

POTENTIAL STUDY: SAIL CARGO SHIPS

Potential and applications of primary wind-powered cargo ships in sustainable freight logistics

A study by MOVE4WARD Innovative Transport Solutions

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FOREWORD

Maritime logistics faces the urgent challenge of significantly reducing its emissions and developing climate-neutral transport solutions in the long term. Alongside alternative fuels and efficiency improvements, a long-established form of propulsion is once again attracting attention: wind power. Cargo vessels using wind as their primary means of propulsion are increasingly being discussed as a potentially viable option for decarbonisation. International projects such as “Neoliner” and “TOWT” demonstrate that wind-powered cargo shipping is technically feasible and can be commercially viable under certain conditions.

However, the German logistics market has so far lacked a systematic, evidence-based assessment of this mode of transport. This study, conducted as part of the project Competence Centre GreenShipping Lower Saxony, therefore examines the market opportunities and the economic and environmental conditions for deploying sail-powered cargo ships in German freight logistics. It identifies suitable market segments and cargo categories, assesses the implications for emissions and costs, and provides a realistic appraisal of opportunities and limitations. Its aim is to make an objective contribution to the debate on alternative maritime propulsion concepts and provide a sound basis for decision-making by industry, policymakers and researchers.

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MARKET ANALYSIS

Maritime transport accounts for almost one-third of Germany's foreign trade

Maritime transport plays a central role in German foreign trade. Its share of Germany's total imports and exports rose from 27.0% in 2019 to 31.8% in 2024. Almost one-third of German foreign trade by volume is therefore carried by sea. This development highlights the structural importance of maritime transport chains for a highly export-oriented economy.

Figure: German seaborne cargo throughput and foreign trade in 2024 (million tonnes)



Source: Destatis (Table 46331-0001, 51000-0001); own illustration.

German seaports handle around 274 million tonnes in 2024 – maritime traffic remains clearly import-dominated at 61%

In 2024, almost 274.0 million tonnes of cargo were handled through German seaports. On an annual basis, approx. 166.5 million tonnes were incoming (imports) and around 107.4 million tonnes outgoing (exports). German maritime traffic is thus clearly import-dominated, with incoming cargo flows accounting for around 61% of total throughput.

German seaborne cargo throughput is concentrated in five major ports

Cargo handling is heavily concentrated in a small number of major locations. Hamburg remained Germany's largest seaport in 2024, handling 97.0 million tonnes, equivalent to 35.4% of total seaborne cargo throughput. Of this, 56.4 million tonnes were incoming and 40.6 million tonnes outgoing, indicating a relatively balanced structure with a slight import bias. The ports of Bremen and Bremerhaven followed with a combined 53.1 million tonnes (19.4% market share), almost evenly split between incoming cargo (27.6 million tonnes) and outgoing cargo (25.5 million tonnes). Wilhelmshaven handled 34.5 million tonnes (12.6%) but was clearly import-oriented, with 29.6 million tonnes received against only 5.0 million tonnes dispatched. This underlines its importance as a hub for energy and liquid bulk cargo. In the Baltic region, Rostock followed with 23.2 million tonnes (8.5%) and Lübeck with 15.9 million tonnes (5.8%). Both ports show a comparatively balanced split between incoming and outgoing cargo and are firmly established in short-sea and RoRo transport. Together, these five ports account for approximately 82% of total German seaborne cargo throughput (273.9 million tonnes).*

Figure: Seaborne cargo throughput at selected ports in 2024 (tonnes)

	Import	Export	Total	Share
Hamburg	56,412,883	40,571,503	96,984,386	35.4%
Bremen ports	27,594,263	25,506,353	53,100,616	19.4%
Wilhelmshaven	29,577,036	4,964,328	34,541,364	12.6%
Rostock	13,873,784	9,335,532	23,209,316	8.5%
Lübeck	8,540,994	7,335,249	15,876,243	5.8%
Other ports	30,545,371	19,650,614	50,195,985	18.3%
Total	166,544,331	107,363,579	273,907,910	

Source: Destatis (Table 46331-0001); own illustration.

* Note: The throughput figures shown are based on the official maritime transport statistics of the Federal Statistical Office (Destatis). Differences from throughput figures published by individual ports may arise from different statistical definitions.

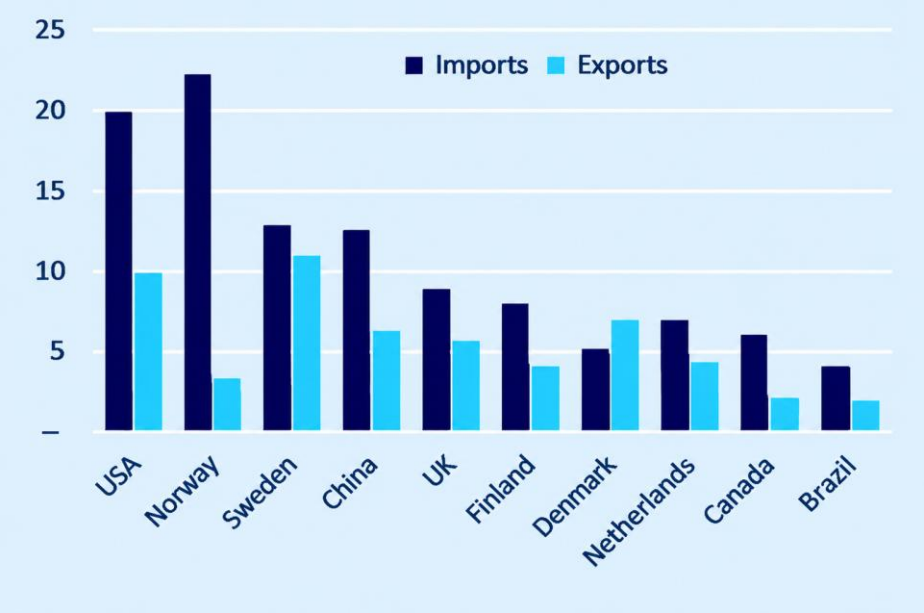
Maritime transport in 2024: USA leads, Europe shapes the underlying structure

In 2024, German maritime transport was concentrated on a clearly defined group of key trading partners. The United States was the most important partner, with total throughput of 29.8 million tonnes (11%), followed by Norway (25.8 million tonnes; 9%) and Sweden (23.8 million tonnes; 9%). China (19.1 million tonnes; 7%) and the United Kingdom (14.7 million tonnes; 5%) followed, alongside European countries such as Finland, Denmark and the Netherlands, each accounting for approximately 4%. This illustrates how both transatlantic and European routes significantly shape the structure of German maritime transport.

An examination of incoming and outgoing cargo reveals a more differentiated picture. Import-dominated routes are particularly evident for Norway (22.3 million tonnes of imports versus 3.5 million tonnes of exports) and the USA (19.9 million versus 9.9 million tonnes). Canada, Brazil and South Africa also show substantial import surpluses. These patterns are primarily driven by energy and raw materials. By contrast, European partners such as Sweden, Denmark, Finland and the Netherlands exhibit relatively balanced trading relationships, reflecting close economic links and integrated value chains in the North Sea and Baltic Sea regions.

Geographically, trade relations show a clear two-part structure. Many of the principal partner countries are located in Europe and are closely integrated into regional short-sea shipping flows. At the same time, major overseas markets such as the USA and China are highly significant for German seaports. Cargo structures vary by route: overseas traffic is often characterised by energy and raw-material imports, whereas industrial goods, intermediate products and containerised cargo play a greater role in intra-European trade. The following figure shows incoming and outgoing cargo through German seaports by partner country.

Figure: Incoming and outgoing cargo for selected countries in 2024 (million tonnes)



Source: Destatis (Tables 46331-0001, 51000-0012); own illustration.

The situation is somewhat different for container throughput. In 2024, German seaports handled 13.3 million TEU. Almost one-fifth (2.6 million TEU) was attributable to China, followed by the USA with around one-tenth (1.3 million TEU). Container trade with China grew moderately by 0.8%, while trade with the USA declined by 3.0%. German container throughput with European Union partner countries (3.6 million TEU), however, increased markedly by 17.7% compared with 2023 and accounted for more than one-quarter of German seaports' container trade.

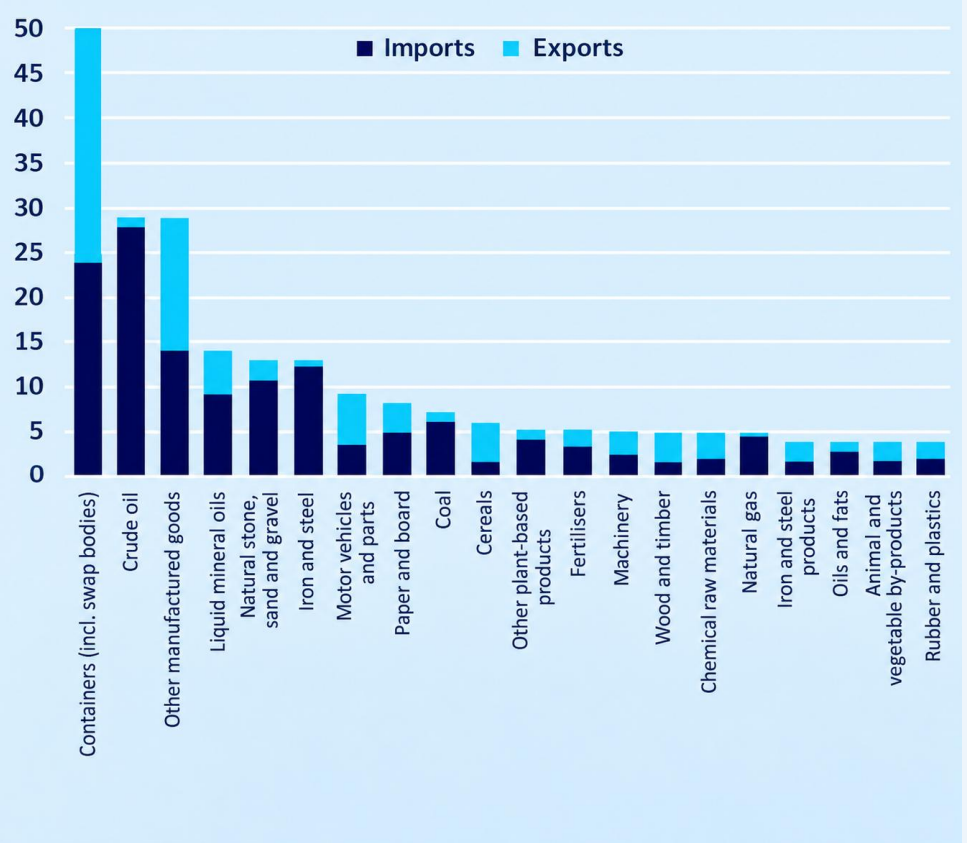
Energy imports and container traffic shape the cargo mix in 2024

As the analysis of trading partners has already shown, trade relations differ not only geographically but also structurally in terms of cargo types. A detailed examination of cargo handled at German seaports using the NST-2007 classification reveals the following structure for 2024. The largest category, unidentifiable goods in containers or swap bodies, accounted for 50.2 million tonnes (18.3%). This segment essentially represents containerised general cargo and highlights the importance of standardised loading units in international trade. A further 28.8 million tonnes (10.5%) comprised other unidentifiable goods, meaning that together almost 29% of total throughput was associated with containers or general cargo.

The energy sector forms a second major pillar. Crude oil, at 29.0 million tonnes (10.6%), was the second-largest category and was clearly import-dominated. This was supplemented by liquid refined petroleum products (14.1 million tonnes; 5.1%), coal (7.3 million tonnes; 2.7%) and natural gas (5.0 million tonnes; 1.8%). The marked dominance of incoming shipments in these categories demonstrates the role of seaports as key gateways for energy- and resource-intensive industrial inputs. Among industrial raw materials, natural stone, sand and gravel (13.5 million tonnes; 4.9%) and iron ores (12.9 million tonnes; 4.7%) followed, likewise predominantly imported. These commodities are closely linked to construction and steelmaking and reflect the basic supply needs of industry.

By contrast, high-value industrial goods show a stronger export orientation. Automotive products accounted for 9.0 million tonnes (3.3%), with outgoing shipments significantly exceeding incoming cargo. Similar patterns are found for machinery and machine tools (5.5 million tonnes), pig iron and steel products (4.0 million tonnes), and selected chemical and manufactured goods. The following figure shows the principal cargo groups in maritime transport in 2024 and the relationship between incoming (imports) and outgoing (exports) cargo.

Figure: Incoming and outgoing cargo for major commodity groups in 2024 (million tonnes)



Source: Destatis (Tables 46331-0001, 51000-0012); own illustration.

Overall, the NST-2007 analysis reveals a dual structure in German maritime transport. On the one hand, high-volume imports of energy and raw materials dominate; on the other, containerised general cargo and export-oriented industrial products play a central role. Seaports therefore serve both as supply hubs for industrial inputs and as export platforms for high-value goods.

Value density and time sensitivity determine the suitability of goods for sail cargo ships

The preceding analysis of Germany's seaborne foreign trade by commodity type highlights the importance of individual commodity groups for maritime transport. However, not all goods are equally suitable for alternative transport concepts as sail cargo ships. The suitability of particular goods depends largely on their fundamental transport-economic characteristics. Of particular importance are the value density of the goods and the time requirements within the respective supply chains.

Value density describes the economic value of a commodity relative to its weight or volume (e.g. EUR/t or EUR/m³). It is a key indicator of a commodity's sensitivity to transport costs and transit times. Goods with a low value density, such as raw materials, construction materials or agricultural bulk commodities, are generally highly sensitive to transport costs, as these costs account for a relatively large proportion of the total value of the goods. By contrast, for goods with a high value density, such as machinery, electronics or high-value industrial products, transport costs play a significantly less important role relative to the value of the goods. Compared with other modes of transport, maritime shipping is characterised by very low specific transport costs. Large cargo vessels can transport substantial quantities of goods with relatively low energy consumption per tonne-kilometre. Particularly in the case of bulk commodities, significant economies of scale result in considerably lower transport costs per unit transported. Maritime shipping is therefore particularly well suited to transporting low-value-density goods, as is typically the case with bulk commodities.

Nevertheless, for many commodity types, maritime transport costs still account for a significant proportion of total supply chain costs. At the same time, absolute costs per tonne-kilometre are very low, making maritime shipping particularly economical over long transport distances.

However, container shipping demonstrates that goods with medium or higher value density are also transported by sea in substantial quantities. In addition to costs and value density, the time dimension plays a central role in selecting suitable modes of transport. Time-related requirements arise in particular from:

- Production and supply chain structures (e.g. just-in-time production);
- The perishability of goods or the potential for deterioration in quality;
- Capital tied up during transportation; and
- Market requirements and delivery deadlines.

Globally integrated supply chains, particularly in container shipping, place high demands on predictability and reliability. Industrial products, intermediate goods and consumer goods are frequently transported within tightly scheduled logistics systems, where delays can have significant economic consequences. At the same time, numerous cargo flows are subject to less stringent time requirements, particularly those involving agricultural products, raw materials and certain semi-finished products.

The structure of German maritime transport illustrates these differing requirements: while energy- and raw-material-intensive import flows are primarily driven by volume and cost considerations, containerised general cargo is more closely integrated into industrial value chains and is therefore often more time-sensitive. The combination of value density, transport cost structure and time-related requirements is thus a key determinant of a commodity's suitability for alternative modes of transport. Transport solutions involving potentially longer transit times but lower energy consumption and operating costs, as can be expected with sail-powered cargo vessels, are particularly suitable for goods with low to medium value density, where transport costs account for a significant proportion of the product's value and where supply chains are less time-sensitive.

MARKET ANALYSIS

The following classification categorises typical maritime cargo groups according to these dimensions and provides an analytical basis for identifying potential applications for slower, energy-efficient transport concepts.

Figure: Classification of Maritime Cargo by Value Density and Time Sensitivity

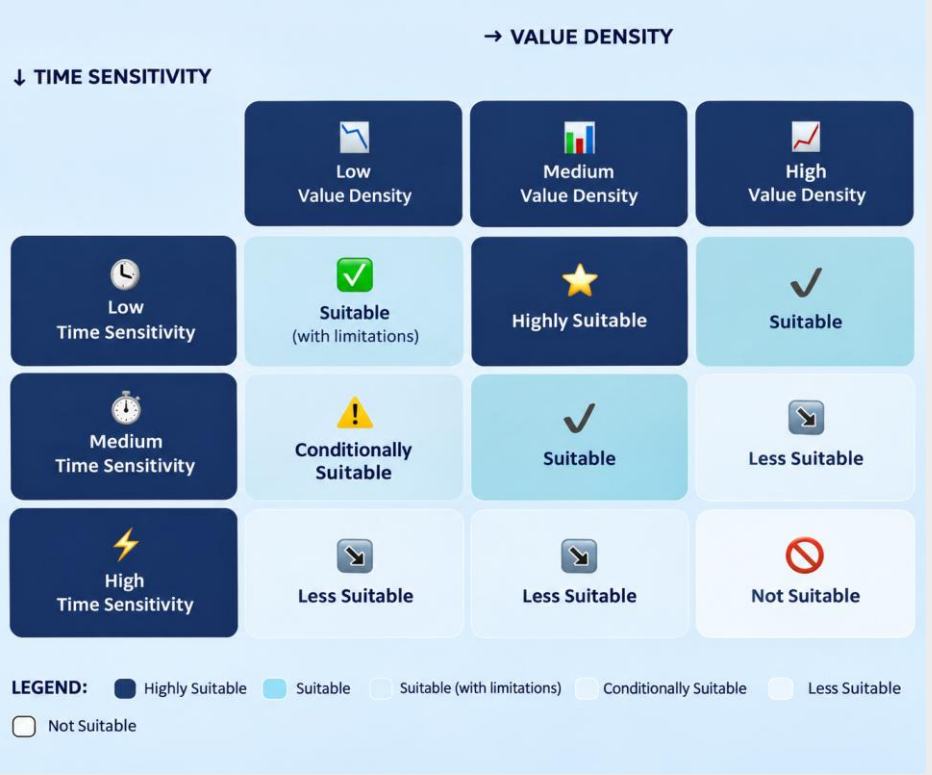
Cargo Group	Typical Examples	Value Density	Time Sensitivity
(Conventional) bulk goods	Coal, iron ore, grain, sand, gravel	Very low	Low
Agricultural raw materials	Grain, oilseeds, animal feed	Low	Low to medium
Semi-finished products	Steel, basic chemicals, paper	Medium	Medium
Wood products	Sawn timber, wood pellets, pulp	Low to medium	Low to medium
Standardised consumer goods	Furniture, clothing, household goods	Medium	Medium
Industrial goods	Machinery, vehicles, industrial equipment	High	High
High-tech products	Electronics, precision instruments	Very high	Very high

Source: Own illustration.

The structure presented illustrates that goods transported by sea differ considerably in terms of their transport-economic characteristics. This results in varying requirements regarding transport costs, speed and reliability. To systematically assess the potential suitability of individual cargo groups for transportation by sail-powered cargo vessels, value density and time sensitivity are used as the key dimensions and compared in a simplified assessment matrix.

Based on this matrix, a further step involves identifying specific types of cargo that appear, in principle, suitable for transportation by sail-powered cargo vessels. The matrix thus provides an analytical basis for systematically narrowing down the relevant cargo groups and assessing their suitability for alternative maritime transport concepts in a differentiated manner.

Figure: Assessment Matrix for the Suitability of Cargo for Wind-Powered Ships



Source: Own illustration.

Sail cargo ships primarily target niche markets with moderate time sensitivity

Based on the transport-economic criteria of value density and time sensitivity outlined above, an initial classification can be made of cargo segments that appear, in principle, suitable for sail cargo vessels. This indicates that goods with medium value density and moderate transit time requirements are particularly promising. In these segments, transport costs still account for a relevant proportion of the value of the goods, while supply chains allow for a certain degree of flexibility in terms of delivery times.

One relevant segment comprises goods that have a relatively high value per unit transported but are not necessarily integrated into highly time-sensitive supply chains. In these markets, sustainability considerations and differentiation along the supply chain may play a role alongside transport costs alone. Another potential application arises for goods with medium to high value density that are transported as general cargo or within project-specific transport chains. Such shipments often require extensive planning but are not necessarily subject to strict time constraints. As ship size increases, economically viable niches for sail cargo ships may therefore also emerge in this segment. By contrast, goods with very low value density are only suitable to a limited extent. These markets are dominated by highly standardised, large-scale transport operations, in which large cargo ships benefit from substantial cost advantages. The pronounced economies of scale associated with conventional bulk shipping therefore limit the competitiveness of small and medium-sized sail cargo ships.

Potential applications for sail cargo ships are primarily found in market segments where there is a balance between sufficient value density, moderate time sensitivity and potential sustainability benefits. By contrast, highly cost-optimised bulk shipping operations offer considerably fewer opportunities for the deployment of sail cargo vessels.

The theoretical classification of potential cargo segments can be supported by examining existing wind-powered cargo ships and those currently under development. According to the International Windship Association (IWSA), there are currently 107 vessels worldwide equipped with wind propulsion technology. However, the majority of these are conventional vessels that use wind merely as an auxiliary means of propulsion. For an assessment of the market potential of cargo vessels predominantly powered by wind, particular attention should therefore be paid to projects in which wind plays a central role in the propulsion system. An examination of these vessels reveals a clear correspondence with the cargo segments identified above. The most significant examples include the following sail cargo ships.

