container ships…*
QP12	*Do stakeholder expectations of sustainable shipping solutions influence your investment decisions?* *Who are the most impactful stakeholders*

QP13	*How do you compare wind-assisted propulsion with other decarbonization strategies?* *Perspective on the place of wind-assisted technologies among other green initiatives.*
QP14	*What role do you believe public perception and brand image play in the adoption of wind-assisted propulsion technologies in shipping?* *Importance of public and market perception in strategic investment decisions.*
QP15	*What advice would you give to companies considering investing in wind-assisted propulsion?* *Practical advice for others in the industry.*
QP16	*Does your company have any future plans for investment in WASP technology?*

Interview transcription - Respondent A

Code	Response
QP01A	Yes, so the eSails by Bound4Blue. We have actually invested in the company. That's public knowledge. It's been shared, I think, last November, October, November, something like that, in a funding round, because we really believe in their technology and believe that, generally speaking, wind-assisted propulsion will play a role in the future. So, yeah, we have invested in them and at the same time built a project together to install some of these e-sails on one of our long-term chartered vessels. On the Juice Carrier. Is there a particular reason why on that vessel? Yes, the reason that we're going for that vessel is, there are several ones. So, one, it's shuttling, meaning that it's going from A to B, it's going between Brazil and Belgium, back and forth all the time. So, we know exactly which parts are being called and we can also know what routes it's going to take. In the dry bulk, I don't know if you're aware, but in the dry bulk, that's a very rare occasion. Usually, in dry bulk, the vessels are tramping, so you never know where they're going to go next. So you never know which constraints you'll have to apply to your vessel in terms of air draft, etc. So, having a shuttling vessel is very, very helpful to anticipate any challenges. And it also allows you to calculate the benefits very precisely or fairly precisely compared to other routes. So, that's the main reason. And then another very important reason is that these vessels or that vessel has been modified already to take in the juice tanks. So, it's already quite purpose-bound and we have it on charter for a very long time, much longer than other standard, let's say, dry bulk vessels. So, we will be able to get the benefits for a long time from the sails, which justify the investment.
QP02A	So, just maybe one step back is that it is not installed yet on the ship. So, installation is planned for early next year. So, we're actually currently in the process of integrating it. And yes, there are challenges, quite a few. You need to make sure that all the loads can be taken by the deck and the foundations can absorb all the forces. So, for that, you need to build foundations that are well integrated. And there are things in the way like piping and cabling, etc., that you need to potentially displace, redirect. And yeah, so quite a few challenges and still going on. So, original installation date, I don't know where you got that, but an original installation date was late 2024 indeed. And it's being pushed to early 2025.
QP03A	So, we have, of course, made the projection and the calculation, basically putting in the unassisted propulsion polar into the historical weather and trying to extrapolate the savings that we will get in the future, that we would have gotten if the sales were on in the past. And I cannot give you detailed numbers there, but we're expecting to exceed 10% savings. And yes, we will measure it. We have some performance measuring tools on board already. And we will have a very good before-after analysis.

	And we want to put concrete data, of course, behind our projections, also to justify internally that we did the right choice there.
QP04A	Yeah, no, absolutely. And yes, we do. So we are not opting for a tiltable solution on that vessel, different to, for example, what Cargill did on the Pyxis Ocean. Or others, like you've seen the rotors, some of them are being tiltable. So we haven't gone for that because we know exactly these constraints that we have, these operational constraints, which are basically an air draft restriction in Ghent. So we had to design everything in a way that we can pass below that air draft restriction. And then for loading, unloading, we're fairly lucky in the sense that since it's transporting juice, it's being loaded and discharged through a manifold. So there's no cranes or other feeders involved in this case.
QP05A	Sure. So, yes, it is expensive. And among the energy-saving technologies that are out there, it's among the most expensive ones, maybe up there with carbon capture and air lubrication as a retrofit, of course, out of these. Now, why we are going with this one still? Well, once you have installed it, the energy is free, right? Like, wind energy is there, and it's just for you to take it. So once it's on, the benefits are pretty high and constant. Now, I cannot give you the exact numbers, unfortunately, but I can tell you that we are looking at a return on investment or a payback period between 5 and 10 years. So it is pretty high compared to other technologies where you're able to get back your money within a year or two. When you're doing, like, smaller things, like, maybe stacks or work equalizing tax in general, or paint upgrades, these kind of smaller things, yeah.
QP06A	Yes, so the sails are designed to get as old as a vessel. So they have a design lifetime of 20 to 25 years. So it's definitely going to be okay on the ship as long as she's sailing. And then we can even take them off and put them on another ship, potentially.
QP07A	There's no exclusion there, meaning that we are looking at all of them. And we're also doing some of those. Like we've done a biofuel trial on this ship exactly, actually. Oh no, it was the sister vessel, the other two's carrier. Some time ago, we've done other biofuel trials. But of course, we make much less noise about those because it's not as big a project. But we're looking at that. LNG, as a retrofit, is very complicated. To retrofit an engine to an LNG engine is very complicated. And then LNG has its own issues. I would say, A, it's fossil fuel still. B, there's the whole question of the methane slip and its GHG potential. So LNG is not for us a favored CO_2 reduction tool. And as we are not owners, once again, this would be another major retrofit where we would have to find a case like the just carrier. But we have a very long shot. We think that there's not one solution that fits all. There will be cases where due to operational profile, due to owners' preferences, due to a whole bunch

	of reasons, sales can or cannot work, air lubrication can or cannot work, work equalizing ducts may or may not improve the vessel's consumption. So there's a lot of things to be done, but not all of them can be done all the time. So you need to have kind of a portfolio of different things that you can deploy. So that's exactly what we're doing. We're trying out different things in partnership with owners always, of course
QP08A	Right. So there's a major regulatory benefit. On CII, yes, but not that much. I mean, that vessel was not in trouble for CII anytime soon. However, since she is calling Europe all the time, right, going back and forth into Europe, she is directly affected by the EU ETS and will be by the fuel EU maritime that is coming into place next year. And that one is actually a major contributing factor. So the ETS, yes, we will reduce our consumption, so we will reduce our emissions, so we will reduce the ETS or the EUAs that we have to pay for. That's a pretty straightforward benefit and helped our business case, of course. And then the fuel EU maritime, I don't know how familiar you are with that regulation, but it's basically giving you a target carbon intensity for your fuel. So it's not looking at how much you're burning, but at what you're burning basically. And if your fuel is greener, basically you can create credits. And if it's purely fossil, then you have to pay a penalty. And sales have a special place in that regulation where when you have a certain amount of installed power with sales as a fraction of your propulsive power, then you get an automatic fuel or carbon intensity reduction of some percent on the fuel that you're using. So this will actually allow us to be compliant and even over-compliant with that regulation, create credits while still burning the standard fuel that we're still burning today. So that's a very big impact and that was kind of a make or break for our project. And now the reputational gains are not to be neglected, but it is also a benefit. And we are, of course, advertising that we're doing things, but the business case also works in itself. Okay, perfect.
QP09A	
QP10A	So to me, it's a medium-term thing. In the short term, I see the things that we mentioned before, like paint upgrades, weight equalizing ducts, LED lights on board, these kind of smaller things that you can do and that you can do quite quickly actually. Routing optimization also being one of them. Now, sales are a sizable investment compared to a vessel's price. I think we will start seeing new buildings that are sails or WAPs ready or even have WAPs on them from the get-go. But you need a few years to build the whole project, let's say, and you need to have them on for a while before they bring you savings. So it's, in my opinion, in the medium-term solutions. But I don't think they will go away, because if we look at the long term, we will be forced to use alternative fuels, greener fuels, biofuel, as much as is available or not, and then methanol, ammonia, LNG, all these alternatives that are being developed and put in place right now.