Table: Reference Examples of Sail Cargo Ships and Typical Cargo

Ship	Length	Deadweight Capacity	Typical Cargo
Grain de Sail I	Approx. 24 m	Approx. 50 t	Coffee, cocoa
Avontuur	Approx. 44 m	Approx. 114 t	Coffee, rum
Grain de Sail II	Approx. 52 m	Approx. 350 t	Food products
NEWTOWT	Approx. 81 m	Approx. 1,000 t	General cargo
Neoliner Origin	Approx. 136 m	Approx. 5,300 t	RoRo cargo
Canopée	Approx. 121 m	Approx. 5,000 t	Specialised cargo
Juren Ae	Approx. 48 m	Approx. 300 t	General cargo

Source: Own illustration based on manufacturers' information.

These examples illustrate that modern sail cargo ships cover a wide range of vessel sizes and can therefore serve different cargo segments, ranging from smaller niche markets for high-value agricultural products to larger-scale general cargo and specialised transport operations. These segments are examined in greater detail below.

Focus on Suitable Cargo Segments for Sail Cargo Ships

A more detailed analysis of the goods transported confirms the market segments identified above and allows for further differentiation into the following segments:

Figure: Suitable Cargo Segments for Sail Cargo Ships



High-Value Agricultural Products

One of the most important current niche markets for modern sail cargo ships is high-value agricultural products. These include, in particular, coffee, cocoa, wine, spirits, spices, sugar and olive oil. These products generally have a medium to relatively high value density but are not particularly time-sensitive. At the same time, climate-friendly transport offers additional marketing opportunities for producers and brands. Several existing operators already focus on this market segment. For example, Grain de Sail I primarily transports coffee and cocoa, while its larger successor, Grain de Sail II, carries not only raw materials but also processed food products such as chocolate and wine. The sail cargo ship Avontuur also regularly transports coffee, rum and cocoa between Europe, the Caribbean and Central America. Typical cargo volumes generally range from approx. 100 to 500 tonnes per voyage.

Premium and Branded Products

Another market segment comprises premium and branded products, for which climate-friendly transport can itself form part of the brand strategy. Examples include craft beer, high-quality food products, fashion items and cosmetics. In these markets, low-emission transport can generate additional marketing value. Several European companies already make targeted use of sail cargo ships to transport selected batches of products sustainably. Cargo volumes generally range from approx. 50 to 300 tonnes per voyage, corresponding to the capacities of smaller vessels.

General Cargo and Project Cargo

As ship size increases, the range of potential cargo types expands to include conventional general cargo and project cargo. Examples include machinery, industrial assemblies, spare parts and wood products. Such goods often have a medium to high value density and can be transported using flexible general cargo or Ro-Ro systems. Examples include the sail cargo vessel Neoliner Origin, which is designed for roll-on/roll-off cargo, and the specialised cargo vessel Canopée, which transports components for the European Ariane 6 rocket, among other cargo. In this vessel size category, cargo volumes typically range from approximately 2,000 to 5,000 tonnes per voyage.

Bulk Cargo (Limited Suitability)

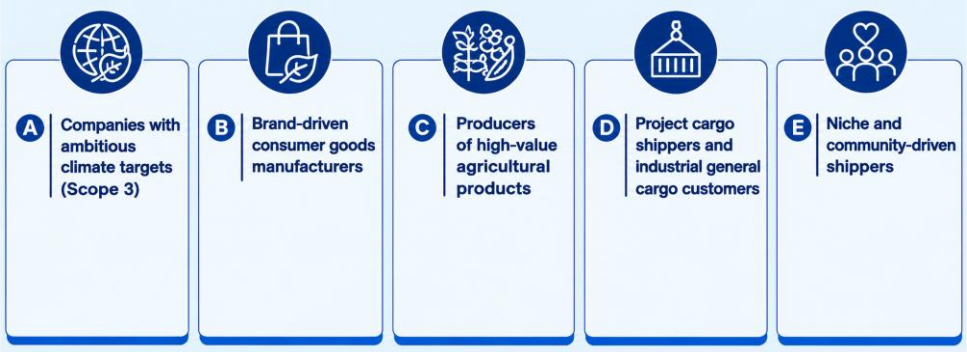
Conventional bulk commodities such as timber, grain, salt and certain recyclable materials are, by contrast, only suitable for transportation by wind-powered cargo ships to a limited extent. These goods generally have a very low value density and are transported within highly optimised global bulk shipping supply chains, in which transit times, capacity utilisation and economies of scale play a central role. Historically, such bulk commodities were among the traditional cargoes carried by sailing ships. Under current market conditions, however, their transportation by sail cargo ships is generally only viable under specific circumstances, such as relatively short transport distances, the use of very large sailing vessels or hybrid propulsion concepts combining wind propulsion with conventional engines.

Systematic Identification and Prioritisation of Potential Customer Groups

Building on the preceding analysis of cargo types suitable for transportation by sail cargo ships, the next step is to systematically identify and classify potential customer groups. The focus is particularly on companies whose product characteristics, supply chain requirements and strategic orientation favour the use of low-emission maritime transport solutions or even generate specific demand for them. These include, in particular, companies that can tolerate longer transit times while placing a high priority on sustainability, CO_2 reduction and transparent supply chains. Equally relevant are businesses whose operating models are characterised by stable, predictable cargo flows and which are willing to give greater consideration to environmental factors in their logistics decisions.

The following section identifies key categories of companies that, based on their demand profiles, sustainability objectives and operational conditions, are considered particularly suitable shippers or cargo owners for sail cargo ships. The figure below provides an overview before each group is described in greater detail.

Figure: Potential Companies and Customer Groups for Sail Cargo Ships



1. Companies with Ambitious Climate Targets (Scope 3 Focus)

Companies with ambitious climate targets represent a key customer segment for sail cargo ships, although their suitability requires a differentiated assessment. In particular, large brand-owning companies, trading organisations with global supply chains and selected B2B industrial companies are under increasing pressure to reduce their indirect emissions (Scope 3). Maritime transport plays a key role in this context, as it accounts for a significant share of total emissions in global value chains while also being comparatively easy to address.

Initiatives such as ZEMBA demonstrate the growing willingness of major shippers to actively invest in low- and zero-emission maritime transport solutions. By aggregating demand and using long-term offtake agreements, such alliances provide greater planning certainty for service providers and lower market entry barriers for innovative technologies. At the same time, they are establishing new procurement approaches, such as the purchase of emissions reduction attributes, which enable physical transport activities to be decoupled from emissions reductions accounted for in corporate emissions inventories.

Demand from this customer segment is driven by three factors:

- Firstly, the regulatory framework – particularly the inclusion of maritime transport in the EU Emissions Trading System (EU ETS) and the expanded reporting obligations under the Corporate Sustainability Reporting Directive (CSRD) – is creating increasing pressure to act. Companies are increasingly required to disclose their emissions transparently and demonstrate concrete emissions reduction pathways.
- Secondly, the strategic management of Scope 3 emissions is becoming increasingly important. Established methodologies such as the GLEC Framework enable the standardised measurement and comparison of logistics-related emissions. This makes transport emissions a measurable and manageable factor within corporate strategy and

brings them increasingly into focus in procurement decisions.
- Thirdly, brand image and reputation play a central role. Consumer-facing companies, in particular, are increasingly using sustainable logistics solutions as a means of differentiating themselves from competitors. Low-emission transport solutions can therefore not only contribute to achieving climate targets but also generate additional marketing and communications value.

Despite the general relevance of this segment, sail cargo ships are not universally suitable for all companies within it. Rather, the key target customers are companies that, in addition to ambitious climate targets, exhibit the following characteristics:
- Significant reliance on maritime freight transport;
- Sufficient flexibility regarding transit times and supply chain integration;
- The ability to arrange the separate transportation of smaller consignments or pilot shipments;
- An interest in sustainability initiatives that can be effectively communicated to stakeholders.

In this context, sail cargo ships are primarily suited to pilot projects or selected cargo flows ("signature shipments"), where the demonstration and communication value is a key consideration alongside actual emissions reductions. Tchibo provides an illustrative example: the company relies heavily on maritime transport as a core element of its logistics operations and participates in decarbonisation initiatives, including ZEMBA. At the same time, selected product flows are specifically used for sustainable transport solutions and related communications activities, creating considerable potential for the deployment of sail cargo ships. Patagonia also pursues a consistent Scope 3 emissions reduction strategy and incorporates sustainable logistics into its brand positioning. Pilot shipments involving selected product lines offer potential in this context, combining environmental benefits with effective brand storytelling.

In the sustainable consumer goods sector, companies such as VAUDE and GEPA demonstrate a strong affinity for alternative transport concepts. These companies have comparatively flexible supply chains and actively incorporate sustainability into their customer communications, making sail cargo ships a credible addition to their logistics operations.

By contrast, large, volume-driven companies such as Amazon and IKEA are also involved in initiatives such as ZEMBA. Although these companies play a significant role in driving market development, their highly standardised and time-sensitive supply chains mean that they primarily depend on scalable solutions. For these companies, sail cargo ships are therefore only likely to be considered for symbolic pilot projects or selected smaller consignments. A more detailed examination of selected stakeholders, their specific requirements and supplementary case studies is provided in Section 4, where the relationships outlined here are analysed in greater depth and supported by empirical evidence.

A key characteristic of this customer segment is its willingness to accept or internally allocate a price premium for low-emission transport solutions (the "Green Premium"). This willingness to pay stems less from purely logistical considerations than from a combination of regulatory pressure, strategic sustainability objectives and additional brand-related benefits.

In practice, a typical pattern of use emerges: companies integrate wind-powered cargo vessels not as a replacement for existing transport chains, but as a complementary solution for selected cargo flows. This enables them to gain initial experience with zero-emission transport concepts, develop internal expertise and, at the same time, demonstrate visible progress through their sustainability communications.

2. Brand-Driven Consumer Goods Manufacturers (Storytelling-Focused)

Brand-driven consumer goods manufacturers represent a particularly suitable customer group for sail cargo ships, as sustainability is not merely an operational objective but an integral part of their brand identity. Typical companies in this segment are found primarily in the premium food and beverage sector (e.g. coffee, chocolate and wine), natural cosmetics, and sustainable fashion and lifestyle products.

A defining characteristic of these companies is their increasingly holistic approach to their value chains, in which transport is also regarded as part of the brand message. The use of low-emission transport solutions enables them to differentiate themselves further within the premium segment and communicate credible sustainability narratives to end consumers. Companies such as Goldhelm Schokolade, Summerbird and COOKO provide illustrative examples. These businesses demonstrate a close connection between product quality, transparency of origin and sustainable brand positioning, making alternative transport concepts such as sail cargo ships are very highly suited to their business models. Their motivation for adopting such solutions is driven less by conventional considerations of logistical efficiency than by the additional brand and communications value they offer. Transport itself becomes a marketable part of the product story (“transported by a sail cargo ship”) and can be deliberately integrated into marketing and sales strategies. This creates additional economic value beyond the transport service itself.

Against this background, brand-driven consumer goods manufacturers are very highly suited to the use of sail cargo ships. Typical shipment volumes range from small to medium-sized consignments (approx. 50–300 tonnes), which align well with the capacities of existing or planned sailing cargo ships. At the same time, these companies are often relatively willing to pay a premium per unit, as the additional costs can be offset, at least in part, through product pricing or the added value associated with the brand.

3. Producers of High-Value Agricultural Products

Producers of high-value agricultural products represent one of the key customer groups for sail cargo ships and are also among the most structurally suitable. Typical commodities include coffee, cocoa, spices, wine and spirits, as well as olive oil and sugar. This segment is characterised by the close interconnection between production, trade and brand development. Many companies pursue approaches such as Fair Trade or Direct Trade, which aim to establish long-term partnerships, transparent supply chains and improved income opportunities for producers. For example, Cafédirect has worked directly with producer organisations since the 1990s and reinvests a substantial share of its profits in the development of agricultural production regions. GEPA, one of Europe's largest Fair Trade importers, systematically collaborates with producers in the Global South and pursues social and environmental objectives throughout the entire value chain. In addition, there is a growing number of specialised coffee and agricultural businesses focusing on direct sourcing and sustainable production, including Coffee Circle, Wildkaffee and Tatico. These companies emphasise transparency, environmentally sustainable cultivation methods and fair pricing structures. At a global level, companies such as ECOM Agroindustrial also demonstrate the increasing importance of sustainable sourcing and marketing, with a significant share of traded products already classified as “sustainable”.

The motivation for using sail cargo ships arises from several factors.

- Firstly, combining sustainable production with low-emission transport offers an opportunity to further enhance the value of the end product (“Direct Trade + Zero Emissions”).
- Secondly, partnerships with European brands and importers are becoming increasingly common. These companies pursue their own sustainability objectives and impose corresponding requirements on their supply chains.

- Thirdly, ESG requirements throughout the supply chain are increasingly extending upstream to the producer level.

Against this background, high-value agricultural products are particularly well suited to the use of sail cargo ships from a structural perspective. The decisive factors are the combination of sufficient value density, relative flexibility regarding transit times and strong storytelling potential. These characteristics make it possible to generate both economic and communications value, positioning this segment as one of the most viable areas of application for low-emission maritime transport solutions.

4. Project Cargo Shippers and Industrial General Cargo Customers

Alongside consumer goods-driven markets, project cargo shippers and industrial general cargo customers represent another relevant customer group for sail cargo ships, albeit one with different structural characteristics. Typical cargo includes machinery and equipment, industrial components and spare parts, timber products, and specialised project cargo, for example from the energy or aerospace industries. A defining characteristic of this segment is the close relationship between transport operations and project-based business activities. Logistics is not viewed solely in terms of efficiency but is often an integral part of complex value creation and project implementation processes. This creates a degree of flexibility regarding transit times and modes of transport, particularly for non-time-critical components or during the early stages of projects. Specific examples can be found particularly within the European industrial sector. As part of its sustainability strategy, Airbus is increasingly pursuing lower-emission logistics solutions, including for the transport of large-volume components. Companies such as Siemens Energy and Vestas are also facing growing pressure to reduce emissions throughout their supply chains, particularly in connection with major international energy infrastructure projects. One specific application can be identified in the context of wind energy projects:

Manufacturers such as Vestas, Nordex and Enercon regularly deliver high-value-density components to international project sites, sometimes within flexible delivery windows. In this context, the use of low-emission transport solutions can contribute to improving the overall sustainability performance of a project. The same applies to specialised transport operations in plant engineering, where clients are increasingly incorporating ESG criteria into tendering processes.

The motivation for adopting such solutions in this segment is primarily driven by external requirements. On the one hand, sustainability criteria are becoming increasingly important in major public and private projects, meaning that low-emission logistics solutions can serve as a differentiating factor in competitive tenders. On the other hand, reputational considerations also play a role, particularly in projects with high public visibility, such as those involving renewable energy or infrastructure.

Sail cargo ships are generally suitable for this segment, although their suitability depends more heavily on operational conditions than in consumer goods-driven markets. Vessel capacity, reliability and integration into existing supply chains are particularly decisive factors. While smaller and medium-sized project cargo shipments are already potentially suitable, broader market penetration is expected as sail cargo ships increase in size and become more standardised.

Overall, this represents a market segment with medium-term growth potential, the realisation of which will depend largely on the extent to which sail cargo ships can be integrated into existing industrial logistics processes while providing reliable transport solutions.

5. Niche and Community-Driven Shippers

Niche and community-driven shippers represent another relevant customer group, particularly during the early stages of market development. This segment primarily includes direct-to-consumer (D2C) brands, Fair Trade cooperatives and innovative, often digitally based trading models, such as those associated with crowdfunding or community commerce.

These companies are characterised by a particularly strong commitment to transparency and close customer involvement in value creation and communication processes. Products are often differentiated not only through conventional sales channels but also through storytelling, direct customer engagement and transparent, traceable supply chains. Transport can deliberately be presented as a visible part of the product story, for example through features such as “track your shipment” or by actively communicating transport routes and conditions. Examples of such approaches can be found at El Puente, a Fair Trade cooperative focused on partnership-based trading relationships. Platforms such as CrowdFarming also demonstrate how digital business models can be used to involve consumers directly in production and delivery processes.

The primary motivation for adopting such solutions in this segment is to maximise transparency and authenticity. Low-emission transport solutions such as sail cargo ships enable companies to extend their brand and product philosophy consistently into their logistics operations. At the same time, they foster a strong sense of customer identification with the product, as consumers become actively involved in its story and can directly trace the sustainable transport routes used.

Against this background, niche and community-driven shippers are very highly suited to the use of sail cargo ships, especially during the early stages of market development. Typical shipment volumes are small but offer disproportionately high communications value. This makes these companies particularly suitable for pilot and demonstration projects, in which new logistics solutions can be tested, showcased and further developed through an iterative process.

Figure: Overview of Companies and Customer Groups for Sail Cargo Ships

Segment	Characteristics and Motivation	Requirements	Use and Willingness to Pay	Suitability
1 – Companies with Climate Targets	Major brands; strong regulatory and Scope 3 pressure; focus on reputation	Ability to handle smaller loads, emissions verification, flexibility	Pilot projects / “signature shipments”; willingness to pay a green premium	Medium –High
2 – Brand-Driven Consumer Goods	Sustainability as part of brand identity; transport as storytelling	Small to medium-sized loads; strong communications potential	Integration into product and brand positioning; high willingness to pay	Very High
3 – High-Value Agricultural Products	Direct/Fair Trade; high transparency; strong value chain integration	Flexibility regarding transit times, value density, certifiability	Regular use; enhanced product value	Very High
4 – Project Cargo Shippers and Industry	Project-based operations; ESG-driven tenders; low time sensitivity	Capacity, reliability, integration	Selective use in projects; limited willingness to pay	Medium
5 – Niche and Community-Driven Shippers	D2C; high transparency; strong customer engagement	Small loads, track and trace, storytelling	Pilot and demonstration projects; very high willingness to pay per unit	Very High

Sail Cargo Ships versus Conventional Shipping

Building on the preceding considerations, an initial assessment of sail cargo ships within the competitive landscape of maritime transport solutions is presented. The aim is to provide a high-level qualitative assessment of the market position of sail cargo ships compared with conventional shipping. A more detailed analysis of their economic and environmental competitiveness is provided in the following sections.

Conventional shipping represents the dominant system underpinning global freight transport and is characterised by highly optimised, globally integrated logistics networks. In container shipping in particular, standardised loading units, frequent scheduled services, extensive hub-and-spoke structures and very large vessel capacities generate significant economies of scale. These result in extremely low unit transport costs while ensuring high levels of reliability, predictability and global availability. This is complemented by efficient port infrastructure, digitalised planning and booking systems, and established logistics service providers that ensure seamless integration into multimodal transport chains.

Furthermore, conventional shipping is characterised by a high degree of operational flexibility and adaptability. Shipping companies can adjust capacity at short notice through fleet management, alliances or schedule adjustments, enabling them to respond to fluctuations in demand. Global liner networks provide high service frequencies on major trade routes, while feeder services ensure connectivity to regional markets. At the same time, long-established contractual arrangements and spot market structures facilitate efficient price formation and risk allocation.

Another competitive factor is the ongoing technological and regulatory development of the sector. Measures such as slow steaming, fleet modernisation and digital route optimisation contribute to continuously improving efficiency and gradually reducing emissions without fundamentally changing the underlying operating model.

At the same time, standardised interfaces and IT systems enable a high degree of transparency throughout the supply chain, particularly in relation to shipment tracking, capacity planning and emissions monitoring.

In addition to the efforts described above to gradually reduce emissions, a broad range of technological approaches to decarbonising maritime shipping has emerged. These approaches are primarily aimed at maintaining the existing system while reducing its emissions intensity. They can be divided into three main categories:

1. Drop-in and Transitional Fuels (e.g. LNG, Biofuels)

These fuels are available in the short term and are largely compatible with existing infrastructure and propulsion technologies. They enable relatively rapid emissions reductions without requiring fundamental changes to the existing system. However, their decarbonisation potential is limited, and there is some uncertainty regarding their actual sustainability benefits. Overall, they should therefore be regarded primarily as transitional solutions.

2. Scalable Zero-Emission Fuels (e.g. E-Methanol, E-Ammonia, E-Fuels)

These options are considered key components of a long-term decarbonisation strategy, as they offer the potential for near-climate-neutral operations when produced using renewable energy. However, significant challenges currently remain regarding costs, availability and the development of the necessary production and bunkering infrastructure. In addition, there is a structural “chicken-and-egg” problem, as investments in fleet retrofitting and fuel production are closely interdependent.

3. Efficiency and Hybrid Solutions (e.g. Wind-Assisted Propulsion Systems, Slow Steaming)

These measures aim to reduce energy consumption within the existing system and can be implemented relatively quickly. They make an important contribution to reducing emissions but do not achieve completely emission-free operations. They should therefore be regarded as complementary efficiency measures.

Against this background, sail cargo ships are currently at a disadvantage compared with both conventional shipping and fuel-based decarbonisation solutions across several key performance dimensions. This is particularly evident in their cost structure, as smaller vessel capacities and a lack of economies of scale result in higher transport costs per unit. In addition, transit times are generally longer and less predictable due to their greater dependence on weather and wind conditions. Integration into existing logistics networks also remains limited, as sail cargo ships are neither widely available nor integrated into established liner services and scheduled transport networks. Compared with alternative fuels such as LNG, biofuels and, in particular, scalable zero-emission fuels (e.g. e-methanol or e-ammonia), sail cargo ships also face disadvantages in terms of system compatibility and scalability. While these fuel-based solutions are designed for use within existing fleets and infrastructure, thereby enabling the gradual decarbonisation of the mass market, sail cargo ships require dedicated logistics concepts and are currently limited to smaller market segments.