	And these are all more expensive than fossil fuels. So you need to make your vessel as efficient as you can in the first place to then save on your fuel bill afterwards. Sails could be added anyway in the future, even if you have a ship that has very green fuel? But if you add sails anyway, you'll just burn less of it anyway and save money. So these alternative fuels will be expensive, so saving them will be crucial. Whatever the fuel you're burning, the goal is to burn the least possible. Absolutely.
QP11A	Well, there is the financial side. You need quite a big investment, and it is only bringing benefits in the medium term, so above five years. So that's some financial barriers, I would say. Not all companies have large amounts to invest, and then wait for several years before bringing in the benefits. I think that's one danger, and I think this will be overcome, or be helped to be overcome by the regulations, especially around Europe, but then potentially in the world, if the IMO puts in place some strong measures in 2027. And then the other barrier that will need more figuring out, more tests, more pilots, is the operations, in the sense that these sails can interfere with feeders, can interfere with regular operations, so this needs to be overcome step by step. And I think it will get there, but it will take some time. Yeah, so the pod installations need to adapt. For now, it's mainly the big players that could invest in these technologies.
QP12A	No, yeah, I don't think there's any external factor pushing for wind-assisted propulsion. There have been customers coming to us, and cargo owners, and internal pushes regarding decarbonizing in general. And what we can do there, that's how we get to some of the biofuel trials, etc. There's no direct push for wind-assisted propulsion from anywhere. It's just that we think that this is part of the mix of solutions, as I mentioned earlier, and we think we should be among, not the very first ones, but among the second wave, let's say, of companies doing these bigger projects as well.
QP13A	It's difficult to say. I think I mentioned earlier, basically, that all of them have their place, and all of them have their cases, and what makes sense in one configuration doesn't make sense in the other. So saying anything is better or worse than the others, and I think the savings are among the biggest ones that you can get from the sails. So the fuel and the CO2 savings. But again, it's a major project, it's a lot of time invested, it's a major modification of your vessel, etc. So it has definitely also drawbacks. It's definitely not a quick fix solution. Whereas upgrading your paint to some top tier, low friction paint, it's fairly quick and easy compared to such a product. So I don't think you could say there's a best or worst.
QP14A	We think so, yeah. I mean, it does play a role. It is not our company's policy to seek that very actively, but of course, once we have nice projects, we also make noise about it and talk about it. But it's not where these projects are born.

	The projects are born out of the desire to reduce our carbon footprint. And I've been specifically hired for that, for example. I'm a decarbonization specialist, so my role was created for this. And it's not to show the world that we're doing something there. It is to do something about it, and then we show the world. So does it play a role? Yes. Is it the initial factor to do anything? No. Yeah, as you said, there are also business impacts about carbon emissions and stuff. Absolutely.
QP15A	Well, I think it's important to go methodically about the whole process, to identify the different options that are out there, align them with your operational profile, that's very important. We think Bound4Blue, the eSails, are a very robust solution, and giving a very good overall benefit. It's not the highest savings, but as a whole package, we think they are really on to something and the most robust. But that can change, of course, based on your operating profile. Rotors, wing sails, kites, they are all having their benefits and their drawbacks. So make sure you choose the right technology and provide enough time for the whole project. It's not a quick thing, such a project. Yeah, you can't just decide to go with wind-assisted propulsion like that. Once you have your decision, make sure you talk to all the stakeholders, from the owners, the chargers, the providers, internally, make sure you have everybody on board to get through the project.
QP16A	No, obviously we are looking at expanding wind-assisted propulsion. Now, I cannot share any specific details or any concrete details, as nothing has been announced, but the goal is, of course, to build more partnerships and more projects around this technology. Well, so far, we are satisfied. But again, it's not on the ship yet. It's still early stages. We'll have to see how it works on the sea then.

Appendix 2 – Interview of Ship performance manager in maritime performance services at an international marine shipping classification, ship design, energy transition advisory, compliance and consultancy services provider (24.04.2024)

Interview Protocol

Code	Question
	Thank you for taking the time to give me an interview. I appreciate it.
QP01	*Could you start by describing your role as a Ship Performance Manager in Maritime Performance Services?* *What are your main responsibilities?*
QP02	*Given your role, how often do you deal with wind-assisted propulsion technologies?* *What has been your experience with these technologies so far?* *Have you seen an increase in interest for WASP ?*
QP03	*Could you explain the types of wind-assisted propulsion systems that are in use or being tested within your operations?* *What are the main technical challenges/benefits involved in integrating wind-assisted propulsion systems with existing ship infrastructure? Same question for Newbuilds?* *Can these systems be implemented to any vessel type and size?*
QP04	*From a financial perspective, what are the initial costs involved in adopting wind-assisted technologies?* *How do these costs compare to traditional propulsion methods?* *Do you have any idea of what is the typical return on investment (payback period) for WASP technology?* *Do you know how much it costs on average to implement WASP technology on a vessel? What are maybe just the types of costs related? And if you know an idea per unit, average price, cost to implement, do you know approximately how much it costs on average to put one unit?*
QP05	*What are the types of cost savings that are obtained through WASP?* *Are there any other benefits than fuel consumption reduction?*
QP06	*How effective have these technologies been in reducing carbon emissions and other environmental impacts in your experience?* *Will there be progress in the future in your opinion?*
QP07	*How do international regulations influence the adoption of such technologies?* *How effective is WASP technology for compliance concerning environmental regulations such as the CII and others?*
QP08	*Where do you see the future of wind-assisted propulsion within the maritime industry?* *Is it a short-term / mid-term / long-term solution?* *Do you see ships being fully propelled by WASP technology in the future?*
QP09	*What advice would you give to companies considering the transition to wind-assisted propulsion technologies?* *Is there a "best" WASP technology?*

QP10	*So the goal of my thesis is to prove or see if wind assisted propulsion technologies are a cost effective tool for decarbonization in the shipping industry. So based on the interview, the questions I asked, do you feel like there's maybe an information that I did not ask for and maybe that could be relevant that we didn't talk about?*

Interview transcription - Respondent B

Code	Response
QP01B	Of course, as a ship performance manager, we do work on advisory and consultancy work for fleets, banks, charters, NGOs, energy efficiency providers, such as wind propulsion. And the aim that we have is to support our clients on how to improve the performance of their vessel. So, it can be driven or just operational measures, or it can be for environmental regulation compliance and how to transition according to the challenge that they have. So, we mix a lot of the technical and regulatory aspects of the fleet, and we measure the exposure, we project into the future, how this may affect and what is the risk of not making a decision, or the risk of going to one solution or the other.
QP02B	So, we definitely have seen a lot of interest picking up, and it has to do a lot as well with the media. It has an important role. When we did the Maersk Pelican back in 2018, there was a large influx of questions and requests for proposals and for engagement advisory work. Now that we are moving like five, four years ahead of that, we started to see a really important uptick of technology questions around wind propulsion, which fleet is applicable, what is the potential benefit that we observe during the operation of the vessel. And as we move into 2024, with LDC announcements and Cargill announcements on their investment in wind propulsion, as well as MOL start creating their wind challenger, we start to see a really massive pickup in interest in a lot of questions, to the point that this is becoming one of the most relevant services that we are offering to our clients. The questions keep on coming, of course. What we try to tell them is that this technology has to be assessed vessel-by-vessel and route-by-route because of the variability of the wind resource that you will find. So, this kind of makes a lot of really good work for the advisory side to inform the client, this vessel from your home fleet is the best option that you have. And we combine now with the EU ETS, the fuel EU reward factor that creates a really interesting business model for this type of technology. So, we are really good on wind propulsion. We have been working with them for at least two decades now. And as I mentioned, the Maersk Pelican probably is the most iconic work that my company has done on wind propulsion because of the transparency of the results, because of the media that Maersk and Norsepower developed for the results that we verified. And from that, allow us to create a really good understanding on how to model this technology. With that, and understanding the aerodynamic characteristics of each device and where they are installed, we have a lot of powerful modeling capabilities to assess how this technology will impact vessel-by-vessel and route-by-route. So, we combine the modeling from our

	side, combine with AS data, combine with MetaOcean information, and this gives a really powerful package. Again, this allows us to be in the middle of the wind propulsion discussion on wind. As well, we are part of the new wind industry joint program from Marin. It is now version 3. We just recently joined on this April and we were present at the first discussion. And at the same time, we attended a lot of the wind propulsion-related conferences, especially for example, Wind Athletics in the UK. We tend to be present there. So, we are moving quite aggressively now on the marketing and the effort to pull more and more queries for wind propulsion due to the expertise that we have. We have a lot of people, this is more from the class side, more than from advisory. We have people in China that are working with a lot of the installation and the safety confirmation of the devices. And we work really closely with ANIMI, Northpower, Mountain Blue, and other companies in China to try to understand how to improve the installation, how to improve the safety, how the training has to be done. And we have been really successful in those parts as well.
QP03B	So, what we, in our research for insights, what we are seeing as the biggest technology share at the moment is flettner rotors. They are quite common. This is now followed by suction sails, then rigid sails, and finally kites. Kites are, we have seen since 2008, a drop of interest because of the complexity of deploying and recovering. I'm not saying that they are not going to be in the mix in the future. There's a lot of innovation happening around kites, which are trying to solve these issues. Or adding other capabilities, which are really interesting to observe at the moment. But going back to the most popular ones, is flettner rotors. There's Alimia and North Power that are leading the effort. But suction sails on year-by-year growth, we're seeing suction sails growing faster than flattened rotors. Again, still it's around 56 ships, as I'm trying to remember, that they have some kind of device installed. However, the benefit of suction sails is the price, to be honest. The main driver is less components moving. You have a fan, of course. And you have the sail rotating, but it's just rotating against the wind to maximize the thrust. With the flattened rotors, it's more expensive and more complicated. I can say that it's extremely complicated, but it's more complicated in that sense. And rigid sails, they are complex structures. They are really big, especially the ones with cargill and BAR. They are just understanding what are the optimization procedures within this test. So, they bring the biggest savings of all the technologies there. But as well, they are the most expensive and the most interesting on deck. So, again, how they're going to be picked up by the industry depends on this multifactor appreciation. Every ship and every owner. And it could be a charter, because now the paradigm is changing a little bit. It's not just the ship owners, but the charters are investing in this technology. It's depending on what they see as more valuable for that. And sometimes it's

	either the company, you can see the case of LDC, that they really like what they saw not only on the product, but also on the company, and how it formed AlphaBlue, that they invested in the company. And we were involved in the whole process with LDC. So, from the feasibility studies, they told us these are our fleet, these are our technologies that we wanted to explore. We simulated the work with them. And then we started to narrow it down. Like, this technology with this vessel is doing really well. They want to focus on the juice carriers, because they touch quite often in European waters. Plus, it's a constant route. And they have a sister vessel, so they are going to be able to compare what is the benefit of the propulsion against the same vessel, coming in the same route. So, at the moment, we're doing a lot of other work behind the scenes for LDC, for the implementation of the devices.
QP04B	Yeah. So, the challenges in general is the variability of the resource and the unknown nature of chart reading, for example. You don't know where the vessel is going to be navigating the majority of the time unless you are in a really constrained route, like is the case of LDC, it was an ideal one. But when you have a vessel that is going to be navigating around the world, it's quite difficult to try to understand what is going to be the benefit. And you will see it with the Maersk Pelican Report that, even in the same route, the same vessel, the same equipment, just because it was a different month of the year from a 12% fuel reduction, we obtain the following month or two months after, like 2 or 3%. And this can be as well negative. And that kind of uncertainty, which is the nature of weather, right? It's kind of one of the boulders that put people to wait in order to make the decision. As well, the other challenge is the cost of the systems. Even though I'm saying subship sales are way cheaper than a rigid sale, the economics still are difficult. We're talking about maybe about 7 to 8 years payback time, which a lot of the stakeholders in the industry don't like to see that number. But they're the first mover to say, yeah, I'm going to keep this ship for 20 years, so 7, 10 years is not a problem. The problem is, it's actually going to return what we think it's going to return. And to be honest with the technologies, when the lower carbon fuels or the net zero fuels arrive, that's going to be an enabler of wind propulsion. Because these fuels are much more expensive, so if you can reduce them 8 or 5% of that fuel consumption, that will make the payback time much more attractive. Combined with that, another enabler is definitely the fuel you reward factors. That can reduce your payback time sometimes by 35 to 75%, depends on the amount of time that you are navigating in European waters. That makes that transition really good. Other challenges is a lot of the markets or the system is asking, what is the effect of manoeuvrability, visibility of installing these devices? Even though what we're seeing initially, this is hearing from Cargill and LDC, but other installations of the Maersk Pelican, we don't see a lot of impact on these aspects of safety on board. Of course, another thing that we need to have in mind is that these are demonstration ships. Now we're starting to transition to fully optimizing, fully