Nevertheless, sail cargo ships offer specific competitive advantages that are becoming increasingly important in the context of the maritime sector's transition towards decarbonisation. Of particular significance is their near-zero-emission operation, which requires little or no fossil fuel consumption and therefore enables direct, physical reductions in greenhouse gas emissions.

Unlike many fuel-based solutions, whose climate neutrality depends on the origin and availability of renewable energy, wind-powered cargo ships are largely independent of new energy infrastructure and scarce resources.

Furthermore, they are largely unaffected by volatile fuel prices and future CO_2 pricing mechanisms, which could contribute to more stable cost structures, particularly in the long term. In addition, they offer considerable differentiation and communications value, especially for companies that actively integrate sustainable transport solutions into their branding and sustainability strategies.

Overall, sail cargo ships are less likely to compete directly with conventional shipping or fuel-based decarbonisation solutions and instead fulfil a complementary role. Their strengths lie particularly in applications where maximum emissions reductions, technological independence and additional value creation through branding and communications are key priorities.

The table on the following page provides a concise overview of the main differences and competitive characteristics of sail cargo ships compared with conventional shipping.

MARKET ANALYSIS

Dimension	Conventional Shipping	Sail Cargo Ships
Basic Concept	Global, highly optimised transport system	Niche-oriented, alternative transport concept
Cost Structure	Very low unit costs due to economies of scale	Higher unit costs due to limited vessel capacities
Speed & Predictability	High speeds, reliability and predictability	Longer, less predictable transit times (wind-dependent)
Scalability	Very high (mega-carriers, global networks)	Limited; currently small to medium cargo volumes
Network Integration	Fully integrated (hub-and-spoke, liner services)	Limited integration; no comprehensive networks
Infrastructure & Systems	Advanced port infrastructure, digital systems, standardised processes	Infrastructure gaps and lower levels of standardisation
Flexibility	Highly adaptable (alliances, spot markets, schedule management)	Less flexible; project- or shipment-based operations
Decarbonisation Pathway	Emissions reductions through efficiency measures and alternative fuels (e.g. LNG, e-fuels)	Fundamentally zero-emission approach based on wind propulsion
Energy & Fuel Dependence	High, including for alternative fuels (dependent on availability and infrastructure)	Very low (primarily wind energy, minimal auxiliary energy)
Emissions Profile	Reduced emissions, but generally not entirely emission-free	Near-zero emissions (direct physical avoidance of emissions)
System Compatibility	Very high (existing fleets and infrastructure can be used)	Lower (requires adapted logistics and planning systems)
Price Stability	Dependent on volatile fuel prices and CO_2 regulations	Greater stability due to low energy dependence
Marketing & Differentiation Potential	Evolution rather than revolution; decarbonisation within the existing system through alternative fuels	Very high (“zero-emission transport” as part of brand identity)
Typical Applications	Mass markets, standardised global supply chains	Niche markets, premium products, pilot projects

Based on the findings of the market analysis so far, key requirements for business and operating models for sail cargo ships can be identified. These arise primarily from the need to align the specific strengths of wind-powered cargo vessels with the requirements of potential customers and existing logistics systems.

Requirements for Deployment and Operating Profiles

Deployment and operating profiles must be closely aligned with the identified market segments and their requirements, and therefore differ fundamentally from conventional, highly standardised liner services. While conventional shipping is optimised for maximum utilisation, regular schedules and predictability, sail cargo ships require greater flexibility, segment-specific differentiation and closer integration of logistical, environmental and communications objectives.

1. Focus on Flexible, Non-Time-Critical Cargo Flows

Sail cargo ships should be deployed where transit-time flexibility is possible and strict just-in-time requirements do not apply. This includes:

- Cargo with low time sensitivity (e.g. coffee, cocoa, wine, spirits, spices and selected project cargo)
- Supply chains with existing buffers, such as inventory holdings or seasonal procurement cycles
- Products with predictable demand that is not subject to short-term fluctuations

Supply chains are particularly suitable where transit time is not the dominant competitive factor or is deliberately deprioritised in favour of sustainability and differentiation.

Implication: Rather than conventional just-in-time operations, a buffer-based approach is needed, incorporating longer and more variable transit times into supply chain planning. Shippers may need higher safety stocks or earlier shipment planning.

2. Shipment-Based Rather Than Volume-Driven Operations

Unlike mass container logistics, sail cargo ships carry smaller, clearly defined shipments:

- Typical shipment sizes: approx. 50–500 tonnes
- Individual shippers often do not fill an entire vessel
- Mixed cargo (different products and customers on each voyage)

Commercial viability therefore depends not on maximising the scale of individual shipments, but on intelligently consolidating compatible cargo.

Implications:

- Develop multi-customer transport models in which several shippers share capacity
- Develop consolidation and platform solutions to coordinate supply and demand
- Greater coordination requirements than standardised container processes
- Establish clear criteria for combining cargo (e.g. compatibility, destination ports and delivery windows)

3. Focus on Stable, Wind-Favourable Corridors

Route planning is much more dependent on natural conditions than in conventional shipping. Efficient operations are particularly feasible on routes with reliable winds:

- e.g. transatlantic routes (Europe–Caribbean–Central/South America)
- Potentially selected north–south routes with reliable trade winds
- Less suitable for fragmented, high-frequency short-sea networks

Complex, tightly scheduled rotations involving numerous port calls should also be avoided, as they reduce predictability.

Implications:

- Move partly away from global, highly interconnected liner networks
- Develop specialised, stable “Green orridors”
- Focus on a few clearly defined routes with recurring customer demand
- Establish long-term route partnerships (e.g. between producing regions and consumer markets)

4. Integration of Hybrid Operating Models

Primary wind-powered transport faces practical limitations in predictability and reliability. A hybrid approach is therefore often required:

- Combine wind propulsion (primary energy source) with supplementary engine power
- Use auxiliary propulsion to meet port slots and minimum speeds
- Allow adjustments during unfavourable weather

This creates a trade-off between maximum emissions reductions and operational reliability.

Implications:

- Develop a balanced operating strategy combining environmental and logistical objectives
- Define minimum service levels (e.g. maximum delays and guaranteed arrival windows)
- Communicate expected deviations transparently to customers
- Differentiate offerings (e.g. “wind-only” versus “hybrid-optimised”)

5. Visibility and Traceability as Integral Operating Features

A key distinguishing feature of sail cargo ships is their visibility and communications potential. Transport is not merely a functional supply chain element but part of value creation and brand communications.

- Track routes and vessel positions (e.g. public maps and live tracking)
- Document emissions savings
- Integrate data into ESG reporting and sustainability reports
- Use transport data for marketing and storytelling

Implication:

Operating sail cargo ships should be viewed not only as a logistics service but also as a communications and engagement platform. This requires:

- Digital interfaces giving customers access to data
- Transport information tailored to different audiences (B2B and consumers)
- Close coordination between logistics, sustainability management and marketing

The specific deployment and operating requirements also affect suitable contractual and cooperation arrangements. Conventional shipping contracts (spot and long-term freight-rate agreements) are only partly transferable, since they are designed for standardised, high-volume, frequent services. Sail cargo ships therefore require more flexible, cooperative arrangements reflecting their particular operational and market conditions.

Requirements for Contractual and Cooperation Arrangements

Conventional shipping contracts (spot and long-term freight-rate agreements) are only partly applicable to sail cargo ships. They are based on standardised, high-volume, frequent services with clearly defined service levels. Wind-powered operations instead require greater flexibility, closer value-chain cooperation and the integration of additional value dimensions, including sustainability and communications. Adapted contractual and cooperation models are therefore necessary.

1. Combining Transport Contracts with Sustainability Services

For sail cargo ships, conventional transport services are extended by components beyond physical carriage. Whereas conventional maritime contracts focus primarily on cost, transit time and reliability, environmental impact and communications value become especially important.

The service can therefore be understood as a hybrid combination of:

- Physical transport
- Quantifiable emissions reductions (e.g. for inclusion in Scope 3 inventories)
- Narrative and marketing-related added value

This expansion means transport is increasingly part of strategic corporate objectives rather than merely an operational service. Particularly in consumer-facing sectors, transport can become a visible part of the brand and product story (“transport as a feature”).

These additional service dimensions require systematic integration into core business functions, particularly:

- Sustainability strategies and decarbonisation pathways
- ESG reporting and CO_2 accounting
- Brand, communications and sales strategies

The resulting sustainability impacts must also be recorded, quantified and reliably demonstrated to internal and external stakeholders using standardised methods. This covers both methodology (e.g. calculation approaches) and formal requirements (e.g. certification and audits).

Implication: “Green transport agreements” are becoming increasingly important. They extend beyond conventional freight-rate contracts by explicitly covering the additional services, potentially including:

- Standardised CO_2 reporting and emissions verification
- Allocation and use of emissions reduction attributes
- Transparency and traceability requirements
- Rules governing communications use (e.g. marketing)

Transport contracts thus increasingly become integrated service and impact agreements linking logistical, environmental and communications value.

A further consideration concerns contracts between shipowners and charterers. Under conventional time charters, fuel costs typically fall to the charterer, while the owner bears investment costs. Sail cargo ships therefore require appropriate investment incentives for owners, such as higher charter rates for low-emission vessels, long-term offtake guarantees, shared-savings arrangements or payments for emissions reductions.

2. Multi-Stakeholder Cooperation Along the Value Chain

Sail cargo ships often require substantially closer coordination between value-chain participants than conventional shipping. Whereas container shipping is mainly characterised by bilateral contracts between shippers and carriers, wind-powered transport gives rise to more interconnected, multilateral cooperation structures.

This is particularly because additional value dimensions such as sustainability, transparency and communications potential must be considered and jointly developed alongside physical transport. Transport becomes an integrated part of the entire value chain rather than an isolated logistics step.

Typical participants include:

- Producers (e.g. coffee, cocoa or spice growers)
- Brand owners and processors (e.g. food or consumer goods manufacturers)
- Importers and trading companies
- Logistics providers for pre-carriage, onward transport and distribution
- Operators and providers of sail cargo ships

These networks involve specialised but closely connected roles. Producers supply sustainably produced raw materials, while brand owners incorporate low-emission transport into their product and communications strategies. Logistics providers organise and synchronise upstream and downstream transport, while vessel operators provide the carriage itself and the associated emissions benefits.

The overall value is not created by individual actors in isolation, but through their coordinated interaction. Combining sustainable production, low-emission transport and transparent communications creates additional value throughout the supply chain.

Implications: This structure creates specific organisational and contractual requirements:

- Cooperation platforms, networks and consortia involving multiple parties become more important than purely bilateral contracts
- Coordination requirements increase substantially, particularly for volumes, time windows, communications and data provision
- New opportunities arise for sharing risks relating to utilisation, costs and operational uncertainty
- Joint marketing becomes possible, bringing multiple value-chain partners into a coherent sustainability and product narrative

Overall, the focus shifts from isolated transport contracts towards integrated cooperation models that jointly create and distribute logistical, environmental and communications value.

3. Aggregating Demand (Similar to the ZEMBA Model)

A key structural feature of the market is that many potential shippers, especially sustainable consumer goods businesses, high-value agricultural producers and niche suppliers, lack sufficient individual volumes to fill an entire vessel. Demand aggregation is therefore crucial.

Unlike conventional container shipping, with its standardised, high-frequency cargo flows, sail-powered services often need to combine small and medium-sized shipments from several shippers. Different delivery windows, destination ports, product types and quality requirements must be coordinated within a coherent transport concept.

Consolidation helps ensure adequate utilisation of individual voyages, improving commercial viability. It also provides operators with greater planning certainty and facilitates more reliable integration into existing supply chains.

Implications: Synchronising demand requires new organisational and contractual approaches:

- Buyer pools, consortia and platform-based cooperation models become more important, allowing multiple shippers to combine demand and book capacity.
- Capacity can be sold in advance, for example through fixed allocations per voyage or seasonal booking models.
- This reduces the risk of underutilisation for vessel operators, particularly during early market development.

Early demand aggregation also increases planning certainty for everyone involved, as transport volumes can be consolidated and coordinated in advance. It offers strategic opportunities: as with ZEMBA, coordinated demand can both secure utilisation and actively support market development. Larger shippers or alliances can act as anchor customers and help scale these solutions.

4. Pilot and Demonstration Projects as a Market Entry Strategy

Pilot and demonstration projects are central to the current development phase of sail cargo ships. Providers and prospective customers must test and validate new operational, commercial and organisational concepts under real-world conditions. Pilots are therefore important learning and experimentation environments.

Such projects typically involve carefully selected small to medium-sized volumes and often attract substantial visibility through communications, media coverage and marketing or sustainability campaigns. Transport is deliberately showcased to demonstrate the concept's feasibility and value to internal and external stakeholders. Pilots are also explicitly experimental: rather than primarily maximising efficiency, they test processes, identify operational challenges and develop suitable business and cooperation models. They are iterative learning processes in which experience systematically informs further development.

Implications: The special role of pilot and demonstration projects creates specific contractual and organisational requirements:

- Project-based contracts for individual voyages or defined project periods take precedence over conventional long-term liner agreements
- These entail less long-term commitment but considerably greater flexibility for all parties
- Pilot projects support gradual, iterative business model development by applying lessons directly to subsequent projects
- They also serve as proof of concept for the later scaling and standardisation of sail-powered transport services

Pilot projects additionally send important market signals. Successful demonstrations can build trust among prospective shippers, support investment decisions and help establish initial best practices. They therefore contribute to market development and the adoption of innovative transport solutions beyond operational testing alone.

5. Pricing Models Incorporating a Green Premium and Marketing Value

Pricing for sail cargo ships differs fundamentally from conventional, primarily cost-based freight rates. Whereas efficiency, economies of scale and competition produce highly standardised prices in conventional shipping, the economic value of sail-powered transport reflects several interconnected dimensions.

Beyond carriage itself, environmental impact and additional communications and brand value are important pricing factors. The total value of a shipment can be understood as combining:

- Conventional logistics services (transport costs)
- Quantifiable sustainability benefits (e.g. CO_2 reductions and contribution to ESG targets)
- Communications and brand value (e.g. differentiation, storytelling and customer loyalty)

This multidimensional value means shippers' willingness to pay is influenced not solely by logistical efficiency but largely by strategic, regulatory and marketing factors.

Implications: This expanded value proposition creates specific pricing requirements:

Pricing models must accommodate different corporate budgets, particularly:

- Logistics budgets (physical carriage)
- Sustainability or ESG budgets (emissions reductions and target achievement)
- Marketing and communications budgets (brand and storytelling benefits)

- A “Green Premium” is emerging that goes beyond transport costs and reflects additional environmental and communications benefits.
- Willingness to pay this premium is often strongest where sustainability is strategically embedded or used for market differentiation.
- In many cases, additional costs can be recovered at least partly through higher product prices, premium positioning or increased brand value.

Hybrid pricing models may also develop, with value components itemised and priced separately (e.g. transport costs and emissions reduction value). This improves transparency and allows more targeted internal allocation of costs and benefits.

6. Optional Separation of Physical Transport and Emissions Benefits

As the market matures, partial separation of physical carriage from the accounting of emissions benefits may become more important. Similar to established “book and claim” approaches in other areas of sustainable logistics and energy, this offers additional flexibility and scalability.

At its core, the model separates:

- The actual physical movement of goods
- The accounting allocation of emissions reductions

Whereas these are traditionally inseparable, decoupling allows climate benefits achieved through low-emission transport to be allocated independently of specific cargo movements. Emissions reductions thus become separate, tradable attributes.

This creates new applications:

- Shippers can benefit from emissions reductions without necessarily using sail-powered transport for their own physical cargo
- Supply chain planning becomes more flexible because operational constraints (e.g. delivery windows or routes) need not be directly tied to sustainability objectives
- Providers can use limited physical capacity more efficiently and allocate emissions benefits to a larger customer base

Implications: This development has far-reaching consequences for market structures and contracts:

- Additional scaling opportunities arise by making the benefits of low-emission transport available beyond the physical capacity deployed
- Standardised certification, verification and evidence systems become increasingly important to ensure credibility and comparability
- Compatibility with established reporting standards and initiatives (e.g. Scope 3 accounting) becomes a critical success factor
- New market mechanisms may allow emissions reduction attributes to be traded or allocated in ways similar to certificates

However, these models impose greater requirements for transparency, governance and prevention of double counting. Acceptance among businesses and stakeholders depends heavily on transparent, standardised and credible methodologies.

Overarching Implications for Business Models

The requirements for deployment and operating profiles, together with contractual and cooperation arrangements, lead to wider implications for viable business models for sail cargo ships. These extend well beyond conventional logistics models and require an integrated view of transport services, sustainability impact and market-oriented value creation.

Three core principles are particularly important for developing and scaling such business models:

1. From Transport Provider to Solutions Provider

Providers of sail cargo ships are evolving beyond conventional carriers into integrated solutions providers addressing and linking several dimensions of value. The focus shifts from physical carriage alone towards a holistic offering combining logistical, environmental and communications aspects.

Beyond transport itself, the offering includes:

- Emissions reductions as a quantifiable contribution to customers' Scope 3 strategies and corporate decarbonisation pathways
- Brand and communications value through visibly sustainable transport that can be incorporated into marketing and product strategies
- A signal of innovation and transformation, positioning companies as pioneers in making global supply chains more sustainable

Transport thereby becomes a strategic instrument extending beyond logistics and contributing directly to corporate sustainability and differentiation objectives.

At the same time, providers face requirements that go considerably beyond conventional transport services, including:

- Providing standardised emissions data and reporting interfaces for integration into existing ESG and management control systems
- Helping customers integrate transport into sustainability strategies, including advice on applications, accounting and impact
- Developing tangible, communicable use cases (e.g. specific product lines or campaigns) that visibly showcase sustainable transport

Transparency, traceability (“track and trace”) and the ability to cooperate with diverse value-chain stakeholders are also becoming more important.

Implication: Business models are evolving from primarily operational carriage towards multidimensional offerings integrating logistics, sustainability and communications. Providers increasingly enable sustainable supply chains and create value far beyond the transport function itself.

2. Platform and Network Models Rather Than Individual Customer Focus

Limited transport capacity and highly fragmented demand make purely single-customer models difficult to sustain. Many prospective shippers have only small or medium-sized shipments, insufficient on their own to fill individual voyages economically. Platform- and network-based models are therefore increasingly important.

The focus is on systematically consolidating and synchronising demand from multiple shippers. Wind-powered operations also require close coordination among value-chain participants to integrate differing delivery windows, routes and product types into a coherent transport concept. The aim is to establish stable, recurring cargo flows based on aggregated volumes, ensuring reliable capacity utilisation.

Core elements include:

- Aggregating demand across multiple shippers
- Coordinating and integrating different supply chain participants
- Establishing predictable transport structures through consolidated, recurring volumes

Possible approaches include:

- Digital platforms efficiently matching cargo demand and available capacity
- Consortia or buyer groups combining demand, similar to initiatives such as ZEMBA
- Long-term partnerships along defined routes, for example “green corridors”

Implication: Sail-powered vessel operators increasingly move from being conventional carriers to orchestrators of complex networks, consolidating demand, integrating participants and actively shaping cargo flows.

Commercial success depends largely on their ability to:

- Aggregate sufficient demand
- Maintain stable utilisation
- Efficiently coordinate the different requirements of all participants

Data availability, digital coordination mechanisms and close customer integration are particularly important. Platform and network capabilities are becoming key differentiators in the emerging market.

3. Combining Physical Operations with Intangible Added Value

A defining feature of sail cargo ship business models is the close link between physical carriage and intangible value components.

These include:

- ESG impact (e.g. CO_2 savings and contribution to climate targets)
- Supply chain transparency and traceability
- Storytelling and brand integration (e.g. “transported by sail cargo ship”)

This creates a hybrid value proposition: logistics services + sustainability benefits + communications services.

Implications:

- Quantify measurable emissions savings using transparent methodologies
- Develop digital interfaces and tracking solutions
- Work closely with customers' marketing and sustainability departments.

MARKET ANALYSIS - SUMMARY

Market Overview

- Maritime transport represents a key pillar of German foreign trade and is characterised by high cargo volumes, significant economies of scale and a strong concentration of activity at a small number of major ports. The market structure is divided into two main segments: on the one hand, high-volume energy and raw material flows dominate, while on the other, containerised goods are characterised by higher added value and greater logistical differentiation. This structure favours established, large-scale transport solutions and imposes clear limitations on concepts such as sail cargo ships.

Suitability of Cargo for Sail Cargo Ships

- The analysis shows that cargo suitability is primarily determined by two factors: value density and time sensitivity. Sail cargo ships are particularly suitable for transporting goods with medium to high value density that are not subject to strict delivery time requirements. Conventional bulk cargo and highly time-sensitive supply chains, by contrast, are largely unsuitable.
- This results in a clearly defined area of application: sail cargo ships do not target volume-driven, standardised transport operations, but rather specific segments in which flexibility and sustainability take precedence over maximum efficiency and speed.