	maximizing the wind resource that you can gather in the vessel. So now we're going to start seeing massive installations, or we're going to start firing one or two technologies. So probably this is going to change. But again, how do you measure the manoeuvrability of these devices? This is something that they are asking us all around. Do you do sea trials? And in what position would you need to put the sail? If you have a collapsible system, do you collapse because you already know that you're on board, so you want to minimize that windage area? Or if it's fixed, should you stop the rudder when you have bad weather? So there's a lot of questions that the industry is trying to answer. And that's why we joined the industry program, because they're kind of the central part of the project, is to answer those questions. And you have 25 different groups of companies covering different aspects of the industry trying to answer these questions. So you have that part that is sort of known, like how the operation is going to be affected. Are you going to operate with a massive amount of water just to try to compensate? What type of software do you deviate a lot from the optimal routes in the shorter distance just to catch the wind? And how far is it going to take you? How vulnerable are you going to be? But to that, and it was really interesting when I went to Geneva in February, yeah, February or March, with Luke, actually. And we spoke, we had a roundtable with Cargill and LDC, and they were explaining their experience, mainly Cargill, about how the crew has been adapting to operating with that. And it seemed that they learned really quick. They feel empowered about using wind propulsion, and that enables us to optimize the operation of the system. Even though the knowledge is just, the learning curve is just starting, the crew is really aware of that. And they have discovered really interesting things on how to move, even in difficult weather conditions, how they can use the wind system to help them get out of the bad weather really quickly with not that much power. So I think there's the challenge in that on the moment that we are in the transition, and with all the marketing information that the decision makers are bombarded, and you have full paintings that they promise you 15-20% reduction, wind system, as you see, 70% reduction. Under what conditions? Why are you saying that? And so there's no transparency, there's a lot of uncertainty, plus the nature of the industry that is quite conservative, they tend to wait and see, to be honest, what is going to happen. And jumping into the technology, and even though you have LR, D&B, validating these technologies and bringing nice numbers, I wouldn't say that if you have 6% I think it's still good enough. There's no technology that can offer you that. And on a normal basis, up to 12-15% in regional voyages, then it's really not that bad. But still there's not a lot of trust in this, because how things pan out. Like you invest a lot of money and then the results are not coming here. You don't see anything, if you say. So that uncertainty, that bombardment of information, is another of the challenges that they are facing, and they're holding back a lot of the investment.

	And saying that, as I mentioned, the growth that we are seeing, again we're seeing exponentially year on year, like it grows much more every year from the previous year. So I think it's following a similar trend to what air lubrication did from 2015-2016. It's growing in that direction, and you can see the number of players compared to lubrication is much wider. The innovation as well allows you to be much more broader with what is coming out. But at the same time, with this innovation, uncertainty arrives on the market, which is a chicken and egg problem. I think through investment from the government, I'm thinking European Union is one of the best examples, and Banfor Blue, that they give some money to do this pilot test. So we are working with Bound4Blue for one of those projects to try to validate that it's going to be transparent, the reports are going to come out with the performance, and people can access that. And the idea is a double benefit for Banfor Blue. One, it validates its technology internally. Second, it's a good marketing tool to go out. And hopefully, this investment from the European Union can incentivize other wind propulsion manufacturers to follow the same pathway. And at the same time, with this trust, or this evidence, transparency, people that are sitting in the fence can start moving faster into the wind propulsion movement. Size doesn't matter at all, but you have to remember that, say, for example, sails have been in small ships, and then you have the jets doing sails, and you have now container ships, even considering having wind propulsion, which if you asked me three years ago, I would say this is ridiculous. But now you're starting to see this innovation, again, breaking the barriers of common knowledge and trying to expand to the market. And because of the transition, it's pushing really hard, and there's no really other solution that can give you a lot of benefits than just a lot of investment and innovation in this area. And I forgot to tell the difference with new fuels or advantages or disadvantages between new fuels and retrofits. The most challenging one that we are seeing is you have an existing ship, you have a structure, or you have equipment on board, and you need to find the place where you can put these sails. So playing around with where you're going to install, and you have to think that the bases are really critical in the installation of the sails. They're really big. They're heavy. So it's not that simple to put it as you can do in the drone and say, yeah, you can put four. In reality, you have helipads, you have catches, you have ports that you have to arrive. So in a retrofit, you need to give a lot of thought to what you're going to put in. When you have new fuels, even if you don't install it from the get-go, you can plan the structure. You can plan where this metal is going to be installed. As well, from the cost perspective, all the bracing that you need to add on to the existing ship is quite expensive and complicated, as I mentioned. But in a new fuel, if it's considered since the beginning, you know the weight of the system plus the fatigue plus the load. It allows you to optimize and it will create a structure internally to support that weight and that trust. So our expectation is that installing from a new fuel should be easier, should be less expensive compared to retrofit. But everything

	that we are seeing right now is retrofit and they're hitting all the challenges without a problem. Of course, it's expensive. The less owners, it's quite important. The LDC one, which I think is one of the most complicated that I have seen, because you have to use carrier tags and you don't have a lot of space to put this really massive. Even if it's smaller compared to a floating rotor or a rigid sail, still, it's really massive. So that kind of challenge they are tackling is difficult, but not impossible. So I feel that a new fuel is going to be much more simpler and cheaper when you're doing all the metal work that you need. Again, the base, you create the base, and then whenever the system is ready, you can install it maybe five years, ten years after the vessel that you have already everything in place to just plug it in. Yeah. So on proportional terms, well, kites are the cheapest one, but you have to recover. Like when you lose them, you have to recover. You have to buy basically almost half of the system just to recover the kite if you lose it. Then it's followed by suction sails. And let's say that this is a unit of cost, the suction sail. Then you move to the flattened rotor, and this is normally 2 to 2.5 times the cost of a suction sail. And then you move to the rigid sail, and this is going to be around 3 to 3.5. When you go to the Michelin one, probably it goes to 4 to 4.5 per sail. So it's another technology which has not been that successful. I think the cost barrier is the one that is blocking a little bit the presence of that. Then you have the MOL-1, which is an interesting one. It's a rigid one, but segmented, because you can have different heights depending on the width. I don't know the price, but due to the complexity and being a rigid sail, I would say that it's more expensive than the rigid sail that you have on VAR. And it goes as well like 54 meters, I think, tall in the maximum expansion. So I'm expecting that that's going to be much more expensive than the common rigid sail. But I will say that it's in between the Michelin and the VAR solution on that sense. So that's kind of the unit. Plus, the important thing is, as well, the base, and that's where it hits really hard. The base tends to be the same price as a soft-sail, and it's fixed. So you have that same price. But if you start to add rails, which is, I think, the next cheaper option on the deployment or how you fix the sails in the next one, probably it's going to be 1.5 of the fixed base. And then you have the collapsible ones, which is kind of what the ANIMI VAR, they are using to put down their sail, and that's going to be almost double the price of the fixed sail. So this is really kind of a hidden cost that nobody sees coming. And the reason is the amount of metal that you need. Because, again, we're talking about sails that are done with really light materials, but they're massive. And on top of that, you're doing a collapsible system that normally is hydraulic. So that whole system and the safety requirements and all the pressure levels, that stuff makes it really, really expensive. So as you can see, a really interesting trend.

	Between 2019 to 2021, there was an uptick of really big flipper rotors with collapsible bases. And now we're going back to smaller flipper rotors, so you can cover the air draft in the ports, but fixed bases. Because, again, on the business case, that's making a lot of sense. So I'm not saying that the prices of the bases are not going to come down. And I think, again, if you plan it from a new build, it should be much, much lower, all these costs that you need to add. Because the complexities are becoming quite big. When you collapse it, you have to see what is the visibility, how it's going to be affected, how much you can tilt it. So it's a lot of questions, and the base has to be adapted to that precise location. And that precise system on that base. So it's not like you can just produce this in series and then you can sell it abroad. So it's just one base per system, per location, and then you move to the next. So it's quite expensive now, but maybe, I don't know if you think the same, but I'm assuming that over time, it's going to get cheaper and cheaper.
QP05B	There's a lot of learning curve which goes to optimize the production line. The best case is Bound4Blue, which they are using the existing production lines of wind turbines, and they just say, I want this amount of suction sails for now, and in between wind farms, or the base of the wind farm, they put one of them. Now that they are growing, they have invested in creating their own dedicated production lines for the same manufacturing company. So, what do you do? You leverage all the knowledge that you have on wind farms. But now you have a dedicated one. And it's a good business for the manufacturer, but it's a good business as well for you because you have better control on how to produce it. And another good example of the learning curve is with ANIMI. And there's a paper that we wrote, well, not me, my company wrote with ANIMI for the BATS RIGNA conference. And it's the experience that they have on installing the vessel. So they have the Gen 1 flattened rotor and now they are trying the Gen 2. And one difference of the Gen 2 is that what they discovered is that instead of trying to install, at the same time, the base and the flattened rotor, they install first the base, they put all the electronics and electrics that they need, and one month or 12 months after, when the vessel is around the shipyard, they go and just install the flattened rotor. And with that, they managed to reduce the time in the write-up, which is something critical for the clients who are barbaric as well. And then they managed to minimize the price and the cost of the whole process because there's no delay. You don't need to wait for everything to start, to be there, you don't need to expedite everything. So that allows to reduce pressure as well, to reduce cost. And this is just the first generation, the next version of the flattened rotor. The same is going to happen with VAR, the same is going to happen with suction sails. They are learning really fast. And other technologies that are there, that are being selected as well, I think is that. The only thing that I'm seeing struggling a little bit more is the kite because, again, there's not that much that you can do when you use the kite.

	Even though they are trying to force the behavior of the kite to be made, and having hydraulic pumps to generate electricity. So you have priority to arrive. And that is a saving on CO2, time, you become really efficient. It's the only port in the world, I don't know if this is going to be replicated, The other one that we are starting to explore, and it's going to become a really important topic in the future, is underwater noise radiation. And we believe that because you're using wind propulsion, you load less your propeller, and the vibrations of the vessel, so you could get lower noise levels transmitted to water. And it's not a saving, there's no penalties right now. But, for example, if you go to Vancouver Port, and it's the only one in the world, and you demonstrate that you produce less noise than the average, you have a discount on the port rate. So it's something that probably is going to come playing forward. The other one, and if you want to see a saving, is the fuel-energy reward factor, because it doesn't have to do anything on what you're doing with the vessel. The only thing that you need to demonstrate is that the installation is capable of reaching a certain threshold in power return, and this is done through the aerodynamic characteristics of the system. Plus the wind map that the IMO gives you, in the sequence 8, 9, 6, yeah. And you demonstrate through that, that what is the potential benefit. If you reach a certain threshold, you have a fuel-energy reduction factor of 1%, 2%, and I think it goes to 5, something like that. And that's a part, like, you can switch it off, you can collapse everything, you never use it, you get that 5% if you reach that threshold. Of course, in reality, you want to use it, but it's an independent way of saving that plus, saving you money, basically. The other one that we're learning and supporting in Brazil, I forgot the name, and this is happening only with the Cargill one. If you arrive with dedicated wind sail technology to the port, you can jump the queue. or when you have millions of these vessels, this is going to be not attractive. But today, they are incentivizing the arrival of wind ships in Brazil through giving this benefit. But that's a good cost-saving, because maybe for charters, they can avoid paying damage and even receive money from the ship owner, depending on the charter type they have. So I think that's a good cost-saving as well, this one. Jumping the queue is quite interesting. It's only one port, but it's a really nice experiment. Yeah, that can happen in a couple of years. It might change, there might be many ports in the world that will do that. And I think the European Union will be really interested on that kind of framework, just to impose this take-off of wind propulsion, especially in this decade. Probably this is another really interesting one you want to have.
QP06B	
QP07B	Yeah, so it's kind of broad in the sense that they have a, the majority of the ships, especially war carriers and tankers, they have an issue with their CII. The EEXI, the problem that they have is the power limitation at the moment because there are some that they don't manage to reach the desired EEXI goals so they need to reduce the power so you are limited already in the speed

	that you can operate and that impacts your operation. I haven't seen yet that this is the main reason why they are moving to wind propulsion. As I mentioned, it's a lot of pilot testing to see what to do with this technology. However, it will impact your, if you reduce your fuel saving by 8%, your CII will improve by 8%. But when you see the trend and the line of the CII, how it reduces year on year, you are at the point, and we have in 2026, it's 2.75% per year. That means that your installation, even if it gives you 8%, let's say, in three years it's going to be back to where it was before you installed it. So the length of the resilience that wind propulsion gives to your ship is not that much, especially when you think it has to arrive to 2050. So there's an incentive from that side, but it's not that powerful. What we are seeing as an enabler, as I mentioned, the fuel-to-fuel report factor has been a big enabler to a lot of the new installations on ships. And the driver is the saving. It allows not only the saving of fuel, but the saving of the penalty after you consume the fuel. So that's another of the drivers. Of course, I think people, the first movers, and I think the people that are putting the wind cells, I consider them as first movers, they're taking a hit. So they're taking when this, the really expensive fuel, and when the transition, when they finally give some tooth into the regulations that they have, like actual penalties and all this stuff, what can we do? And that is when the narrative changes that, yeah, probably it's going to be a driver. However, we don't know if the CII is going to exist by then, when you have the fuel standard that probably is going to replace the CII because it makes more sense in terms of density, and you cover this threshold or not, and what happens if you don't cover that threshold? Is it a tax? Is it a levy? Is it a fee base? Like, still there's a lot of blurry lines to be decided. But probably that, you don't need to have the CII, but you have the fuel standard, or whatever is going to be the name. So I don't know how it's going to be, but definitely whatever is going to be in the future, the regulation, I predict that they have to have some punitive action, because it's not that the industry is not going to do anything. They already laughed about the CII because there's nothing. There's just stress at the beginning, and then it's like, well, nothing's going to happen to me. They claim that probably the charters can change the preference if your vessel is A or B. Perfect, I will pay you what you're asking, I will pay that much money for your shipped vessel. But I still have to see the evidence that this has happened in the market. And I'm not involved in that, but maybe you can ask Luke if this is happening or not. But I do think that the driver is the business case on the reward factors and fuel savings, and preparing themselves for what is going to come into the future. And a really interesting thing that we have been discussing, the production lines are not there to one mass adoption. So these people are creating a relationship with the wind propulsion manufacturers, and they're learning how long it takes, what are the problems