Target Markets and Areas of Application

- The most promising areas of application are found in clearly defined niche markets. These include, in particular, high-value agricultural products such as coffee, cocoa and wine, where product quality, origin and mode of transport all play an important role. Brand-driven consumer goods are equally relevant, as sustainable transport can be actively used to strengthen brand positioning.
- Further opportunities exist in general cargo and project cargo transport, provided that sufficient flexibility regarding transit times is available.

Target Customer Groups

- Potential customers can be divided into several clearly defined groups. Companies with ambitious climate targets, particularly regarding Scope 3 emissions, represent an important target group, as they are actively seeking alternative transport solutions. Brand-driven consumer goods manufacturers also benefit from the communications value of low-emission transport.
- Producers of high-value agricultural products are particularly well suited from a structural perspective, as their products often combine high value density with flexibility regarding transit times. Other relevant customer groups include project-oriented industrial companies and smaller, community-driven businesses, which frequently act as early adopters and pilot customers.
- These customer groups share a greater willingness to pay a premium for sustainable transport solutions, as well as a readiness to integrate innovative logistics concepts into existing supply chains.

Competitive Positioning

- A direct comparison with conventional shipping reveals significant differences. Conventional transport solutions are highly efficient, cost-effective and reliably scalable. Sail cargo ships, by contrast, face structural disadvantages in terms of costs, predictability and capacity.
- However, these disadvantages are offset by significant benefits, particularly near-zero-emission transport, independence from fossil fuels and considerable differentiation potential for customers. Sail cargo ships should therefore be regarded not as a replacement for existing logistics systems, but as a complementary transport solution.

MARKET ANALYSIS - SUMMARY

Implications for Business Models

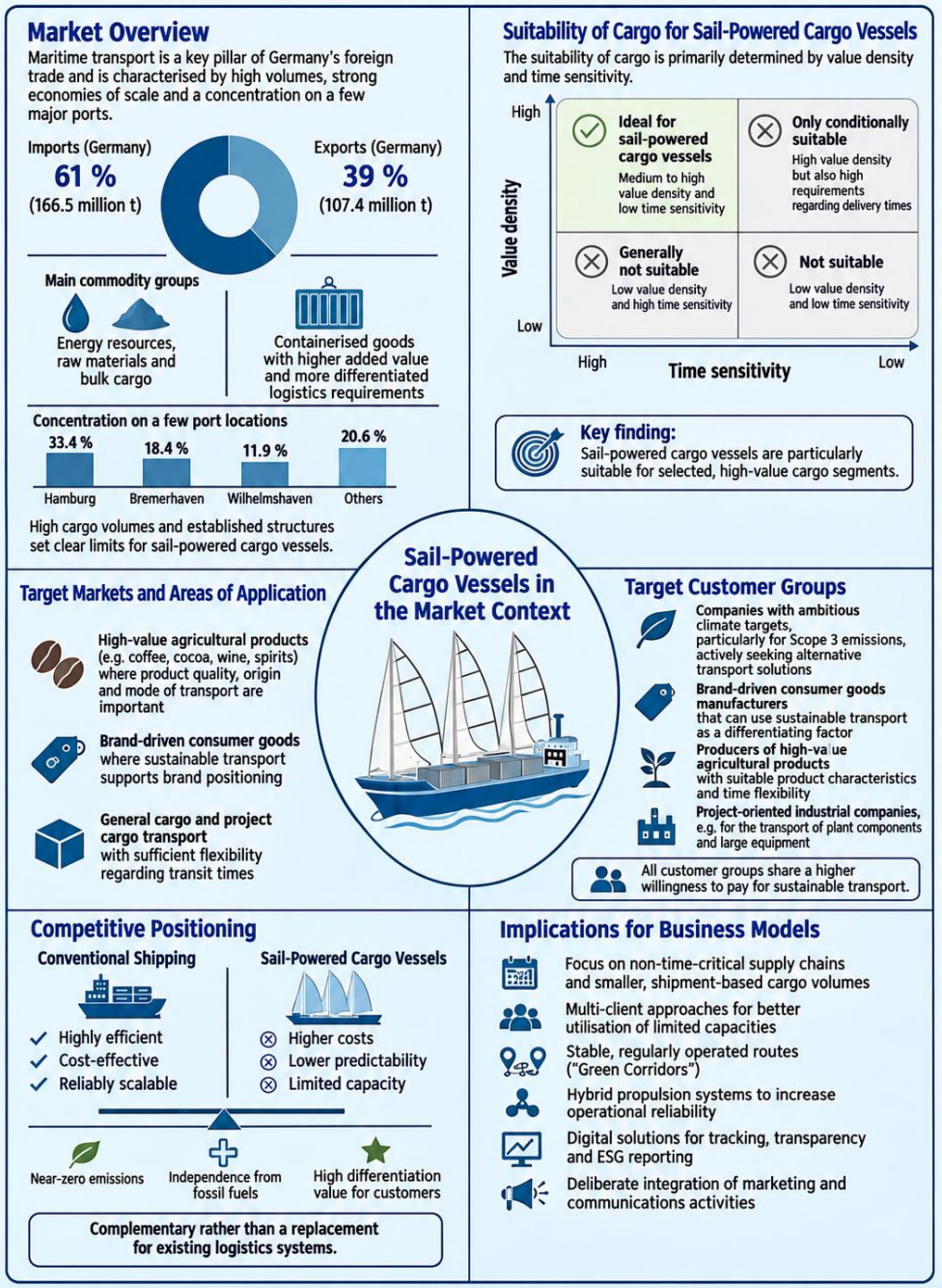
- The successful integration of sail cargo ships requires adapted business and operating models. A key priority is to focus on non-time-critical supply chains and smaller, shipment-based cargo volumes. Multi-client approaches can help achieve better utilisation of limited vessel capacities.

- Furthermore, stable, regularly operated routes (“Green Corridors”) are becoming increasingly important. Hybrid propulsion systems are also relevant for improving operational reliability. Digital solutions for tracking, transparency and ESG reporting, alongside the deliberate integration of marketing and communications activities, represent further key success factors.

Overall Assessment

- In summary, sail cargo ships have no mass-market potential but have clearly defined and growing potential within niche markets. Their strategic value lies less in economic efficiency than in their environmental benefits and their ability to provide differentiation.

- Success will depend critically on targeting suitable cargo segments and customer groups while developing business models that meet the specific requirements of this form of maritime transport.





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ECONOMIC VIABILITY

Preliminary Considerations

The aim of the economic feasibility assessment is to develop a transparent, modular evaluation framework that enables a systematic analysis of the economic viability of operating sail cargo ships. The model is intended to systematically capture both the main cost categories and potential revenue streams and integrate them into a consistent overall framework. The model is designed not only to reflect the current situation but, more importantly, to serve as a tool for scenario analysis and decision-making. Given the considerable uncertainties surrounding factors such as wind availability, technological performance and market price developments, a flexible structure is required to allow key variables to be adjusted.

The **cost assessment** follows a holistic approach that systematically considers not only capital investment costs but also all operating and subsequent costs. This is particularly relevant for sail cargo ships, as higher initial investments may be offset by potential savings during operation, with economic viability only becoming apparent over a longer period.

Under the proposed approach, the costs associated with a sail cargo ship are divided into several components:

1. Acquisition Costs

These include the construction or purchase costs of the ship, as well as the costs of integrating the propulsion technology. Financing costs, such as interest payments and loan terms, are also taken into account, alongside registration and documentation fees.

2. Operating Costs

Ongoing operating costs represent a significant component of overall economic viability. These include, in particular, fuel and lubricant costs, which vary depending on the propulsion technology, as well as crew costs, training expenses and related expenditure. Other key cost items include repairs and maintenance, insurance (e.g. Hull & Machinery and Protection & Indemnity), and port and canal dues.

3. Regulatory and Compliance Costs

These include expenses associated with classification societies, certifications and safety-related inspections. In addition, costs arise from compliance with environmental regulations, for example those relating to emissions reduction technologies, monitoring systems or ballast water treatment. Government charges, such as flag state fees or tonnage taxes, must also be taken into account.

4. Downtime and Opportunity Costs

These costs arise from lost revenue during planned or unplanned periods of downtime, such as dry-docking or repairs. In addition, market fluctuations, particularly in charter rates, can affect achievable revenues and must therefore be considered in the assessment.

The **revenue assessment** covers all revenue streams that can be generated from operating a sail cargo ship. The aim is to systematically identify and model the revenue mechanisms in a way that makes their structure, variability and dependence on operational and market-related factors transparent and quantifiable. As with the cost assessment, revenues are divided into several key components, taking into account both direct income from transport operations and indirect economic effects.

This differentiated approach is particularly necessary given the technological and market-specific characteristics of sail cargo ships.

The following factors are taken into account in the revenue assessment:

1. Transport Revenues

The primary source of revenue from operating a sail cargo ship is income generated from transport services. This is determined by the freight rate, cargo volume transported and transport frequency. Key influencing factors include vessel capacity, capacity utilisation and the number of round trips per year, which depend largely on vessel speed and route conditions. When using wind propulsion systems, potential trade-offs must be considered, such as those between reduced operating costs and potentially lower speeds or cargo capacities.

2. Sustainability-Related Revenue Potential

Sail cargo ships enable low-emission transport and can therefore generate additional revenue, particularly through price premiums (“Green Premiums”). The level of these premiums depends on the market segment, customer group and regulatory environment. Furthermore, sustainability-oriented transport solutions can facilitate the conclusion of long-term contracts and create a competitive advantage in certain market segments.

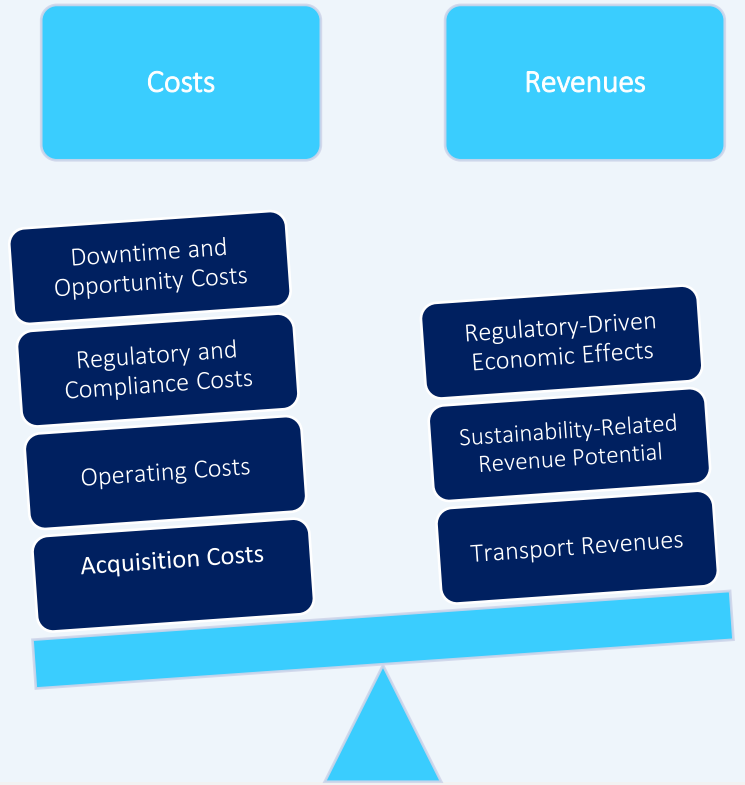
3. Regulatory-Driven Economic Effects

In addition to direct revenues, indirect effects must also be considered, such as reduced costs resulting from lower emissions under CO_2 pricing schemes. From an economic perspective, these effects are equivalent to additional revenue, as they reduce net costs. Furthermore, regulatory requirements can influence a ship's long-term revenue potential.

Revenues are subject to external factors such as fluctuating freight rates, changes in demand and structural market developments. Sustainability-related revenues, in particular, are associated with uncertainties that are accounted for in the model through scenario analysis.

The cost and revenue components outlined so far highlight the considerable complexity and wide range of factors influencing the economic viability of operating sail cargo ships. A comprehensive representation of all influencing factors and their interdependencies is only possible to a limited extent within the scope of this assessment. Therefore, a simplified modelling approach is adopted, focusing on the key parameters relevant to decision-making. The following sections systematically derive and quantify the main cost and revenue components to establish a robust basis for further analysis and evaluation.

Figure: Overview of Cost and Revenue Components



Cost Assessment

The detailed cost assessment follows the framework described above. Appropriate estimates for the individual cost components are systematically derived and quantified below to provide a consistent, robust basis for further analysis. Wherever possible, corresponding figures for conventional vessels are included to enable comparison.

Acquisition costs cover all initial expenditure required to provide an operational vessel. In addition to the construction or purchase price, they include numerous other cost components, which are particularly relevant in the context of innovative propulsion technologies. Accordingly, acquisition costs are divided into several key categories.

The largest component is the cost of shipbuilding itself, i.e. the actual construction or purchase price of the vessel. This is primarily influenced by vessel type and size, the chosen shipyard and its location, equipment standards and the degree of specialisation. For sail cargo ships, this remains the dominant cost category, typically accounting for approx. 60–80% of total investment. However, additional design requirements arise compared with conventional vessels. These include structural modifications to integrate wind propulsion systems, such as deck reinforcements or changes to the vessel's layout. Such requirements increase construction costs from the planning and design stage onwards. A key difference from conventional vessel concepts is the additional investment in wind propulsion systems, including Flettner rotors, rigid or flexible sails and kite systems. Empirical studies indicate that investment costs for these systems typically cost approximately USD 2–4 million per vessel, depending on the technology, number of units installed and their dimensions (see Lloyd's Register, 2024). This generally represents around 5–15% of total investment.

In addition to the system costs themselves, integration and engineering costs form a substantial part of the overall investment. These include structural modifications (e.g. foundations and reinforcements), integration into electrical and control systems, and extensive planning and design work. For retrofit projects, integration costs typically amount to around 25% of system costs, compared with approximately 18% for newbuilds (ibid.). This represents around 2–5% of total investment. The literature also identifies so-called 'hidden costs' associated with integrating wind propulsion systems. These include additional steelwork, engineering services and regulatory and classification requirements, which are often not fully accounted for at the outset.

Financing costs represent another significant cost category and have a substantial impact on project viability. They include interest on debt, repayment structures and equity requirements. Given the still limited market maturity and standardisation of wind propulsion technologies, additional risk premiums may increase financing costs. Transaction and ancillary costs incurred during project implementation must also be considered, including registration and flagging fees, classification society charges, insurance during construction (e.g. Builder's Risk), and legal and administrative expenses.

ECONOMIC VIABILITY

Given the limited market penetration to date and the lack of standardisation in some areas, acquisition costs for sail cargo ships are estimated as ranges. For larger ships with a deadweight capacity of at least approx. 10,000 dwt, investment costs typically range from EUR 25 million to EUR 40 million. The actual amount is largely determined by ship type, size, technological configuration and the degree of integration of wind propulsion systems.

By comparison, newbuilding costs for conventional vessels in similar segments are lower. General cargo vessels of approximately 10,000 dwt typically cost around EUR 18–25 million. Comparable container vessels often require investment of up to approx. EUR 30 million owing to greater technical requirements, higher engine power and more complex equipment. Overall, sail cargo ships generally involve a moderate investment premium compared with conventional vessels of similar size.

This range is broadly supported by current developments in wind-powered cargo shipping. Specific newbuild and demonstrator projects show considerable differences in investment costs depending on vessel type, size and technical configuration. According to publicly available information, projects such as Grain de Sail III and vessels developed by TOWT (e.g. Anemos) fall within the EUR 30–40 million range. These vessels combine moderate dimensions with a high proportion of wind-based propulsion. Their integrated design incorporates wind propulsion systems from the newbuilding stage, resulting in a comparatively balanced cost structure. By contrast, larger concepts include Neoliner Origin, designed as a RoRo vessel more than 130 metres long, with correspondingly high transport capacity. Due to its larger dimensions and the complex integration of extensive sail systems, investment costs are considerably higher, reaching approximately EUR 60 million. Other projects occupy smaller or more experimental segments and are often designed as demonstration or pilot projects. Owing to their smaller size, lower cargo capacity and generally reduced technological complexity, these concepts usually require substantially lower absolute investment. One example is SV Juren Ae, whose investment costs are estimated at approx. EUR 8–15 million.

For a comprehensive economic assessment, the capital investment in a sail cargo ship must be converted into annual cost components. One-off acquisition costs are therefore allocated over the vessel's economic useful life through depreciation. This converts the investment into annual costs that can be consistently incorporated into viability calculations. It also enables a realistic assessment of the long-term sustainability of operations, particularly given the high initial investment. In shipping, depreciation periods of approximately 20–25 years are typically assumed, depending on vessel type, technical service life and operating concept. Financing costs must also be considered, reflecting the capital structure and applicable interest terms. Under current market conditions, interest rates of around 4–6% may be considered realistic for debt financing. Innovative or not yet fully established technologies, such as sail cargo ships, may face somewhat higher financing costs because of increased perceived risk.

ECONOMIC VIABILITY

The structure and dynamics of **operating costs** for sail cargo ships can differ considerably from those of conventional vessels. Wind propulsion offers potential savings, particularly in fuel costs, but also creates additional cost components that must be considered. Fuel remains a major cost category and can be reduced through the use of wind energy. However, savings depend heavily on route characteristics, wind conditions and the technology used, and are therefore subject to substantial variation. Conventional propulsion generally cannot be replaced entirely, so significant fuel consumption remains.

Conversely, maintenance and repair costs may increase because of the greater technical complexity of wind propulsion systems. At the same time, reduced loads on the main engine may generate some savings. Overall, maintenance costs are therefore likely to be broadly comparable or slightly higher. Personnel costs may also change, as operating additional systems requires specific qualifications. Moderate cost increases are more likely in the short term, while automation may help stabilise costs in the longer term. Other cost components include insurance and energy- and system-related expenditure arising from the additional propulsion systems. Overall, this results in a more differentiated and, in some respects, more complex operating cost structure than for conventional vessels. Given the strong dependence on external factors, particularly wind conditions, a static assessment of operating costs is insufficient. Scenario-based modelling is therefore required to realistically capture the range of possible outcomes.

To quantify operating costs, a daily cost model is initially used to capture the main components of operating a sail cargo ship. These include crew costs, maintenance and repairs, insurance, ongoing technical operating expenses and activity-related expenditure such as energy consumption by auxiliary propulsion systems, port dues and canal charges. Administrative costs cover management, administration and sales activities. These are currently somewhat higher for sail cargo ships because of the greater coordination and marketing effort involved. On this basis, operating costs for a 10,000 dwt sail cargo ship are estimated at approx. EUR 8,000–14,000 per day, with a realistic midpoint of EUR 10,500 per day. For smaller vessels of around 5,000 dwt, lower absolute operating costs can be expected due to their smaller size and less extensive technical systems. A range of approximately EUR 5,300–8,400 per day appears realistic.

Based on these assumptions, total costs per voyage can be calculated by multiplying daily costs by the voyage duration. However, the wind-dependent performance of sail cargo ships means that voyage times naturally vary. Variations in wind conditions, route adjustments and possible waiting times directly affect operating costs. To ensure a minimum level of predictability and contractual reliability, fixed transit times incorporating suitable buffers are generally agreed in practice. Calculations typically assume an average service speed of 11–12 knots using a combination of wind and auxiliary propulsion. A round trip on a North Atlantic route (Europe–North America–Europe) is assumed to take approx. 28 days. This is based on reference projects (e.g. the Saint-Nazaire–Halifax route at around 11 knots).

ECONOMIC VIABILITY

Based on an average rate of EUR 10,500 per day, this results in a total of EUR 294,000 per round trip. It should also be noted that deviations from the planned voyage duration lead directly to proportional changes in costs. At the same time, efficiency gains achieved through optimised route planning and digital weather-routing systems can help reduce costs per voyage.

To gain a better understanding of the cost structure, a comparison with conventional vessels is useful. Operating costs can vary considerably depending on vessel type, size and operational profile. For conventional general cargo vessels with a deadweight tonnage of approximately 10,000 dwt, daily operating costs typically range from around EUR 8,300 to EUR 13,800, with a realistic average of EUR 11,000 per day. The actual costs are influenced in particular by crew size, fuel consumption, maintenance requirements, port calls and the vessel's level of technical equipment. For smaller general cargo vessels with a deadweight tonnage of approx. 5,000 dwt, operating costs are correspondingly lower. A realistic range of approximately EUR 5,500 to EUR 8,800 per day appears plausible. For conventional vessels of this size, a comparable round trip to North America typically takes between 18 and 21 days, depending on vessel speed, weather conditions and time spent in port.

This results in total operating costs of approx. EUR 99,000 to EUR 184,800 per voyage for smaller vessels (around 5,000 dwt), and EUR 149,400 to EUR 289,800 per voyage for vessels in the 10,000 dwt class.

The following table summarises the typical operating cost structures of sail cargo ships and conventional general cargo vessels in the 5,000 dwt and 10,000 dwt size categories.