	that you have when you install. They're learning, they're ready for when they have to deploy a lot in the fleet, they're ready, they have a relationship with them that will let them be in front of the king. So I think that's what they're doing right now, so they're learning. And that's why I call them first mover, because they're learning. And the more valuable thing that they have is the knowledge.
QP08B	My opinion is you could do it, but you have to go back to the way that we operate the market. So I think, in realistic terms, I don't think it's going to be possible. You will have to have some kind of mechanical propulsion or electrical propulsion to assist you. Similar to any sailing boat, competition sailing boat, when you need to arrive to the port to start, you use your engine just to move, right? The evolution, I see, again, a lot of optimization in different areas, like production line, as I mentioned, design. And there's a lot of, even though they're really good companies that you have, they're just learning, they're investing in CFD, they're investing in people that can bring that. They're understanding what is working and what is not working on the first generation of systems. And if we see it, like, I always think about the sailing racing boats. They are people innovating, and when you compare the best from early 2000s to the ones that we have now, the difference, the technology is totally different. Before, they invest a lot of money in that. But similar levels of investment probably will interact to this sector. And shipping being stocked with no fuel, green fuel in the future for now, this decade, that incentivizes a lot of this development really quickly, hopefully. And at the same time, having enough money on the market, and a lot of universities, a lot of people thinking, and a lot experiencing that can create their own entrepreneurial efforts and bring new technologies on the front. And we are seeing some prototypes of new sails, new concepts, that try to reduce the shortcomings of existing technology. And how they're going to materialize in the future depends a lot on that funding, and how successful they are on putting money and demonstrating pilot testing to develop that. So I see an important role of this decade on the government, to incentivize low TRL concepts in order to make it up, and support the expansion of TRL 7 to 9 of companies, that they have a solid prototype. And I don't think we're going to arrive to one technology or one family of technology for everyone. I think each technology offers you a benefit and a drawback, that is better, is weighted more for a certain type of ships operation, and another one for another one. So I see that as a really evolving field. I think sails are coming to stay. I see the role as assisting, not as a full propulsion. I can imagine that, and this is a work that probably we're going to explore more with, the work that we're doing with Power for Blue, finding geographical areas where wind propulsion could be super constant, or constant enough, enough reliability in that number. And how big that area will be, how much activity is going to be in the geographical area.

	And maybe under those conditions, probably full wind propulsion can happen, but the ship will have to have some certain amount of propulsion, because when you have bad weather, you need that certainty that you can get out of the storm. And I'm really partial that when you talk to the International Wind Association, they're super passionate on 100% full propulsion. I really don't think it's viable. I think we need to focus on just making the wind assist happen, and to be widespread where it makes sense, while the fuel comes in. And as I mentioned, when the fuel comes in, the green fuel, this is green or blue, or the color, whichever color it is, and biofuels, I believe that this technology will enable to reduce the operational cost, and the business case will make much, much sense. So probably, even if you are uncertain in the wind resource, because of the payback time that you may have, we will have a larger adoption of this technology in the future. But again, we need a lot of things to happen in this decade of wind propulsion to get the show up, and start evolving the technology and the service, and the support that the client needs. Because that's a really big point. Like, you see a difference on the service delivery, on the different manufacturing plants. We have seen companies that they offer the whole support from. We model you the stock. We convince you, we help you to install the system, and we join you through your path, your voyage with wind propulsion. There's other companies that the only thing that they do is, I model you, I sell you the tape, and you tell me when I'm going to install it, and that's it, you say, they clean their hands. And I think people or ship owners are not satisfied with that approach, especially in these early stages of wind propulsion. I see a lot of added value with the manufacturing of the wind sail, or the sail joining the customer. Of course, there's a limit on how much you can join them when you have a lot of vessels at this point in time where the installation is not that much. And there's a lot of things to learn to have this more customer-centric approach. Yeah, more of a collaboration to help install it and prove that it's efficient. So, show some motivation to make it work, actually. They cannot be seen at this stage as engines, you just produce them as a bunch and it's your problem how you install it. I know that that's an approach that some companies have at this point. It's more collaborative, closer, customer care is super important if you want your technology to be successful in a highly competitive and highly skeptical market. Okay. So, yeah, what I thought about when the system propulsion, I kind of see it, I think you confirmed that, it will always be an additional tool to help ships. So, if we get, imagine we make hydrogen engines and they're efficient, well, we can always consume less hydrogen with wind and save money anyway. So, that's what I think about it. Totally. Perfect. I see the role with hydrogen or whatever in the fuel, even electrification, whatever the source of the energy is coming, wind is going to be there because it allows you to save money and the payback time is going to be more attractive.

	I think it is, for sure, a short-term measure that allows them to comply with the environmental regulation. For sure, it's going to be a mid-term one. We are thinking about the evolution of all the technology. When the fuels are starting to arrive, and could be biofuels, wind methanol, that is the closest probably to arrive to the market. That would allow to offset a lot of the cost plus regulation. And the long-term, when we have the green fuel, whenever it's going to happen, it's a cost reduction enabler and allows you to keep the operation cost low. So it's useful now, it's useful in a couple of years, and over the long term, it's always going to be helpful. It depends on where the ship is operating at the end of the day. It's not that everybody is going to have this, if the wind resource is there. But for sure, you will see it. So I guess we'll see over time, ships operating in certain zones of the world, because it's where they're more useful, and maybe other places where there's less wind, they'll find, maybe they'll focus on engines and other solutions. And one thing that I have thought about it, and especially with the question, and now I'm starting to speak it, but I have thought about it, but never spoken, that probably for the variability of the routes, what may happen into the future, is that all vessels will have the basis to install the wind device, and the company is going to all, or they have a work out where they have all the wind resources, and when the vessel is chartered to go, I don't know, in a heavy wind area, they install the rotors. They arrive, and then they have to move to another place. There's no wind, and we need to reserve this for the return trip, whenever it happens. So they store the wind system. So kind of like in the battery, the battery idea that you don't, you change the battery instead of charging it, because it's already charged, so you spend little time on that. Probably shipping could be a really interesting business model when the cost reduces, and you don't understand your operation, to be managing ships and managing devices, and you install it depending on where you are navigating.
QP09B	So my recommendation is that knowledge is your best weapon to make a decision. So I will first ask for independent advice. I'm promoting myself. To do a pre-feasibility study. Why? Because it will understand your operation, what you do, what are the limitations on ports, the routes, how you operate, and will single out the best that are at the most potential for repropulsion. And understanding that, knowing the potential of the ship, then you move to what technology is more applicable to my operational business. And again, you simulate that. And you start to filter out now vendors. And finally, you match a vessel with the top three vendors. And then you go and talk to the vendors and say, what offer do you need me? What is the customer care? How do you success cases? All this stuff. So my recommendation is, first, do your due diligence to detect what vessels and what routes are the ones that you need to focus. So you reduce the risk of putting a lot of money into repropulsion and let's see what happens.

	You invest a little bit in the beginning. And it's not that expensive, to be honest, when you compare it to the price of the wind cell. And allow them to have a plan. And you say, OK, I have 10 vessels of my whole fleet. And it's going to cost me approximately, let's say, $5 million per vessel. So how do I start creating that pathway of investment and de-risking the model so I can make the decision which one? And you can go in the direction that Cartier is doing. They are putting different technologies. They have the rigid sails. We have where they're working with the flettner rotors. And I'm sure they put a suction cell in another class society. So they're trying the three technologies. And they're letting me rip. Give me data. Let's see how the experience is with the manufacturers. So this is more mature. And, of course, we're talking about Cargill. They have a lot of capital to do this experiment. But if you're a smaller one, I think this first stage will allow you to focus your investment. You probably want to do a pilot test first. You don't put the maximum number. Maybe put one or two. And you see how the crew behaves, how they feel, if the models and the promises are being delivered. If yes, then you can probably just start to expand that into the rest of the fleet. So I think that will be the best way to start. Inform yourself which of your fleet vessels give you the potential. Big companies like Corgill, LDC, that have bigger pockets are kind of opening the gate for smaller companies to invest. They're proving that it works.They're paying. Let's say they're investing instead of them. They're showing the world it's possible.And then the other companies will be convinced and maybe start investing also. And more and more companies will invest over time. And that's kind of the biggest barrier that we mentioned at the beginning. Like that uncertainty on the performance and the business case of the technology is one of the big drawbacks. But as you start to push information out over that, which is the European Union, the UK Commission, if I'm going to pay more money, you need to put this outside so people can get trust with that.
QP10B	We have our calculator, I think it's called Flettner on Rotter. I will send it to you. I will put it in the chat. It's a really interesting tool that you have in mind to simulate voyages. And the idea that we had from our point of view, they are going to come and ask us more about Flettner on Rotter. That's not really happening. I think it's more when we talk to people about this that we get the business model. I think that's a really good resource that you can use to play a little bit to, if you want to demonstrate a case, like we have different vessels, you can play with the route that you want. And you can showcase with that, with examples, what is the variability, how sensitive is the propulsion to different conditions. And it's really interesting. But I think it's a really nice technical resource. It doesn't give you the business, but it gives you the fuel savings and how we can change through different months on the same route and different operational speeds and draft of the vessel. I'll try to go maybe on that.

Appendix 3 – Interview with founder and managing director of Geneva based company providing services to the International Trading and Shipping industry (14.05.2024)

Interview Protocol

Code	Question
	Thank you for taking the time to give me an interview. I appreciate it.
QP01	*How do regulations such as the CII or EU ETS affect the shipping industry? Who are the most impacted industry players? How effective are these regulations for the decarbonization of the shipping industry?*
QP02	*What are your thoughts concerning WASP technologies? Do you see a future for them? What are the main benefits/challenges you see?*
QP03	*Is WASP technology a short-term, mid-term or long-term solution for decarbonization and compliance with these regulations? How do you see the future of WASP technology in this industry?*
QP04	*Is WASP technology a cost-effective investment tool for shipping companies? What are the main barriers preventing shipping companies from investing in these technologies?*
QP05	*If not WASP, what is the best solution for cost-effective decarbonization of the shipping industry?*

Interview transcription - Respondent C

Code	Response
QP01-05C	As far as CII and EU ETS, a lot of the shipping industry is calling for a level playing field. And so these regulations, they ensure that everybody involved in similar businesses are actually paying the same costs. However, the regulations themselves are not always designed very well. So the CII, the problem is that it actually ends up with being incentives to sail further. So that doesn't really make much sense. And the EUETS is only applying to cargo coming into and out of Europe. And so again, that causes a bit of an issue. And so they are changing, they are affecting the shipping industry. I'm just not convinced they're changing as fast as we need to change, and whether they will continue to change quickly. Who are the most impacted industry players? Having to go through the value chain, at the end of the day, who's paying for these things? It's the consumer that's paying. But not just the consumer, because all the parties along the value chain are paying by a reduction of their profits. And so I think in the short run, it ends up being the ship owners who are paying for these. And so the most impacted, but then they managed to work it into their freight rates. And so then it ends up moving down the value chain and ends up being the final receiver who pays for them, who is most, let's say, most impacted. If you mean which sector has the most impact, I mean, for the CII, then you're probably looking at some of the larger vessels, some of the bigger charters, because they're the ones who are going to pay much attention to it. And if you're looking at EUETS, it's just a question of what goods are moving in and out of Europe. How effective are these regulations on decarbonisation of the shipping industry? They're a step in the right direction. I'm just not convinced that they are going to get us all the way there and what else needs to be done. But certainly, they're better than nothing. And they do show that we are looking to move in this direction. How long is it going to take and whether that's going to be effective? Again, I'm not 100% sure. You're asking about wind-assisted. Essentially, there are going to be many angles to the solution to decarbonisation. And those angles are going to be a question of how much do we end up saving, how much do we reduce in the emissions, and how much does it cost? And the problem is that the wind-assisted, we're essentially talking about sails. And so the bar technology at the moment, that Cargill have put on their vessels, I think that they are too expensive at the moment. They cost too much to install and they don't actually reduce the fuel consumption by enough. And the problem is that as we end up going into

	more expensive fuels, then that calculation becomes even more problematic. And so, yes, I think they're interesting. I think that as their volumes increase, then the price will go down. And then it will become more interesting to see them kind of being installed on more vessels. They are part of the future. They're certainly not going to be the sole solution going forward, but they are definitely a part of the solution going forward. The main benefits, the main benefits is the efficiency, the cost reduction, the reduced fuel use, which then results in reduced emissions. Challenges, challenges is the cost, but also as soon as you start ramping up the installation, you either install them on a new vessel or as a conversion from a previously built vessel. If you are converting, then you need to go into a shipyard. You need to have shipyard space. There is already a massive shortage. We don't have enough shipyards to build new vessels, let alone get all of the world's fleet into the shipyards in order to install these new sails. So I think unless there's a massive shift somewhere, it ends up just being a bit of a nice concept. So is it short- term, mid-term, or long-term solution? I can only really see it as in its present form as short-term. I think they would have to change quite significantly to be a long-term. But I think that we need to have, essentially, if you get five or six different technologies on board of a vessel, you can then end up reducing the consumption, reducing the emissions by maybe 20%, 30%, maybe up to 50%. And that's already a massive, massive step in the right direction. How do I see the future of watch technology in this industry? It's basically the same question. I see it as a part of the solution, but we don't know how much of a part. Is it cost-effective today? No, no. It doesn't make sense. I mean, you invest in a vessel, you buy a vessel for 20 years. I think at the moment, they take more than 20 years to pay off. If you do a very, very straightforward calculation, you'd say they save in the region of, what, about five tons of fuel per day. If we imagine our vessel is sailing for 200 days a year on average, let's say 250 days a year to be generous, times 250, that's 1,250 tons of fuel. And then you multiply that by $600 a ton, and you end up with $750,000 of saving per year. These things cost five to $6 million to install. And so you're already looking at, I guess, with that calculation, maybe after 10 years, they become cost-effective. But there are a lot of ifs in there. And so the barriers of what I've already gone over, they're the questions above. And what is the, if not WASP, what is the best solution for cost-effective cargo shipping industry? It's going to be a long list of things. First of all, fuel. So we're going to have to figure out what fuel we're going to be using, and I don't think we're going to end up with the whole industry using one fuel. There's a very, very good point that someone made the other day, that as soon as the industry decides which fuel to use, the price of that fuel is going to shoot up, and suddenly it's not going to become economically feasible. So what kind of, we're going to need fuel.