Table: Comparison of Typical Daily Operating Cost Structures

	5,000 dwt		10,000 dwt	
Category	Sail Cargo Ship	Conventional General Cargo Ship	Sail Cargo Ship	Conventional General Cargo Ship
Crew Costs	1,500–2,000	1,200–1,800	2,000–3,000	1,800–2,500
Maintenance	1,200–1,800	800–1,200	2,000–3,000	1,200–2,000
Fuel Costs*	1,000–1,500	2,000–3,000	1,500–3,000	3,000–5,000
Insurance	300–600	300–500	500–1,000	500–800
Fees & Charges	800–1,500	800–1,500	1,000–2,000	1,000–2,000
Administration	500–1,000	400–800	1,000–2,000	800–1,500
Total / Day	**5,300–8,400**	**5,500–8,800**	**8,000–14,000**	**8,300–13,800**
Assumed Value	EUR 6,500	EUR 7,000	EUR 10,500	EUR 11,000

The **regulatory and compliance costs** encompass all expenses arising from compliance with international, regional and national regulations in the maritime sector. They represent a further component of the overall cost structure and are becoming increasingly significant in light of growing environmental and climate-related regulatory requirements. A major cost category arises from technical approval and classification procedures. Particularly in the case of innovative technologies such as wind propulsion systems, certification requirements are often more extensive, as additional evidence relating to safety, stability and operational performance is required. Furthermore, additional costs arise from compliance with international safety, environmental and emissions standards (e.g. IMO requirements). Meeting these requirements necessitates investment in technical systems as well as the associated certification and compliance verification procedures.

* The fuel costs shown do not directly correspond to the proportion of propulsion provided by wind power. Even with a high proportion of wind propulsion, energy is still required for auxiliary machinery, onboard power supply, port manoeuvres and supplementary propulsion under unfavourable weather conditions.

Climate-related regulations, such as the EU Emissions Trading System (EU ETS) and the FuelEU Maritime Regulation, are also becoming increasingly relevant. These either impose direct costs on CO_2 emissions or establish requirements concerning the greenhouse gas intensity of energy used by ships. While these regulations place additional financial burdens on conventional vessels in particular, sail cargo ships may benefit from potential cost advantages due to their lower emissions. In addition, further national regulations must be taken into account, including registration fees and tax liabilities.

Regulatory and compliance costs can also be quantified. For conventional vessels, emissions-related regulations such as the EU Emissions Trading System result in costs of approximately EUR 2,600 to EUR 7,500 per day. A significant proportion of these costs is attributable to CO_2 emissions, with the actual amount varying considerably depending on vessel type and operational profile. For sail cargo ships, the cost structure is different. While classification and certification expenses tend to be slightly higher due to technological complexity, emissions-related costs are significantly lower. Overall, regulatory costs for sail-powered cargo vessels range from approx. EUR 1,300 to EUR 3,800 per day.

Table: Daily Regulatory and Compliance Costs

Cost Components	Sail Cargo Ship	Conventional Ship
Classification & Inspections	400 – 900	300 – 700
Certification & Approval	200 – 500	100 – 300
Environmental Compliance	200 – 400	200 – 500
CO_2 Costs (EU ETS)	500 – 2,000	2,000 – 6,000
Taxes & Charges	comparable	comparable
Total (EUR/day)	1,300 – 3,800	2,600 – 7,500

Downtime and opportunity costs encompass all economic losses arising from planned and unplanned periods of vessel unavailability, as well as unrealised revenue potential. Unlike direct operating costs, these are indirect costs that arise primarily from lost revenue during periods when the vessel is not in productive operation.

Planned downtime results mainly from scheduled maintenance and dry-docking intervals. Major dry-docking typically takes place every 2.5 to 5 years and lasts approximately 10 to 20 days. In addition, annual maintenance activities are required, typically accounting for a further 3 to 5 days. On an annual basis, this corresponds to an average planned downtime of approx. 5 to 10 days. Assuming average daily revenues of around EUR 5,000 to EUR 10,000, this results in opportunity costs of approximately EUR 25,000 to EUR 100,000 per year.

Unplanned downtime resulting from technical failures or the need for urgent repairs must also be taken into account. Sail cargo ships can be expected to have a slightly higher susceptibility to technical faults, partly due to the greater complexity of their wind propulsion systems compared with conventional vessels. This may result in unplanned downtime of approx. 2 to 6 days per year, corresponding to additional opportunity costs of around EUR 10,000 to EUR 60,000 annually.

ECONOMIC VIABILITY

A key difference between conventional cargo vessels and sail cargo ships arises from market-related opportunity costs. These result primarily from delays caused by variable operating conditions. While conventional vessels benefit from relatively stable and predictable voyage durations due to their consistent propulsion power, sail cargo ships are subject to greater variability as a result of wind-dependent speeds. This can lead to longer voyage durations and, consequently, fewer round trips per year. Although voyages undertaken by sail cargo ships are generally planned with appropriate time buffers, deviations from the schedule cannot be entirely avoided. Overall, additional delays of approx. 5 to 10 days per year can therefore be expected, potentially resulting in opportunity costs of around EUR 25,000 to EUR 100,000 annually.

Furthermore, short-term market fluctuations, particularly changes in charter rates, can further increase opportunity costs. Even minor delays of just a few days may mean that subsequent transport contracts cannot be secured or can only be fulfilled on less favourable terms, resulting in additional revenue losses. These are not considered further in the following analysis.The table below provides an overview of downtime and opportunity costs.

Table: Downtime and Opportunity Costs

Cost Category	Sail Cargo Ship	Conventional Ship
Planned Downtime (Dry-Docking, Maintenance)	EUR 25,000-100,000 p. a.	EUR 25,000–100,000 p. a.
Unplanned Downtime	EUR 10,000-60,000 p. a.	EUR 5,000–30,000 p. a.
Opportunity Costs Due to Fewer Round Trips	EUR 25,000-100,000 p. a.	Low / Negligible
Total per Year	EUR 60,000 – 260,000	EUR 30,000–130,000

Revenue Assessment

The revenue assessment follows a structured, model-based approach, analogous to the cost analysis. The aim is to systematically identify the main revenue sources associated with operating sail cargo ships, establish appropriate assumptions and integrate them into a consistent overall assessment. Given the existing uncertainties, particularly regarding market developments and willingness to pay a premium for sustainable transport, revenues are also modelled using ranges and scenarios.

The primary source of revenue from operating sail cargo ships is income generated from transport services (**transport revenues**). These revenues are determined by the combination of freight rates, cargo volumes transported and transport frequency, and can formally be expressed as the product of these three variables. This fundamental revenue model is the same as that used in conventional shipping. However, differences arise in the characteristics of the individual parameters, particularly with regard to speed, capacity and market segmentation. Key influencing factors include vessel capacity, capacity utilisation and the number of round trips per year, which depend largely on vessel speed, route length and operational conditions. While conventional vessels can achieve a high degree of predictability and capacity utilisation due to their higher and more consistent operating speeds, these factors are more dependent on external conditions, particularly wind conditions, in the case of sail cargo ships. To quantify transport revenues, the following analysis considers sail cargo ships of different size categories, particularly ships of approximately 5,000 dwt and 10,000 dwt. Different capacity utilisation rates are also taken into account to reflect varying market and operating conditions.

To put the results into context, a comparison is also made with conventional ships of comparable size categories. It should be noted that conventional ships often have significantly greater capacities, allowing them to benefit from economies of scale.

ECONOMIC VIABILITY

The freight rate represents the remuneration for the transport service itself and must reflect the specific cost and performance characteristics of operating sail cargo ships. Due to lower economies of scale, fewer round trips and higher investment costs, freight rates are generally higher than those charged by conventional general cargo vessels. Achievable freight rates vary depending on the market segment and cargo type. Based on market assessments, freight rates of between EUR 50 and EUR 120 per tonne can be assumed for general cargo and niche markets. These rates are often higher than those in conventional general cargo shipping, where intense competition and a high degree of standardisation result in lower margins. This translates into transport revenues ranging from approximately EUR 175,000 to EUR 1,100,000 per voyage.

Another key influencing factor is the number of round trips per year. While conventional vessels can typically complete around 18 to 20 voyages annually due to their consistent propulsion power, sail cargo ships often achieve approx. 12 to 14 round trips per year, depending on the route and wind conditions. This results in annual transport revenues of approximately EUR 2.1 million to EUR 15.4 million. The lower frequency of round trips represents a key difference compared with conventional shipping and has a negative impact on revenue generation.

When using wind propulsion systems, specific trade-offs must also be considered. On the one hand, reduced operating costs may enable competitive pricing compared with conventional operators. On the other hand, lower average speeds can lead to longer voyage durations, reducing the number of annual round trips and potentially limiting total revenues. Furthermore, structural modifications, such as the integration of sail systems, may restrict available cargo capacity, whereas conventional vessels can generally utilise their full capacity for cargo transport.

The following table provides an overview of the key parameters influencing transport revenues.

Table: Comparison of Transport Revenues

Parameter	Sail Cargo Ship	Conventional Ship
Transport Capacity per Voyage	5,000 – 10,000 t	5,000 – 10,000 t
Capacity Utilisation	70–90%	80–95%
Cargo Volume per Voyage	3,500 – 9,000 t	4,000 – 9,500 t
Freight Rate	50 – 120 EUR/t	20 – 80 EUR/t
Revenue per Voyage	EUR 175,000–1.1m	EUR 80,000–0.8m
Voyages per Year	12 – 14	18 – 20
Annual Revenue	EUR 2.1–15.4m	EUR 1.44–15.2m
Speed	Lower, Variable	High, Consistent
Schedule Reliability	Limited (Wind-Dependent)	High
Market Segment	Niche / Premium Markets	Mass Markets



ECONOMIC VIABILITY

Due to their specific cost and capacity structures, sail cargo ships generally require higher freight rates than conventional vessels. A distinction must be made between these higher freight rates and a potential “Green Premium”, which represents additional remuneration for sustainability-related benefits, such as verifiable emissions reductions or added brand and communications value. Whether such a premium can be achieved depends on the market segment and customers' willingness to pay. The greatest potential therefore lies in high-value or sustainably positioned goods, for which transport costs are of relatively minor importance. The Green Premium should thus be regarded as an optional additional revenue stream rather than a prerequisite for economic viability. The Green Premium can typically be quantified as ranging from approximately 2% to 15% of the standard freight rate. In conservative scenarios, relatively modest premiums of around 2% to 5% can be assumed, while premiums of 10% to 15% may be achievable in established niche markets or where sustainability requirements are particularly stringent. Based on the transport revenues outlined previously, this results in the following additional revenue potential: With annual transport revenues of approx. EUR 2.1 million to EUR 15.4 million, additional annual revenues of EUR 42,000 to EUR 2,310,000 could be generated.

By comparison, conventional vessels currently have very limited potential to generate similar additional revenues, as their higher emissions generally prevent them from commanding price premiums. Instead, they are increasingly exposed to pricing pressure, particularly as a result of regulatory measures and rising CO_2 costs.

Beyond direct price premiums, further sustainability-related revenue opportunities arise from structural changes in the market. For example, sail cargo ships may facilitate access to long-term transport contracts, particularly with companies pursuing their own climate targets or subject to regulatory requirements.

These contracts are often characterised by more stable freight rates and lower volatility, thereby contributing to greater predictability of revenue streams. In addition, environmental differentiation can create a competitive advantage, which may indirectly translate into higher capacity utilisation or preferential contract awards. While conventional vessels compete primarily on price and efficiency, sail cargo ships offer opportunities for market positioning based on sustainability and innovation.

In addition to direct transport revenues and sustainability-related price premiums, **regulatory-driven economic effects** must also be taken into account. Although these do not constitute conventional revenues in the strict sense, they have an equivalent economic effect, as they reduce effective costs and thereby improve net margins. The main factors in this context are emissions-related regulations, particularly the EU Emissions Trading System (EU ETS) and the FuelEU Maritime Regulation. These either impose direct costs on CO_2 emissions or establish minimum requirements regarding the emissions intensity of transport services.

For conventional vessels, these regulations result in significant additional costs. Assuming typical emissions of approx. 20 to 35 tonnes of CO_2 per day and CO_2 prices of around EUR 80 to EUR 100 per tonne, costs of approximately EUR 1,600 to EUR 3,500 per day arise. On an annual basis, assuming approx. 250 operating days, this corresponds to additional costs of around EUR 400,000 to EUR 875,000 per year.

Sail cargo ships have significantly lower emissions intensity due to their use of wind energy. Depending on their operational profile, emissions reductions of approximately 20% to 50% can be achieved. This results in correspondingly lower CO_2-related costs of approx. EUR 800 to EUR 2,800 per day, or around EUR 200,000 to EUR 700,000 per year.

ECONOMIC VIABILITY

Comparative Analysis of Different Sail Cargo Ship Sizes

The economic viability assessment is based on two reference vessels of different size categories. The aim is to systematically analyse the effects of vessel size, capacity, capacity utilisation, voyage duration and cost structure on economic viability. For this purpose, a sail cargo ship of 5,000 dwt and a second ship of 10,000 dwt are considered. Realistic operational and market assumptions are applied to both ship categories.

The selected parameters are based on the previously established ranges for freight rates, capacity utilisation, operating costs, Green Premiums and regulatory costs. The assumptions have been chosen to illustrate potentially economically viable operating models for both ship concepts and to enable a transparent analysis of the effects of different ship sizes.

To put the results into context, both sail cargo ships are compared with conventional general cargo vessels of similar size. This makes it possible to assess the extent to which sail cargo ships can compete economically with conventional transport solutions under the assumptions made.

Reference Case A

The first reference case considers a smaller sail cargo ship with a deadweight tonnage of 5,000 dwt. Due to its lower transport capacity, freight rates are assumed to be significantly higher than those of conventional general cargo vessels, reflecting a focus on high-value and sustainability-oriented market segments.

The key assumptions are:

- Deadweight tonnage of 5,000 dwt
- Capacity utilisation of 70%
- Higher freight rate due to positioning in sustainability-oriented niche markets
- Moderate Green Premium
- Voyage duration based on a typical transatlantic operating profile
- Reduced emissions-related costs compared with conventional vessels
- Financing costs of 5% to account for technological and market-related risks

This reference vessel is representative of smaller sail cargo ships operating primarily in specialised market segments where customers have a high willingness to pay for low-emission transport.

Reference Case B

The second reference case considers a larger sail cargo ship with a deadweight tonnage of 10,000 dwt. Its greater transport capacity enables better utilisation of economies of scale and allows fixed costs to be spread over larger cargo volumes.

The key assumptions are:

- Deadweight tonnage of 10,000 dwt
- High capacity utilisation due to stable demand
- Competitive freight rates above those of conventional general cargo vessels
- Higher Green Premium
- Slightly shorter voyage duration due to optimised operating conditions
- Reduced emissions-related costs compared with conventional vessels
- Financing costs of 5% to account for technological and market-related risks

This reference ship represents larger sail cargo ships, for which economies of scale, higher cargo volumes and improved capacity utilisation can significantly enhance economic viability.

ECONOMIC VIABILITY

	Sail Cargo Ship		Conventional General Cargo Ship	
Parameter	5,000 dwt	10,000 dwt	5,000 dwt	10,000 dwt
Transport Capacity per Voyage	5,000	10,000	5,000	10,000
Capacity Utilisation	70%	80%	90%	90%
Cargo Volume per Voyage	3,500	8,000	4,500	9,000
Freight Rate	EUR 110	EUR 80	EUR 65	EUR 60
Transport Revenue per Voyage	EUR 385,000	EUR 640,000	EUR 292,500	EUR 540,000
Green Premium	2%	5%	0%	0%
Green Premium Revenue per Voyage	EUR 7,700	EUR 32,000	0	0
Total Revenue per Voyage	EUR 392,700	EUR 672,000	EUR 292,500	EUR 540,000
Voyage Duration incl. Port Time	28	26	20	20
OPEX per Day	EUR 6,500	EUR 10,500	EUR 7,000	EUR 11,000
OPEX per Voyage	EUR 182,000	EUR 273,000	EUR 140,000	EUR 220,000
Regulatory Costs per Voyage	EUR 36,400	EUR 52,000	EUR 60,000	EUR 100,000
Total Costs per Voyage	EUR 218,400	EUR 325,000	EUR 200,000	EUR 320,000
Operating Profit per Voyage	EUR 174,300	EUR 347,000	EUR 92,500	EUR 220,000
Round Trips per Year	13	14	20	20
Annual Operating Profit	EUR 2,241,000	EUR 4,804,615	EUR 1,850,000	EUR 4,400,000
Annual Downtime and Opportunity Costs	EUR 60,000	EUR 75,000	EUR 30,000	EUR 50,000
CO_2 Pricing	EUR 200,000	EUR 400,000	EUR 500,000	EUR 875,000
Annual Profit Before CAPEX	EUR 1,981,000	EUR 4,329,615	EUR 1,320,000	EUR 3,475,000
Capital Investment	EUR 20,000,000	EUR 40,000,000	EUR 14,000,000	EUR 25,000,000
Annual Depreciation	EUR 800,000	EUR 1,600,000	EUR 560,000	EUR 1,000,000
Annual Financing Costs	EUR 1,000,000	EUR 2,000,000	EUR 560,000	EUR 1,000,000
Annual CAPEX-Related Costs	EUR 1,800,000	EUR 3,600,000	EUR 1,120,000	EUR 2,000,000
Annual Profit Including CAPEX	EUR 181,000	EUR 729,615	EUR 200,000	EUR 1,475,000

ECONOMIC VIABILITY

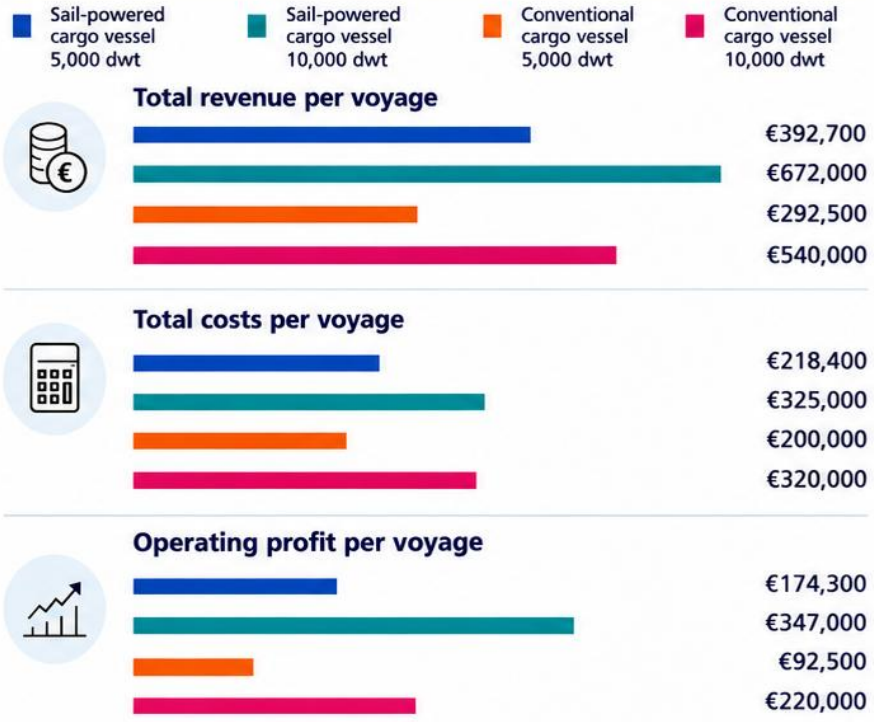
SAIL-POWERED CARGO VESSEL · 5,000 DWT
Annual result incl. CAPEX
+€0.18 million
Positive result after all costs

SAIL-POWERED CARGO VESSEL · 10,000 DWT
Annual result incl. CAPEX
+€0.73 million
Positive result after all costs

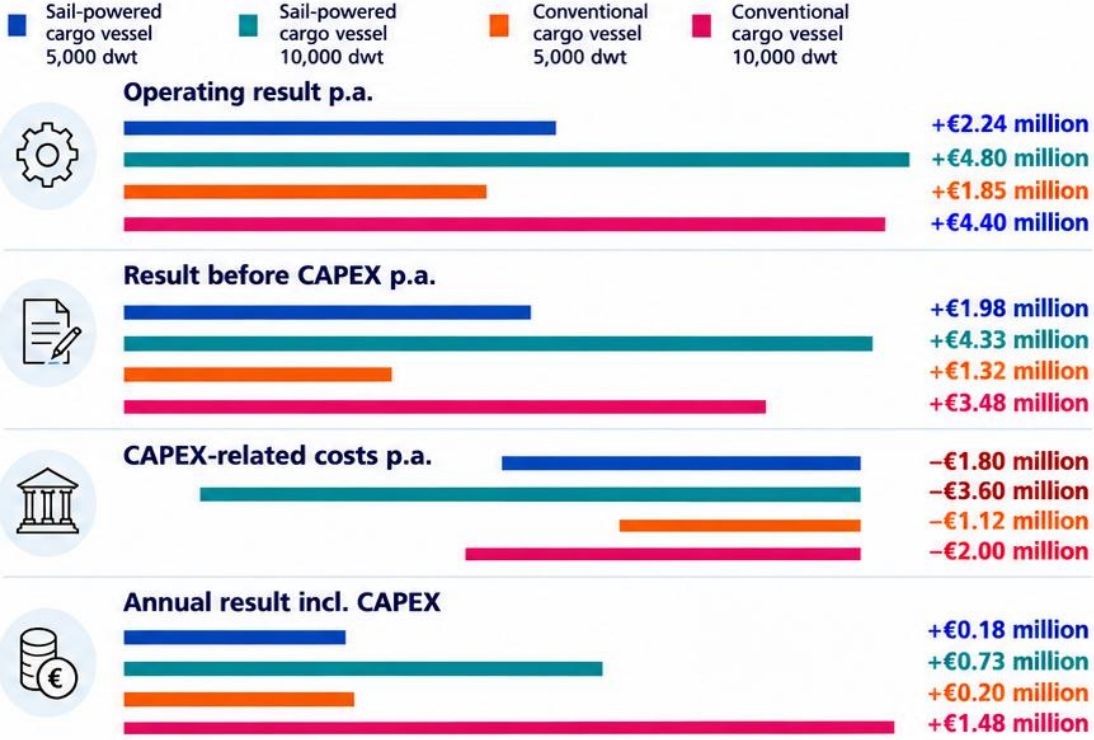
CONVENTIONAL GENERAL CARGO VESSEL · 5,000 DWT
Annual result incl. CAPEX
+€0.20 million
Positive result after all costs

CONVENTIONAL GENERAL CARGO VESSEL · 10,000 DWT
Annual result incl. CAPEX
+€1.48 million
Positive result after all costs

REVENUE & COSTS PER VOYAGE



RESULT STRUCTURE P.A. – OPERATING → BEFORE CAPEX → AFTER CAPEX



All amounts are in EUR. Values are rounded. DWT = deadweight tonnage.
Revenue and costs per voyage are based on the parameters specified in the table.