	We're also going to have different technologies, such as hull design, such as bubble technology that reduces the friction. We're also going to have anti-fouling technology. We're going to have wind-assisted technology. We're going to have vessel optimization. So all these things on the technology side, and then also regulations. And so basically forcing people to do, take the steps is going to be a big part of it. And by denying them access to certain ports around the world is going to be one of the best ways of this. Also, I think certification is going to be very, very important. So having something we can actually trust. And so if we can actually get together and say, yes, we all trust the means that are being used, then I think that's a lot of difference. So these are my answers. I hope they're useful. Cheers.

Appendix 4 – Comparative Table – Existing WASP Technologies

Rotor sails	
Provider(s)	Anemoi / Norsepower / Enercon / MariGreen
Product name	Rotor sails / Norsepower Rotor sails / Enercon / Eco Flettner
Vessel types	Bulk Carrier / Gas Carrier / Tanker / Ro-Ro & Lo-Lo / General Cargo / Ferry / Combination Carrier
Vessel sizes (DWT)	Up to 400'000
Newbuild / Retrofit	Both
Height (m)	18 to 35
Diameter (m)	4 to 5
Weight (t)	34 to 90
CAPEX per unit	- Asset costs: 560'000 to 1'050'000 EUR - Installation costs (newbuild): 84'000 to 158'000 EUR - Installation costs (retrofit): 140'000 to 260'000 EUR
OPEX per unit	- Annual maintenance & repair: 12'000 to 22'000 EUR - Annual energy consumption: 26'000 to 79'000 EUR
Training costs	10'000 EUR
Challenges	Size / weight / not for all vessel types / dependent on wind
Benefits	Fuel consumption & GHG emissions reduction / lifespan
Fuel / emissions reduction	up to 30%
Sources: (European Maritime Safety Agency 2023)	
Soft sails	
Provider(s)	Michelin
Product name	WISAMO sail
Vessel types	Ro-Ro
Vessel sizes (DWT)	8'600
Newbuild / Retrofit	Both
Height (m)	13 to 60
Challenges	Size / weight / not for all vessel types / dependent on wind
Benefits	Fuel consumption & GHG emissions reduction / lifespan
Fuel / emissions reduction	About 20%
Sources: (European Maritime Safety Agency 2023; Michelin 2023a; 2023b)	
Hard sails	
Provider(s)	AYRO / BarTech, YaraMarine (Manta Marine Technologies) / DSIC / MOL / NAOS / Wallenius / Chantier des L'Atlantique
Product name	Ocean-wings / WindWing / DSIC AeroFoil / Wind Challenger / Wing Sail Module / Oceanbird / SolidSail
Investor	Cargill (Pyxis Ocean)
Vessel types	Catamaran / Cargo ship / Bul Carrier / Tanker / Passenger & car ferry / Cruise ship / Ro-Ro

Vessel sizes (DWT)	Up to 306'750
Newbuild / Retrofit	Both
Height (m)	28 to 50
Diameter (m)	10 to 20
Weight (t)	45 to 100
CAPEX per unit	- Asset costs: 438'000 to 876'000 EUR - Installation costs (newbuild): 66'000 to 130'000 EUR - Installation costs (retrofit): 109'000 to 219'000 EUR
OPEX per unit	- Annual maintenance & repair: 8'000 to 18'000 EUR - Annual energy consumption: No data
Training costs	10'000 EUR
Challenges	Size / weight / not for all vessel types / dependent on wind
Benefits	Fuel consumption & GHG emissions reduction / lifespan
Fuel / emissions reduction	**Pyxis Ocean**: average 14% / up to 37% with good conditions
Sources: (European Maritime Safety Agency 2023; Cargill, Incorporated. 2024)	
Suction Wings	
Provider(s)	Bound4blue / Econowind
Product name	eSail / Flatrack Ventifoil / Ventifoil / Containerised Econowind unit / Ventofoil
Investor	Louis Dreyfus Company (Juice vessel - 34'584 DWT - at least 10% fuel & emissions rteduction)
Vessel types	Theatre ship / Fishing vessel / General cargo / Ro-Ro / Container feeder / Cement carrier / Chemical tanker
Vessel sizes (DWT)	Up to 84'860
Newbuild / Retrofit	Both
Height (m)	17 to 26
Diameter (m)	3 to 6
Weight (t)	15 to 55
CAPEX per unit	- Asset costs: 200'000 to 900'000 EUR - Installation costs (newbuild): 30'000 to 135'000 EUR - Installation costs (retrofit): 50'000 to 225'000 EUR
OPEX per unit	- Annual maintenance & repair: 4'000 to 18'000 EUR - Annual energy consumption: 26'000 to 53'000 EUR
Training costs	10'000 EUR
Challenges	Size / weight / not for all vessel types / dependent on wind
Benefits	Fuel consumption & GHG emissions reduction / lifespan
Fuel / emissions reduction	>= 10% (expectation for LDC juice carrier)
Sources: (European Maritime Safety Agency 2023; Louis Dreyfus Company 2023)	
Kites	
Provider(s)	Airseas
Product name	Seawing
Vessel types	Any type
Vessel sizes (DWT)	Above 250'000

Newbuild / Retrofit	Both
Surface area (m2)	300 to 1'000 m2
Weight (t)	Below 1
CAPEX per unit	- Asset costs: 340'000 to 2'345'000 EUR - Installation costs (newbuild): 51'000 to 351'000 EUR - Installation costs (retrofit): 85'000 to 586'000 EUR
OPEX per unit	- Annual maintenance & repair: 17'000 to 117'000 EUR - Annual energy consumption: No data
Training costs	10'000 EUR
Challenges	Dependent on wind
Benefits	Fuel consumption & GHG emissions reduction
Fuel / emissions reduction	Average 20%
Sources: (European Maritime Safety Agency 2023; AIRSEAS, SAS 2023)	