ECONOMIC VIABILITY

The preceding table shows that the economic viability of sail cargo ships depends largely on vessel size, freight rates, capacity utilisation, round-trip frequency and the CAPEX structure. Under suitable market and operating conditions, these vessels can be economically viable. Larger vessels tend to deliver more robust results thanks to economies of scale and higher cargo volumes.

Significant differences are already apparent in revenue per voyage. At 70% utilisation and a freight rate of EUR 110/t, the 5,000 dwt sail cargo ship generates transport revenue of EUR 385,000 per voyage. Including a 2% Green Premium, total revenue is EUR 392,700. Despite a lower freight rate of EUR 80/t, the 10,000 dwt vessel generates around EUR 672,000 per voyage owing to its higher cargo volume. Conventional general cargo vessels, by comparison, generate approx. EUR 292,500 and EUR 540,000 respectively. This illustrates how sail cargo ships can strengthen their market position through higher freight rates in specialised segments and additional revenue from sustainable transport.

The concepts also differ in their costs. At around EUR 6,500 per day (5,000 dwt) and EUR 10,500 per day (10,000 dwt), operating costs are similar to those of conventional comparison vessels. Sail cargo ships also benefit from lower regulatory costs due to reduced emissions. This produces operating profits of approximately EUR 174,300 and EUR 347,000 per voyage respectively.

Both figures exceed the operating profits of comparable conventional vessels. Longer voyages and fewer round trips nevertheless affect annual performance: sail cargo ships complete 13 or 14 round trips, compared with around 20 for conventional general cargo vessels. Their higher revenue per voyage still generates annual operating profits of approx. EUR 2.24 million and EUR 4.80 million. After downtime and opportunity costs and CO_2 pricing, annual results before CAPEX are EUR 1.98 million and EUR 4.33 million. CO_2 pricing costs of EUR 200,000 and EUR 400,000 per year are substantially lower than for conventional vessels.

CAPEX-related costs remain a major influence on overall viability. Higher investments in sail cargo ships entail higher depreciation and financing costs. Even so, after all costs, annual profits remain positive at approximately EUR 181,000 for the 5,000 dwt vessel and EUR 730,000 for the 10,000 dwt vessel. The conventional comparison vessels achieve around EUR 200,000 and EUR 1.48 million respectively.

Overall, sail cargo ships can be economically viable under appropriate market conditions. Larger units benefit particularly from economies of scale, higher cargo volumes and better allocation of fixed costs. Freight rates, utilisation, round-trip frequency, CO_2 costs and CAPEX-related costs are therefore critical to their long-term competitiveness.

Analysis of Influencing Factors

Having identified and quantified the principal cost and revenue components of sail cargo ship operations, the next step is to examine systematically how individual parameters affect economic viability. The aim is to move beyond a description of cost and revenue structures and develop a deeper understanding of the factors driving financial performance.

The preceding analysis has shown that individual cost and revenue parameters can vary considerably. This reflects market uncertainty, technological characteristics and external conditions, particularly wind conditions and regulatory developments. Freight rates, utilisation, voyage duration or round-trip frequency, and emissions-related costs are particularly relevant.

Freight rates determine revenue per tonne carried and are therefore the principal revenue driver. They are shaped by supply and demand in each market segment. Rates also vary between cargo groups, with specialised or sustainability-oriented transport potentially commanding higher prices. Utilisation determines actual cargo volumes and directly affects results when operating costs are largely fixed. It depends on market demand and the ability to secure sufficient cargo on a continuous basis. Demand fluctuations can therefore change revenue directly.

Voyage duration and round-trip frequency determine the number of transport cycles possible each year and are thus key structural variables. Conventional vessels benefit from relatively predictable schedules because of their consistent propulsion power.

For sail cargo ships, voyage duration varies more because of dependence on wind. This increases scheduling uncertainty and may limit the number of achievable round trips. Emissions-related costs primarily affect expenditure, but are becoming increasingly important with tighter regulation, especially CO_2 pricing. They influence the relative competitiveness of propulsion systems and may provide long-term economic advantages for low-emission technologies.

Against this background, the following analysis varies selected parameters to assess their effect on financial results. Its purpose is to identify the factors with the greatest impact on viability and hence the key management variables or economic levers.

A simplified sensitivity analysis is performed using a reference scenario. Individual parameters are varied separately, and their effect on financial performance is quantified in simplified form as profit contributions per voyage or per year.

The starting point is a smaller sail cargo ship (5,000 dwt), carrying 3,500 tonnes per voyage at EUR 110/t, with operating costs of EUR 6,500 per day and a voyage duration of 28 days.

ECONOMIC VIABILITY

Impact of Freight Rates

Freight rates have a particularly strong influence on the economic viability of sail-powered cargo operations and are the main revenue driver. Even relatively small changes can significantly alter financial performance because each change applies to every tonne transported and therefore directly affects revenue per voyage.

The reference case is a 5,000 dwt sail cargo ship. At 70% utilisation, 3,500 tonnes transported per voyage and a freight rate of EUR 110/t, transport revenue is EUR 385,000 per voyage. Including a 2% Green Premium increases total revenue to EUR 392,700. Against total costs of EUR 218,400 per voyage, this yields an operating profit of around EUR 174,300. After downtime and opportunity costs, CO_2 pricing, depreciation and financing costs, the annual result is positive at approx. EUR 181,000.

Sensitivity analysis demonstrates the strong response of economic viability to freight-rate changes. Raising the rate by just EUR 10/t produces significant improvements at unchanged utilisation; falling rates can substantially impair viability. The effect also depends heavily on utilisation. Low utilisation can produce unsatisfactory results even at high rates, while high utilisation can make moderate rates economically attractive. The following table shows annual results by freight rate and utilisation.

Table: Annual Results under Parameter Variation (5,000 dwt Sail Cargo Ship)

Freight rate	70%	80%	90%	100%
EUR 70	-1,655,000	-1,196,000	-737,000	-278,000
EUR 80	-1,196,000	-671,429	-146,857	377,714
EUR 90	-737,000	-146,857	443,286	1,033,429
EUR 100	-278,000	377,714	1,033,429	1,689,143
EUR 110	181,000	902,286	1,623,571	2,344,857
EUR 120	640,000	1,426,857	2,213,714	3,000,571
EUR 130	1,099,000	1,951,429	2,803,857	3,656,286
EUR 140	1,558,000	2,476,000	3,394,000	4,312,000

The results underline the importance of freight rates for the economic viability of sail cargo ships. Operators have only limited influence over rates, however, as these are largely determined by external market conditions. Supply and demand within the relevant segment and customers' willingness to pay for sustainable transport are particularly important. Higher rates may be achievable for specialised segments or emissions-sensitive cargo, substantially improving economic performance.

Utilisation is different: operators have considerably more scope to influence it. Targeted marketing and sales activities, long-term customer relationships and optimised operational processes can increase utilisation and sustainably improve the viability of operations.

ECONOMIC VIABILITY

Impact of the Green Premium

A Green Premium can create additional revenue potential for sail cargo ships. In the reference case of a 5,000 dwt sail cargo ship, a Green Premium of 2% is assumed. Based on transport revenue of EUR 385,000 per voyage, this results in additional revenue of EUR 7,700 per voyage. If the Green Premium were to increase to 10%, this additional revenue would rise to EUR 38,500 per voyage. However, compared with total voyage revenues and other cost components, the contribution of the Green Premium remains limited. The analysis shows that the economic viability of sail cargo ships is influenced to a much greater extent by factors such as freight rates, capacity utilisation, round-trip frequency and investment costs. Although the Green Premium can improve economic viability and generate additional contributions to profitability, it does not represent the decisive economic driver. Nevertheless, the Green Premium is becoming increasingly relevant as sustainable supply chains gain importance. Corresponding price premiums can be achieved particularly in market segments with stringent requirements regarding the carbon footprint of the transport chain, such as high-value consumer goods, food products and sustainability-oriented branded products.

Impact of Voyage Duration and Round-Trip Frequency

Voyage duration and the resulting round-trip frequency represent another factor influencing the economic viability of sail cargo ships. Although voyage duration does not directly affect revenue per tonne transported, it largely determines the number of round trips that can be completed annually and, consequently, the ship's total annual transport capacity. In the reference case of the 5,000 dwt sail cargo ship, a round-trip duration of 28 days, including time spent in port, is assumed. Under these conditions, approximately 13 round trips can be completed per year. Even a moderate reduction in voyage duration to 26 days increases the number of potential round trips to approx. 14 per year, thereby improving the vessel's economic performance.



IMPACT OF VOYAGE DURATION AND SERVICE SPEED

	REFERENCE CASE (28 DAYS)	MODERATE ACCELERATION (26 DAYS)	SIGNIFICANT ACCELERATION (20 DAYS)
Voyage duration (round trip incl. port time)	28 days	26 days	20 days
Service speed (average)	11–12 knots (Ø 11.5 knots)	~12.5–13 knots (Ø 12.8 knots)	~16.5–17 knots (Ø 16.8 knots)
Required increase in service speed (compared with reference case)	–	+ ~11 %	+ ~46 %
Reduction in voyage duration (compared with reference case)	–	– 2 days (– 7 %)	– 8 days (– 29 %)
Round trips per year (approx.)	~13 round trips	~14 round trips (+1 round trip)	~18 round trips (+5 round trips)

SUMMARY

- At a service speed of 11–12 knots, the round-trip duration is 28 days.
- An increase to approximately 12.5–13 knots reduces the voyage duration to around 26 days and enables an additional round trip per year.
- A reduction to approximately 20 days requires service speeds of around 16.5–17 knots and thus around 5 additional round trips per year.
- Higher service speeds improve the round-trip frequency, but are usually associated with additional CAPEX and OPEX requirements.
- The economic benefits therefore depend on the relationship between the additional revenues and the additional costs required.

The analysis shows that voyage duration and the resulting round-trip frequency have a significant impact on the economic viability of sail cargo ships. Even a reduction in round-trip duration from 28 to 26 days increases the number of potential round trips per year, thereby improving the ship's economic performance. A further reduction in voyage duration creates additional revenue potential by increasing the ship's annual transport capacity. At the same time, higher service speeds can generally only be achieved through technical modifications and additional propulsion assistance. However, optimised hull designs, more powerful wind propulsion systems or supplementary auxiliary propulsion systems often lead to higher investment and operating costs. The economic benefits of shorter voyage durations therefore depend critically on whether the additional revenues generated by higher round-trip frequencies exceed the additional costs required to achieve them.

ECONOMIC VIABILITY

Impact of OPEX

Operating expenditure (OPEX) is an important cost-side factor in the economic viability of sail cargo ships. The reference scenario assumes average operating costs of approximately EUR 6,500 per day. Over a 28-day round trip, this gives total operating expenditure of EUR 182,000 per voyage. Changes in daily costs directly affect operating profit. Even moderate increases can significantly weaken viability, while efficiency gains have the opposite effect.

Sensitivity analysis indicates that operating costs matter, although their impact is less pronounced than that of freight rates and utilisation. Lower OPEX immediately improves viability; higher costs reduce profits. In the reference case, an increase from EUR 6,500 to EUR 7,000 per day would almost entirely eliminate the positive annual result. This demonstrates sensitivity to ongoing expenditure.

Crew, maintenance and energy costs are particularly important, accounting for a substantial share of OPEX. Sail cargo ships may require more highly qualified personnel because of their additional wind propulsion systems and more complex operations. Sail management, weather routing and system monitoring can increase skills requirements and personnel costs. Over time, however, automation and technological maturity could unlock efficiency gains.

Automated sail controls, digital weather-routing systems and integrated vessel-management software can reduce operational workload and improve process efficiency. These technologies also require additional investment and thus increase CAPEX. Lower OPEX therefore often comes at the expense of higher capital investment.

Fuel-price developments also substantially affect viability. Fuel is one of the dominant costs in conventional shipping and fluctuates sharply with volatile energy prices. Wind power reduces this exposure for sail cargo ships, but does not eliminate it because auxiliary and safety propulsion remains necessary. Complete independence from energy-market developments is therefore impossible.

Further fuel savings are achievable by improving sail-system efficiency and reducing the need for supplementary conventional propulsion. At the same time, rising fuel prices give sail cargo ships a relative competitive advantage because they consume substantially less fossil fuel. Wind-powered transport concepts are therefore likely to become more competitive as energy prices rise.

ECONOMIC VIABILITY

Impact of Investment Costs and CAPEX-Related Costs

Alongside operational variables, high investment costs significantly affect the overall economic viability of sail cargo ships. An investment of approx. EUR 20 million is assumed for a smaller sail cargo ship, compared with around EUR 14 million for a conventional general cargo vessel. This results in substantially higher depreciation and financing costs.

Annual CAPEX-related costs for the sail cargo ship amount to approximately EUR 1.8 million, compared with around EUR 1.1 million for the conventional reference vessel. High initial investment and associated financing costs therefore represent a major constraint on viability. The technology standard is particularly important. Projects such as Neoliner show that larger vessels, extensive technical systems and automation can substantially increase investment requirements; CAPEX of around EUR 60 million has been discussed for Neoliner.

Experience from smaller projects suggests that capable sail cargo ships can also be built at much lower cost if a simpler technical approach is adopted. In the longer term, increasing standardisation, technological learning and economies of scale as market adoption grows could reduce CAPEX. Greater experience in construction and operation should make both production processes and technical systems more efficient.

Sensitivity analysis shows that reducing investment costs to EUR 15 million would significantly lower annual depreciation and financing costs. In that case, annual CAPEX-related costs would fall by EUR 450,000, making an important contribution to overall profitability. Investment costs are therefore a key lever for long-term competitiveness.

Impact of Emissions-Related Costs

Emissions-related costs are becoming increasingly important because of tighter regulation and climate policy, affecting the relative competitiveness of propulsion concepts. Conventional vessels incur substantial CO_2 costs because they burn fossil fuels, whereas predominantly wind-powered vessels enjoy significant savings.

The reference scenario assumes annual CO_2 costs of approx. EUR 200,000 for the sail cargo ship, compared with around EUR 500,000 for a conventional general cargo ship. The resulting annual cost advantage of approximately EUR 300,000 contributes materially to viability and strengthens the sail cargo ship's competitive position.

Emissions-related costs are, however, only one factor. Freight rates, utilisation, round-trip frequency and investment and financing costs still strongly influence overall results. Rising CO_2 prices and tighter regulation are likely to increase the economic importance of low-emission transport, making emissions-related costs an increasingly significant long-term lever in favour of sail cargo ships.

ECONOMIC VIABILITY

Summary and Identification of Economic Success Factors

The analysis shows that the economic viability of sail cargo ships depends on numerous interconnected factors. Freight rates, utilisation, round-trip frequency, operating and investment costs, and regulatory conditions determine whether operations can be profitable. Sail cargo ships also face structural competitive disadvantages compared with conventional vessels, which can be offset only under certain market and operating conditions.

Conditions for Economically Viable Operations

Sensitivity analysis identifies freight rates as a key driver of commercial success. Even moderate changes directly affect revenue per voyage. In the reference scenario, a freight rate of approx. EUR 106/t would be required to break even at annual result level including CAPEX under otherwise unchanged conditions. Higher utilisation also significantly improves viability. Market segments offering both higher rates and stable utilisation are therefore particularly important, especially sustainability-oriented niches and emissions-sensitive cargo groups.

Voyage duration and the resulting round-trip frequency are another major success factor. Because sail cargo ships generally operate at lower and more variable speeds, they complete fewer round trips per year than conventional ships. Shortening voyages therefore increases annual revenue. Reducing round-trip duration from 28 to 26 days permits one additional voyage per year, with a positive economic effect.

Higher service speeds generally require additional technology, however, leading to increased CAPEX and OPEX.

Operating costs are another important factor. Sail cargo ships benefit from lower fuel consumption and emissions-related costs, but incur additional expenditure due to more complex systems and higher personnel and maintenance requirements. Automation and digitalisation offer long-term potential to reduce OPEX.

Investment costs are particularly important. The analysis shows that high CAPEX-related costs are currently among the greatest economic constraints. Financing costs and depreciation substantially affect annual profits. Over time, standardisation, economies of scale and technological learning could lower investment requirements. Viable operations are therefore especially likely where investment costs can be reduced substantially while sufficient revenue is maintained.

Regulatory conditions are also becoming increasingly important. Higher CO_2 prices and stricter emissions requirements improve the relative competitiveness of low-emission transport. Sail cargo ships benefit from significantly lower emissions-related costs than conventional vessels. This advantage is likely to grow as regulatory burdens on fossil-fuel propulsion increase.

Structural Competitive Advantages of Sail Cargo Ships

Despite the challenges outlined, sail cargo ships offer several structural advantages over conventional ships. These may become increasingly important as requirements to decarbonise maritime transport intensify.

A major advantage is their substantially lower emissions intensity. Wind propulsion significantly reduces fossil-fuel consumption, CO_2 emissions and associated regulatory costs under schemes such as the EU Emissions Trading System and FuelEU Maritime. As regulation tightens and CO_2 prices rise, the relative competitive position of sail cargo ships improves.

They also provide access to market segments in which sustainability is important to transport purchasing decisions. Companies with ambitious climate targets or demanding supply-chain carbon requirements are increasingly willing to procure low-emission transport, creating opportunities for higher freight rates and Green Premiums.

Another advantage is reduced dependence on fossil fuels. Conventional ships are highly exposed to fuel prices, whereas sail cargo ships obtain part of their propulsion energy from wind at no fuel cost. This reduces sensitivity to rising energy prices and geopolitical volatility. Sail cargo ships can also differentiate themselves from standardised services: conventional shipping competes primarily on price, speed and capacity, while sail-powered transport can offer added value through sustainability, innovation and brand positioning.

This is particularly relevant for high-value consumer goods, food and other products for which the environmental characteristics of the supply chain form part of brand communications.

Structural Competitive Disadvantages of Sail Cargo Ships

Despite their potential, sail cargo ships have several structural disadvantages compared with conventional ships. The most important is lower transport output per unit of time. Lower and wind-dependent speeds mean significantly fewer round trips per year, reducing annual revenue and economies of scale.

Operations are also less predictable. Conventional ships have relatively consistent journey times, whereas wind conditions cause greater variability for sail cargo ships. This increases the risk of delays, opportunity costs and lower reliability in logistics networks, particularly in tightly scheduled supply chains.

Higher investment costs are another structural disadvantage. Integrating wind propulsion systems entails additional construction, integration and financing expenditure. Limited standardisation also increases technological and financial risks, leading to substantially higher CAPEX-related costs than for conventional vessels of comparable size.

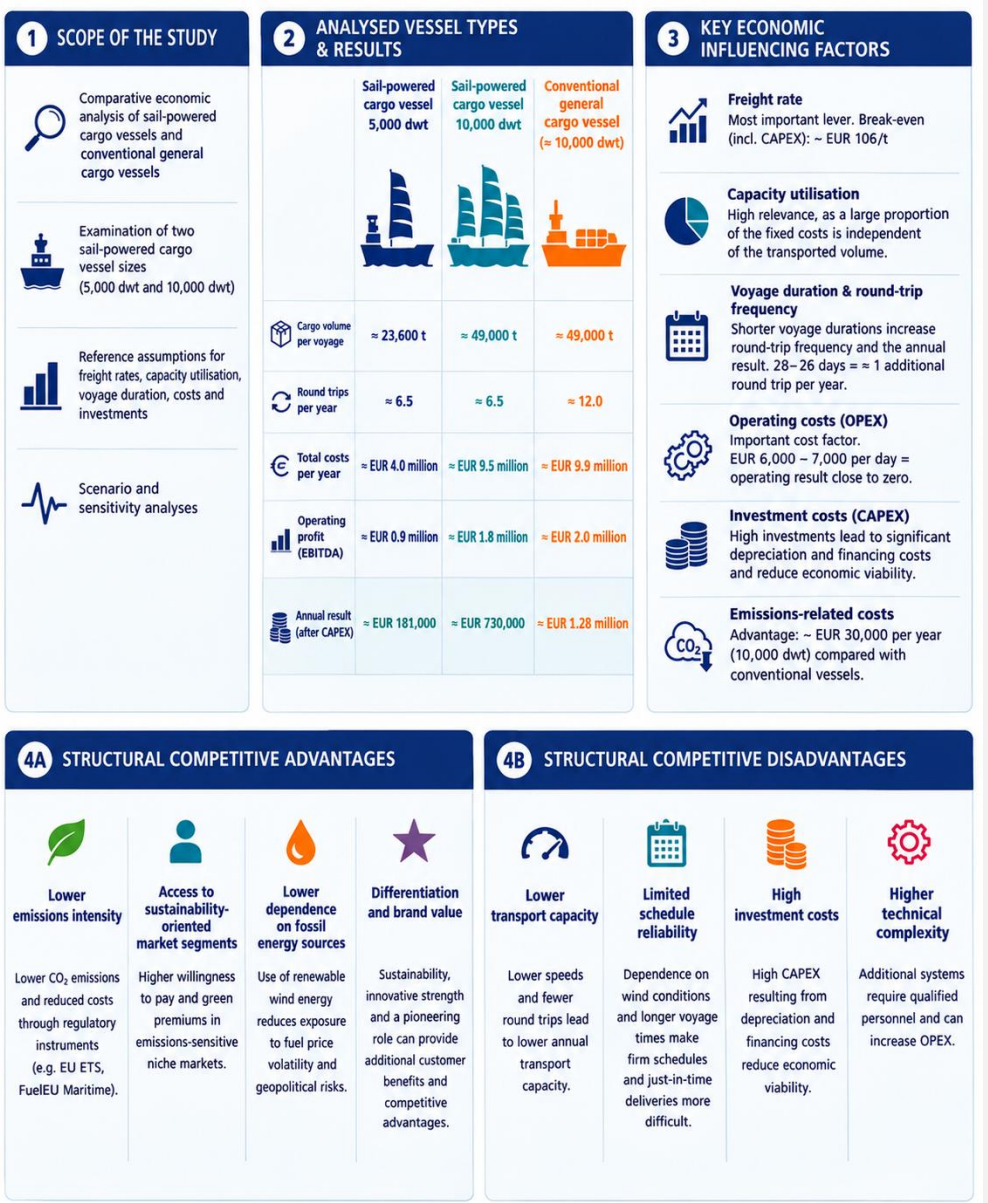
Finally, technical trade-offs exist between wind propulsion, cargo capacity and speed. Sail systems may reduce available cargo space or impose additional design requirements, while complex systems increase maintenance and operating demands.

ECONOMIC VIABILITY

Overall Assessment

In summary, the analysis shows that, under current market conditions, sail cargo ships can be operated economically, particularly in specialised market segments where customers have a high willingness to pay for sustainable transport. The key success factors include high freight rates, stable capacity utilisation, reduced investment costs, optimised round-trip frequencies and increasing regulatory costs for conventional vessels.

At the same time, it is evident that sail cargo ships currently face significant structural competitive disadvantages compared with conventional vessels. In particular, lower transport output, limited schedule predictability and high investment costs currently restrict their competitiveness in the mass market. In the long term, however, technological advances, standardisation effects and rising CO_2 costs could contribute to a significant improvement in the economic competitiveness of sail cargo ships.



ECONOMIC VIABILITY - SUMMARY

Fundamental Principles of the Economic Viability Assessment

- The economic viability of sail cargo ships is largely determined by the interaction between revenues, operating costs (OPEX), capital expenditure (CAPEX), round-trip frequency and regulatory conditions.
- Compared with conventional shipping, sail cargo ships exhibit structural differences in terms of speed, predictability, capacity and cost structure.
- While conventional vessels achieve economic advantages primarily through economies of scale, high round-trip frequencies and standardised processes, sail cargo ships offer particular potential in the areas of low-emission transport and sustainability-oriented market segments.
- The analysis is based on a scenario-based approach to account for uncertainties relating to wind conditions, market prices, technological developments and regulatory frameworks.

Cost Structure of Sail Cargo Ships

- The cost structure of sail cargo ships comprises acquisition costs, operating costs, regulatory and compliance costs, as well as downtime and opportunity costs.
- Investment costs are higher than those of conventional vessels of comparable size due to the integration of wind propulsion systems. For medium-sized sail cargo ships, capital investments of approximately EUR 20 million to EUR 40 million are assumed. Projects such as Neoliner demonstrate that particularly large and technologically complex concepts can involve investment costs exceeding EUR 60 million.
- Operating costs typically range from EUR 5,300 to EUR 14,000 per day. The main cost components are crew costs, fuel costs and maintenance costs.
- The use of wind energy can reduce fuel costs, although auxiliary and safety propulsion systems remain necessary. At the same time, additional technical systems result in higher maintenance requirements and, in some cases, increased crew requirements and associated costs.
- Regulatory costs are becoming increasingly significant as environmental and climate regulations become more stringent. In this context, sail cargo ships benefit from lower CO_2-related costs compared with conventional vessels.

Revenue Structure and Market Potential

- The primary revenues are determined by freight rates, cargo volumes transported and the number of round trips per year.
- Due to their lower capacities and longer voyage durations, sail cargo ships generally transport lower cargo volumes than conventional vessels. At the same time, higher freight rates can be achieved in specialised market segments.
- Additional revenue potential arises from so-called Green Premiums. These typically range from 2% to 15% of the standard freight rate and depend largely on customers' willingness to pay and the respective market segment.
- Sustainability-oriented niche markets appear particularly relevant, including high-value agricultural products, brand-driven consumer goods and project-related transport operations with low time sensitivity.
- Furthermore, sail cargo ships can benefit from regulatory-driven economic advantages, particularly through lower costs associated with CO_2 pricing mechanisms such as the EU Emissions Trading System (EU ETS) and the FuelEU Maritime Regulation.

ECONOMIC VIABILITY - SUMMARY

Comparative Analysis of Different Sail Cargo Ship Sizes

- The economic viability assessment shows that both smaller and larger sail cargo ships can be operated economically under suitable market conditions. In the reference case, the 5,000 dwt sail cargo ship achieves a positive annual result of approximately EUR 181,000, while the 10,000 dwt sail cargo ship generates a significantly higher annual result of around EUR 730,000.
- Larger vessels benefit particularly from higher cargo volumes, economies of scale and a more favourable distribution of fixed costs. As a result, they generally demonstrate more robust economic viability than smaller vessel concepts.
- Conventional general cargo vessels continue to achieve better economic results due to higher round-trip frequencies and lower specific investment costs. At the same time, sail cargo ships can partially offset these structural advantages through higher freight rates, Green Premiums and lower emissions-related costs.

Key Economic Influencing Factors

- The freight rate represents the most important revenue driver. Even moderate changes have a direct impact on revenue per voyage and the annual financial result. The sensitivity analysis shows that, in the reference case, a freight rate of approx. EUR 106 per tonne is required to achieve a break-even annual result, including CAPEX-related costs. Validation through stakeholder engagement would therefore appear appropriate.
- Capacity utilisation is also of considerable economic importance. As a large proportion of costs are incurred regardless of the actual cargo volume transported, changes in capacity utilisation have a direct impact on economic viability. Market segments in which both high freight rates and high capacity utilisation can be achieved simultaneously are particularly attractive.
- Voyage duration and the resulting round-trip frequency represent a key structural competitive factor. Shorter voyage durations increase the number of potential round trips per year, thereby improving economic viability. At the same time, higher service speeds often require technical modifications and additional propulsion assistance, which may be associated with increased investment and operating costs.
- Operating costs also have a significant impact on economic viability. In the reference case, an increase in OPEX from EUR 6,500 to EUR 7,000 per day is sufficient to almost entirely eliminate the positive annual financial result.
- High investment costs continue to represent a major financial burden. Depreciation and financing costs have a significant influence on the competitiveness of sail cargo ships.
- Emissions-related costs are becoming increasingly important as CO_2 prices rise and regulatory requirements become more stringent. In the reference case, sail cargo ships achieve an annual cost advantage of approx. EUR 300,000 compared with a conventional general cargo vessel of similar size. This advantage is likely to become increasingly significant in the future as regulatory frameworks become more stringent.

Overall Assessment

- Sail cargo ships currently face structural competitive disadvantages compared with conventional vessels, particularly in terms of capacity, speed, predictability and investment costs.
- Economically viable areas of application are primarily found in specialised niche markets characterised by a high willingness to pay for sustainable transport and lower time sensitivity.
- In the long term, rising CO_2 costs, more stringent regulations, technological advances and declining investment costs could significantly improve the competitiveness of sail cargo ships.



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EMISSIONS

Preliminary Considerations

One of the key advantages of sail cargo ships over conventional cargo ships lies in their significantly lower energy consumption and the resulting reduction in pollutant and greenhouse gas emissions. While international shipping remains predominantly dependent on fossil fuels, wind-powered and wind-assisted cargo ships adopt a fundamentally different approach to propulsion. Wind energy provides a substantial proportion of the propulsive power and can significantly reduce the need for engine-powered propulsion. However, depending on the ship concept, route, weather conditions and operational requirements, engine assistance remains necessary, for example for port manoeuvres, navigating narrow passages, periods of calm weather, maintaining safety reserves, ensuring schedule reliability and supplying energy on board. The environmental advantage therefore does not arise from completely emission-free operation, but rather from a significant reduction in fuel consumption compared with conventionally powered seagoing vessels. The actual emissions reduction potential must consequently be quantified according to the specific route and operating conditions.

At the same time, the environmental assessment of transport chains is becoming increasingly important. Regulatory developments at international and European level, growing requirements for corporate sustainability reporting and the increasing consideration of Scope 3 emissions are bringing the emissions impacts of logistics decisions into sharper focus. Against this background, the potential to avoid emissions represents a key benefit of sail cargo ships. However, a qualitative statement that emissions are lower is not sufficient for a robust assessment of market potential. Instead, it is necessary to quantify the potential emissions benefits and compare them with the emissions generated by conventional transport solutions. Only on this basis can reliable conclusions be drawn regarding the environmental advantages of sail cargo ships, and potential willingness to pay for low-emission transport services or so-called Green Premiums be substantiated in a transparent manner. The objective of this work package is therefore to systematically quantify the emissions generated by a sail cargo ship and compare them with those of conventional seagoing vessels operating under comparable conditions. Particular consideration is given to climate-relevant carbon dioxide emissions (CO_2), as well as nitrogen oxide (NO_x) and sulphur oxide (SO_x) emissions, which are relevant to air quality and environmental impacts. The analysis is based on defined transport routes, technical operating assumptions and appropriate emission factors.

As sail cargo ships and conventional cargo ships can differ considerably in terms of carrying capacity, speed, capacity utilisation and propulsion concepts, an appropriate framework for comparison must first be established. This involves defining the routes under consideration, the functional unit of assessment and the underlying technical and operational assumptions. On this basis, transport-related emissions are then calculated, and the absolute and relative differences in emissions between the two transport options are determined. The results are intended to provide a robust basis for assessing the environmental performance of the sail cargo ship concept and to demonstrate the potential contribution of wind-powered maritime transport to the decarbonisation of maritime supply chains. Furthermore, they serve as a basis for the subsequent market assessment, as the demonstrated reduction in emissions represents a key component of the customer value proposition and, consequently, of a potential business model for sail cargo ships.

Definition of the Comparison Framework

A key prerequisite for comparing different modes of transport is the definition of an appropriate functional unit. This describes the transport service to be provided, independently of the technical characteristics of the mode of transport used, thereby enabling an objective comparison of different transport options. This is particularly important when assessing sail cargo ships. Compared with conventional cargo ships, sail cargo ships can differ considerably in terms of size, speed, transport capacity and propulsion concept. A comparison based on individual vessels or individual voyages would therefore provide results of limited reliability. Instead, the transport performance actually delivered must be used as the reference basis.

For this study, emissions intensity relative to transport performance is therefore used as the central functional unit. This is based on the tonne-kilometre (tkm), an established metric in transport and environmental assessments. One tonne-kilometre corresponds to the transport of one tonne of cargo over a distance of one kilometre. Emissions intensity is therefore expressed in grams of emissions per tonne-kilometre:

$$\text{Emissions intensity} = \frac{\text{Total emissions}}{\text{Cargo mass transported} \times \text{Transport distance}}$$

The following indicators are considered as outcome measures:

- CO_2 emissions in g CO_2/tkm
- NO_x emissions in g NO_x/tkm
- SO_x emissions in g SO_x/tkm

In addition, absolute emissions per voyage are presented for selected example routes. This allows for a better understanding of the actual quantities of emissions generated and the potential savings achievable through the use of sail cargo ships. The combination of relative and absolute emissions indicators ensures, on the one hand, the scientific comparability of different transport concepts and, on the other hand, enables a practical assessment of specific transport scenarios.

Another key methodological basis of the study is the definition of the system boundaries. These determine which processes and emission sources are included in the analysis and which fall outside its scope. In principle, emissions analyses in the transport sector can apply different system boundaries. These range from assessments focusing solely on operational emissions to comprehensive life cycle assessments, including vessel construction, infrastructure and fuel supply. As the present project focuses on the environmental impact of the transport operation itself, an operational emissions assessment has been selected. Accordingly, all emissions generated during maritime transport operations are taken into account. In particular, the following are included:

- Emissions from the main propulsion system
- Emissions from auxiliary engines
- Emissions during port manoeuvres
- Emissions from onboard power generation
- Emissions from engine-assisted propulsion, for example during periods of calm weather

The following are excluded:

- Emissions from vessel construction and scrapping
- Emissions associated with port infrastructure
- Emissions from cargo handling operations
- Emissions from pre-carriage and onward transport
- Emissions from packaging and storage
- Emissions from the production of the fuels used

The study therefore follows a Tank-to-Wake (TtW) approach, in which only the direct emissions generated during vessel operation are taken into account.

Selection of Reference Routes

Following the definition of the functional unit and system boundaries, suitable reference routes must be selected for the emissions analysis. The selection of the routes under consideration has a significant influence on the validity of the study, as both transport distance and climatic and nautical conditions have a substantial impact on the environmental performance of a sail cargo ship.

The aim of the route selection is to represent typical applications of potential wind-powered cargo ship operations. Particular consideration is therefore given to routes that are relevant to sustainability-oriented imported goods and, at the same time, appear fundamentally suitable for wind-powered maritime transport. The selected routes are based on the previously identified potential customer groups in the coffee, cocoa, rum, Fairtrade products and sustainable textiles sectors.

In addition, the following criteria were taken into account during the selection process:

- Relevance to potential target customers of a sail cargo ship
- Regular import flows to Germany and/or Northern Europe
- Long transport distances and, consequently, significant potential for emissions reductions
- Relatively low time sensitivity of the goods transported
- General suitability for wind-powered transport concepts
- Existence of established trade and supply chains
- Existence of actual or planned sail cargo shipping services on comparable routes

Based on these criteria, four representative reference routes are defined.

Route 1: Colombia – Germany

Colombia is one of the major countries of origin for high-quality coffee exports and plays a particularly important role in the speciality coffee and certified sustainable products sectors. The route to Germany represents a typical application for high-value agricultural products with relatively low time sensitivity. Typical goods transported along this route include speciality coffee, Fairtrade coffee, cocoa, cane sugar products and other certified agricultural commodities. The route covers a transport distance of approx. 9,000 km and is generally suitable for the use of low-emission transport solutions due to the high value density of the goods transported.

Route 2: Ghana – Germany

Ghana is one of the world's leading cocoa exporters and therefore represents a key sourcing region for numerous European food and Fairtrade companies. The route to Germany is consequently a particularly relevant application for investigating sustainable transport concepts. Typical goods transported along this route include cocoa, cocoa products, cashew nuts and other agricultural commodities. Covering a distance of approx. 6,500 km, it represents a typical West Africa–Europe shipping route characterised by regular cargo flows and significant potential for emissions reductions.

Route 3: Dominican Republic – Germany

The Dominican Republic has a long tradition of exporting high-quality agricultural products and speciality food and beverage products and is particularly well positioned in the Fairtrade and organic products sectors. The route is therefore especially suitable for examining goods for which sustainability and origin already play an important role in marketing. Typical goods include rum, cocoa, coffee and cane sugar products. Covering a distance of approx. 8,000 km, the route represents a traditional transatlantic connection between the Caribbean and Europe.

Route 4: Halifax (Canada) – Germany

In addition to sustainable agricultural commodities, low-emission transport solutions for high-value consumer and industrial goods are becoming increasingly important. Against this background, a transatlantic route to North America is also considered. This route reflects current developments in sail cargo shipping, such as the Neoliner concept, which envisages connections between Europe and the east coast of North America. Typical goods transported along this route include outdoor and sporting goods, textiles, food and beverages, and industrial products with a sustainability focus. The distance between Canada and Germany is approx. 5,500 to 6,000 km. The route complements the predominantly agricultural South–North connections by introducing an additional market segment and enables the investigation of potential applications in the sustainable consumer and industrial goods sectors.

The figure on the right provides an overview of the reference routes. The selected routes therefore cover both traditional applications involving sustainable agricultural imports and emerging market segments in low-emission transatlantic supply chains. At the same time, they represent typical cargo flows for which sail cargo ships could, in principle, be considered as an alternative transport solution due to the relatively low time sensitivity of the goods and their strong sustainability focus.

Figure: Reference Routes for the Emissions Comparison



Methodological Approach

Following the definition of the reference routes, the emissions generated by the operation of a sail cargo ship are calculated. The objective is to quantify the transport-related carbon dioxide (CO_2), nitrogen oxide (NO_x) and sulphur oxide (SO_x) emissions on the selected routes. The results form the basis for the subsequent comparison with conventional cargo ships. Unlike conventional ships, emissions from sail cargo ships do not primarily result from the continuous operation of a main propulsion engine. Instead, a substantial proportion of the propulsive power is generated through the use of wind energy. Direct emissions therefore arise predominantly from the operation of auxiliary and safety propulsion systems, as well as from engine-assisted propulsion in situations where wind conditions do not provide sufficient propulsive power or where operational requirements make such assistance necessary.

The level of transport-related emissions is therefore largely determined by the proportion of the route covered using engine-assisted propulsion. For the calculation, a distinction is made between the wind-powered and engine-assisted portions of the transport operation. The emissions calculation is generally based on the following influencing factors:

- Transport distance of the respective route
- Quantity of cargo transported
- Resulting transport performance in tonne-kilometres
- Assumed proportion of propulsion provided by wind energy
- Assumed proportion of propulsion provided by engine power
- Emission factors of the fuel used

Emissions are calculated according to the following basic principle:

Emissions = Transport performance × Emission factor × Engine-powered proportion

The emission factors are applied exclusively to the engine-powered proportion of transport performance, as propulsion generated by wind energy does not produce any direct CO_2, NO_x or SO_x emissions during operation. As no reliable operational data are currently available for a commercial sail cargo ship operating on the routes under consideration, the analysis is based on plausible technical assumptions and scenarios. This allows different operating conditions and technical configurations to be taken into account.

Definition of Technical Operating Assumptions

The actual emissions of a sail cargo ship depend significantly on wind conditions, the selected ship concept and operational requirements. As these factors can vary considerably in practice, the emissions assessment is conducted on the basis of several operating assumptions. The primary focus is on the proportion of propulsion provided by wind energy. The stated wind propulsion shares describe the proportion of propulsive power supplied by wind energy and should not be equated directly with an equivalent reduction in fuel consumption. Even with high proportions of wind propulsion, energy is still required for auxiliary machinery, onboard power generation, port manoeuvres and additional propulsion assistance during unfavourable weather conditions. The actual reduction in fuel consumption is therefore generally lower than the respective proportion of propulsion provided by wind energy. Three scenarios are defined for the study.

Conservative Scenario

The conservative scenario represents unfavourable operating conditions. These include prolonged periods of calm weather, unfavourable wind conditions and increased requirements for schedule accuracy.

- Wind propulsion share: 70%
- Engine-powered propulsion share: 30%
- Capacity utilisation: 70%

Realistic Scenario
This scenario represents the expected operating conditions of a sail cargo ship on the routes under consideration (wind propulsion share: 85%, engine-powered propulsion share: 15%, capacity utilisation: 80%).

Ambitious Scenario
The ambitious scenario assumes optimised route planning, favourable wind conditions and extensive use of wind energy (wind propulsion share: 95%, engine-powered propulsion share: 5%, capacity utilisation: 90%).

The selected assumptions are based on the objectives of current sail cargo ship concepts. At the same time, they cover a sufficiently broad range of potential operating conditions and enable a robust assessment of the potential for emissions reductions. In addition to the assumptions regarding the proportions of wind-powered and engine-assisted propulsion, the size of the sail cargo ship under consideration is important for calculating emissions. Ship size influences, in particular, the absolute transport performance per voyage and the emissions intensity per tonne of cargo transported. To represent different scales of potential sail cargo ship operations, two reference sizes are considered: 5,000 dwt and 10,000 dwt sail cargo ships.

The 5,000 dwt variant represents a small to medium-sized sail cargo ship that appears particularly suitable for high-value, sustainability-oriented niche cargoes. The 10,000 dwt variant represents a larger ship for which economies of scale may have a greater impact. This variant is particularly relevant for regular liner services or consolidated cargo flows from multiple customers. For both variants, calculations are performed using different capacity utilisation assumptions based on the defined scenarios. The conservative scenario assumes capacity utilisation of 70%, the realistic scenario 80%, and the ambitious scenario 90%. Depending on ship size, these assumptions result in different quantities of cargo transported per voyage. The following table provides an overview of the input parameters.

Table: Assumptions Regarding Vessel Size, Capacity Utilisation and Cargo Volume Transported

	Small Sail Cargo Ship	Large Sail Cargo Ship
Deadweight Tonnage	5,000 dwt	10,000 dwt
Assumed Capacity Utilisation – Cons. Scenario	70%	70%
Assumed Capacity Utilisation – Real. Scenario	80%	80%
Assumed Capacity Utilisation – Amb. Scenario	90%	90%
Cargo Volume – Conservative Scenario	3,500 t	7,000 t
Cargo Volume – Realistic Scenario	4,000 t	8,000 t
Cargo Volume – Ambitious Scenario	4,500 t	9,000 t

Selection of Emission Factors

Emission factors are used to quantify the emissions generated by vessel operation. Emission factors describe the quantity of a pollutant released when providing a defined amount of transport performance. They are an established tool for estimating environmental impacts in the transport sector. For the present study, emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x) and sulphur oxides (SO_x) are considered. These pollutants represent the principal environmental impacts of maritime transport relating to climate change and air quality. As standardised emissions data for sail cargo ships are not yet available, the calculations are based on a comparison with conventional cargo ships. The emission factor of a conventional reference vessel is applied to the sail cargo ship in proportion to the assumed share of engine-powered propulsion.

This takes into account the fact that a substantial proportion of propulsion is provided by wind energy and that only the engine-powered proportion generates emissions. For the CO_2 calculation, a specific emission factor of 13 g CO_2/tkm is assumed (source: www.climatiq.io). This value falls within the range of published emissions intensities for general cargo vessels and represents a conservative average for conventional vessels of comparable size. For NO_x and SO_x, the literature predominantly provides energy-based emission factors expressed in g/kWh. The EMEP/EEA Guidebook specifies CO_2 emissions of approx. 645 g/kWh and NO_x emissions of approximately 12 g/kWh for seagoing vessels during navigation. This corresponds to a NO_x-to-CO_2 ratio of approx. 1.9%. For the present study, a transport performance-based reference value of 0.25 g NO_x/tkm is derived from this ratio. The level of SO_x emissions depends largely on the sulphur content of the fuel used. As a result of the international sulphur limits in force since 2020, SO_x emissions from modern vessels have decreased significantly. For this study, a conservative reference value of 0.05 g SO_x/tkm is assumed.

In the subsequent calculations, the emission factors are applied exclusively to the engine-powered proportion of transport performance. Propulsion provided by wind energy is considered emission-free, meaning that the emissions of a sail cargo ship depend directly on the assumed share of engine-powered propulsion.

Calculation of Transport Performance

The level of transport-related emissions is largely determined by the transport performance delivered. This describes the quantity of goods transported over a given distance and represents the central reference parameter for the subsequent emissions calculations. As described previously, transport performance is expressed in tonne-kilometres (tkm) in transport and environmental assessments.

The calculation is carried out for all reference routes under consideration and for both sail cargo ship variants with capacities of 5,000 dwt and 10,000 dwt. The calculations are based on the previously defined capacity utilisation assumptions of the realistic scenario, which is used as the reference scenario throughout the remainder of the analysis.

For the 5,000 dwt sail cargo ship, a cargo volume of 4,000 tonnes is assumed at a capacity utilisation rate of 80%. For the 10,000 dwt sail cargo ship, the corresponding cargo volume is 8,000 tonnes. Taking into account the maritime transport distances, the following transport performance figures are obtained.

Table: Transport Performance on Reference Routes

Route	Distance (km)	Transport performance 5k dwt (m tkm)	Transport performance 10k dwt (m tkm)
Colombia - Germany	9,000	36.0	72.0
Ghana - Germany	6,500	26.0	52.0
Dom. Rep. - Germany	8,000	32.0	64.0
Canada - Germany	5,800	23.2	46.4

The results show that transport performance is influenced by both vessel size and transport distance. While larger vessels achieve correspondingly higher transport performance at the same capacity utilisation rate, longer transport distances also result in an increase in tonne-kilometres and, consequently, generally higher absolute emissions. At the same time, long-distance routes offer the greatest potential for emissions reductions through the use of wind propulsion systems.

Calculation of CO_2 Emissions from Sail Cargo Ships

Based on the previously defined transport performance figures and emission factors, the next step involves calculating the transport-related carbon dioxide emissions of the sail cargo ship variants under consideration. As propulsion on a sail cargo ship is predominantly provided by wind energy, direct emissions arise exclusively from the engine-assisted proportion of the voyage. The level of emissions is largely determined by the assumed share of engine-powered propulsion.

The calculation is based on the previously defined reference scenario, which assumes a wind propulsion share of 85% and an engine-powered propulsion share of 15%. An emission factor of 13 g CO_2 per tonne-kilometre is used as the reference value for conventional maritime shipping. This value corresponds to typical emissions intensities of modern general cargo and multipurpose vessels of comparable size. The CO_2 emissions of the sail cargo ship are therefore calculated by multiplying the transport performance by the emission factor of the reference vessel and the assumed share of engine-powered propulsion.

The calculation for the conventional reference vessel follows the same approach, but without accounting for any wind propulsion share.

Table: CO_2 Emissions per Voyage (in tonnes)

Route	Reference Vessel 5,000 dwt	Sail Cargo Ship 5,000 dwt	Reference Vessel 10,000 dwt	Sail Cargo Ship 10,000 dwt
Colombia - Germany	468.0	70.2	936.0	140.4
Ghana - Germany	338.0	50.7	676.0	101.4
Dom. Republic - Germany	416.0	62.4	832.0	124.8
Canada - Germany	301.6	45.2	603.2	90.5

As expected, the results demonstrate a direct relationship between transport performance and absolute emissions. The highest emissions occur on the long transatlantic routes between Colombia and Germany, while the Halifax route exhibits the lowest absolute emissions due to its shorter distance. At the same time, it is evident that the larger 10,000 dwt variant generates approximately twice the absolute emissions because it transports twice the cargo volume at the same capacity utilisation rate. For the environmental assessment, therefore, it is not only the absolute quantity of emissions that matters, but particularly the emissions intensity relative to the transport performance delivered.

To improve the comparability of different vessel sizes, emissions intensity is also examined. Emissions intensity describes the quantity of emissions released per tonne-kilometre of transport performance and corresponds to the functional unit defined previously.

For the sail cargo ships under consideration, the following calculation applies:

13 g CO_2/tkm × 0.15 = 1.95 g CO_2/tkm

The specific CO_2 emissions intensity of the sail cargo ships considered in the reference scenario is therefore approx. 1.95 g CO_2 per tonne-kilometre. By comparison, the conventional reference vessel has an emissions intensity of 13 g CO_2 per tonne-kilometre.

Table: Comparison of Emissions Intensities

	Reference Vessel	Sail Cargo Ship
CO_2 Intensity	13,0 g CO_2/tkm	1,95 g CO_2/tkm
Wind Propulsion Share	0%	85%
Engine-Powered Propulsion Share	100%	15%

CO_2 Emissions Reduction Potential Compared with Conventional Shipping

In addition to absolute emissions, emissions avoidance represents the key assessment criterion. For this purpose, the emissions of a sail cargo ship are compared with those of a conventional general cargo ship.

Table: CO_2 Emissions Reduction Potential Compared with Conventional Shipping

Route	CO_2 Reduction 5,000 dwt (t)	CO_2 Reduction 10,000 dwt (t)	Relative Reduction
Colombia - Germany	397.8	795.6	85%
Ghana - Germany	287.3	574.6	85%
Dom. Republic - Germany	353.6	707.2	85%
Canada - Germany	256.4	512.7	85%

The potential CO_2 emissions savings range from approx. 256 to 796 tonnes of CO_2 per voyage, depending on the route. The greatest absolute savings are achieved on long transatlantic routes and with larger ships. Due to the assumed proportion of wind propulsion, the relative emissions reduction is approx. 85% in all cases. The analysis therefore confirms the key environmental strength of the sail cargo ship concept. Even under conservative technical assumptions, substantial emissions reductions can be achieved compared with conventional general cargo ships. For companies facing stringent requirements to reduce their transport-related Scope 3 emissions, this can make a significant contribution to the decarbonisation of international supply chains while also representing an important element of their sustainability communications.

A comparison of the scenarios illustrates that substantial emissions reductions appear achievable even under conservative assumptions. At the same time, the results demonstrate a high degree of sensitivity to the proportion of engine-powered propulsion. Reducing the engine-powered propulsion share from 30% to 5% results in a calculated reduction in specific CO_2 emissions of more than 80%.

The actual environmental advantage of a sail cargo ship is therefore largely determined by its ability to provide the highest possible proportion of transport performance through wind energy. The following table shows the CO_2 emissions reduction potential for the different scenarios.

Table: Overview of Scenarios

	Conservative	Realistic	Ambitious
Wind Propulsion Share	70%	85%	95%
Engine-Powered Propulsion Share	30%	15%	5%
CO_2 Intensity	3.90 g/tkm	1.95 g/tkm	0.65 g/tkm
CO_2 Emissions Reduction Compared with Reference Vessel	70%	85%	95%

The calculation methodology applied can also be used for NO_x and SO_x. As these emissions are also directly associated with the operation of auxiliary and propulsion engines, their levels decrease in proportion to the assumed share of engine-powered propulsion. For the reference scenario, with a wind propulsion share of 85% and an engine-powered propulsion share of 15%, the following emissions are obtained.

Table: NO_x and SO_x Emissions from Sail Cargo Ships

	NO_x 5,000 dwt (kg)	SO_x 5,000 dwt (kg)	NO_x 10,000 dwt (kg)	SO_x 10,000 dwt (kg)
Colombia - Germany	1,350*	270	2,700	540
Ghana - Germany	975	195	1,950	390
Dom. Rep. – Germany	1,200	240	2,400	480
Canada - Germany	870	174	1,740	348

As with CO_2 emissions, the longer routes generate the highest absolute pollutant emissions. However, due to the high proportion of wind propulsion, emissions are significantly lower than those of a conventional reference vessel of comparable size.

* 4,000 tonnes of cargo and 9,000 km = 36 million tkm. 36 million tkm × 0.25 g NO_x/tkm × 15% = 1,350,000 g = 1,350 kg NO_x.

EMISSIONS

The following table summarises the results of the emissions calculations for the sail cargo ship variants and scenarios under consideration. It presents the specific emissions intensities and the resulting emissions reductions compared with a conventional general cargo vessel of comparable size. The overview illustrates the range of potential environmental impacts under different operating conditions.

Table: Emissions Indicators for the Scenarios Analysed

Indicator	Conventional Reference Ship	Sail Cargo Ship Conservative	Sail Cargo Ship Realistic	Sail Cargo Ship Ambitious
CO_2 (g/tkm)	13	3.9	1.95	0.65
NO_x (g/tkm)	0.25	0.075	0.0375	0.0125
SO_x (g/tkm)	0.05	0.015	0.0075	0.0025
CO_2 Reduction	–	70%	85%	95%
NO_x Reduction	–	70%	85%	95%
SO_x Reduction	–	70%	85%	95%

The following key findings can be derived from the results:

- Even under conservative assumptions, CO_2, NO_x and SO_x emissions can be reduced by approx. 70% compared with a conventional general cargo vessel.
- In the reference scenario, an emissions reduction of approximately 85% is achieved, demonstrating the significant environmental effectiveness of wind propulsion concepts.
- Under favourable operating conditions and with a high proportion of wind propulsion, emissions reductions of up to 95% are achievable.
- The greatest absolute emissions savings are achieved on the transatlantic routes between Colombia or the Dominican Republic and Germany, as these routes account for the highest transport performance.
- The ship size under consideration influences the absolute emissions generated per voyage but has no impact on specific emissions relative to transport performance.
- The proportion of engine-powered propulsion represents the key factor influencing the environmental performance of a sail cargo ship. Accordingly, changes in the respective shares of wind and engine-powered propulsion have a direct impact on emissions levels.
- The results confirm that sail cargo ships offer considerable potential for reducing transport-related emissions, particularly on long-distance routes where time sensitivity is relatively low, and can therefore make a significant contribution to the decarbonisation of maritime supply chains.

Comparison with Alternative Modes of Transport

To assess the environmental performance of sail cargo ships in a broader context, an additional comparison with other modes of transport is carried out on the basis of specific CO_2 emissions per tonne-kilometre. The analysis deliberately focuses on emissions intensity, as the reference routes examined predominantly involve intercontinental maritime transport and therefore cannot be directly replaced by rail or road transport. The following overview presents typical emissions intensities for different modes of transport based on published average values (e.g. UBA TREMOD and the European Environment Agency).

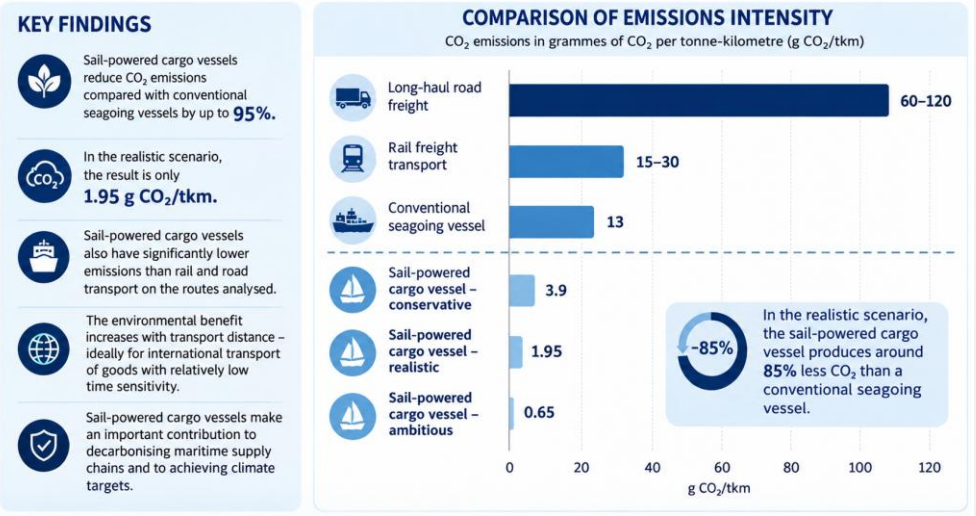
Table: Emissions Intensities of Different Modes of Transport

Mode of Transport	CO_2 Emissions (g/tkm)
Road Freight Transport	60–120
Rail Freight Transport	15–30
Conventional Cargo Ship	13
Sail Cargo Ship – Conservative Scenario	3.90
Sail Cargo Ship – Realistic Scenario	1.95
Sail Cargo Ship – Ambitious Scenario	0.65

The comparison illustrates that even a conventional general cargo or multipurpose ship generates significantly lower emissions than road freight transport in terms of transport efficiency. However, a sail cargo ship examined in this study achieves substantially lower emissions than a conventional cargo ship. In the realistic scenario, an emissions intensity of 1.95 g CO_2/tkm is achieved, approx. 85% lower than that of a conventional vessel.

Sail cargo ships also exhibit significantly lower emissions levels compared with rail freight transport. While modern electric freight trains typically generate emissions of between 15 and 30 g CO_2/tkm, depending on the electricity mix, the emissions of a sail cargo ship remain considerably lower, even in the conservative scenario. In the ambitious scenario, an emissions intensity of just 0.65 g CO_2/tkm is achieved, representing almost emission-free maritime transport.

However, it should be noted that the different modes of transport serve different purposes. Rail and road freight transport offer advantages in terms of flexibility, speed and geographical accessibility, while sail cargo ships appear particularly suitable for the international transport of high-value, sustainability-oriented goods with relatively low time sensitivity. The environmental advantage of sail cargo ships is particularly evident on long-distance routes, as the emissions savings achieved through the use of wind energy accumulate over the entire transport distance. The results therefore underline the potential of sail cargo ships as a particularly low-emission complement to existing international supply chains.



Assessment in the Context of the Identified Market Segments

The market analysis conducted in Work Package 1 (WP 1) shows that sail cargo ships cannot be regarded as a direct replacement for conventional shipping in the mass market. Instead, economically and operationally viable applications are concentrated in specific market segments in which sustainability requirements, brand values and the willingness to pay a Green Premium play a central role. High-value consumer goods, coffee, cocoa, spirits, textiles, outdoor products and other goods with a strong sustainability focus and relatively low time sensitivity appear particularly suitable. In these segments, the significantly reduced environmental impact of transport can create additional customer value and serve as a distinguishing feature compared with conventional logistics solutions. At the same time, the analysis highlights that the identified market segments predominantly represent niche markets. Although the available cargo volumes are sufficient to achieve economically viable capacity utilisation for individual sail cargo ships, they are not sufficient to capture significant shares of the global maritime transport market in the short term. The role of sail cargo ships should therefore be seen less as replacing existing transport structures and more as complementing established logistics systems.

Transport routes involving longer transit times and limited dependence on fixed delivery schedules appear particularly attractive. The routes examined between Germany and Colombia, Ghana, the Dominican Republic and Canada largely meet these requirements. At the same time, the results show that the greatest absolute emissions reductions can be achieved over long distances, providing an additional environmental benefit. The market analysis therefore confirms that sail cargo ships offer realistic potential for deployment primarily in market segments where sustainability has measurable economic value and shippers are willing to accept longer transport times in exchange for a significantly improved carbon footprint.

Assessment in the Context of the Economic Framework Conditions

The economic viability analysis shows that sail cargo ships can, in principle, be operated economically, although their viability depends on several conditions. In particular, freight rates, capacity utilisation, round-trip frequency and investment costs are the key determinants of operational profitability. The results demonstrate that larger sail cargo ships tend to achieve more robust economic results than smaller concepts due to economies of scale and a more favourable distribution of fixed costs. At the same time, conventional general cargo and multipurpose vessels retain an economic advantage due to their higher speeds, greater capacities and lower specific investment costs.

The sensitivity analyses also show that economic viability is particularly dependent on the freight rates that can be achieved. Even moderate changes have a direct impact on revenues. In the reference case, a freight rate of approximately EUR 106 per tonne is required to achieve a break-even annual result, including depreciation and financing costs. It can therefore be concluded that sail cargo ships can only be operated successfully from an economic perspective if at least one of the following conditions is met:

- Ability to achieve a Green Premium from sustainability-oriented customers,
- Consistently high capacity utilisation rates,
- Increasing regulatory costs for conventional ships,
- Declining investment costs for future generations of sail cargo ships.

Regulatory developments are of particular importance in this context. The study shows that a substantial cost advantage over conventional ships already arises under the assumed CO_2 prices. In the reference case, this advantage amounts to approx. EUR 300,000 per year. This effect is likely to become more pronounced as CO_2 costs continue to rise.

The economic assessment therefore concludes that, although sail cargo ships currently face structural competitive disadvantages, their position could improve significantly under the regulatory conditions expected in the future. In the long term, rising emissions-related costs and technological learning effects, in particular, could lead to a gradual improvement in their competitiveness relative to conventional ship concepts.

Realistic Emissions Reduction Potential

The emissions analysis confirms the key environmental strength of the sail cargo ship concept. Even under conservative operating assumptions, CO_2, NO_x and SO_x emissions can be reduced by approx. 70% compared with a conventional general cargo ship. In the realistic reference scenario, emissions are reduced by around 85%, while reductions of up to 95% appear achievable under favourable operating conditions. Specific CO_2 emissions intensity decreases from approximately 13 g CO_2 per tonne-kilometre for a conventional vessel to 1.95 g CO_2 per tonne-kilometre in the realistic scenario. The sail cargo ship therefore not only achieves significantly lower emissions than conventional maritime transport but also reaches levels well below the emissions intensities of road and rail freight transport. Of particular importance is the fact that these emissions benefits are not based on theoretical zero-emission assumptions but remain substantial even when auxiliary engine propulsion is taken into account. The results therefore demonstrate that hybrid operating concepts designed for practical application can already deliver significant climate benefits. For companies with ambitious climate targets, this creates an opportunity to significantly reduce transport-related Scope 3 emissions. Particularly in sectors with stringent sustainability requirements, the use of sail cargo ships can therefore make a measurable contribution towards achieving corporate decarbonisation targets.

Overall Conclusion

The findings of the study demonstrate that sail cargo ships represent an environmentally highly effective concept for the decarbonisation of maritime supply chains. Under realistic operating conditions, emissions reductions of approximately 85% compared with conventional general cargo ships appear achievable. At the same time, the market and economic viability analyses highlight that the concept is currently particularly suited to specialised niche markets with a strong sustainability focus.

In the short term, sail cargo ships should therefore not be regarded as a replacement for conventional maritime shipping. Instead, they can serve as a complementary transport solution for selected market segments in which environmental advantages generate commercially valuable benefits for customers. In the long term, rising CO_2 costs, more stringent regulations, technological advances and declining investment costs could contribute to further improvements in the competitiveness of sail cargo ships and a gradual expansion of their potential areas of application.

EMISSIONS - SUMMARY

Methodological Framework

- The emissions assessment was carried out using selected reference routes between Germany and the regions of origin of the identified market segments.
- Carbon dioxide (CO_2), nitrogen oxide (NO_x) and sulphur oxide (SO_x) emissions were examined.
- A conventional general cargo vessel of comparable size was used as the reference vessel.
- The assessment is based on transport performance expressed in tonne-kilometres (tkm), enabling a robust comparison of different vessel sizes and transport distances.
- Three operating scenarios were defined for the analysis, reflecting different proportions of wind propulsion and, consequently, different shares of engine-powered propulsion.

Emissions Reduction Potential

- Even under conservative assumptions, emissions can be reduced by approx. 70% compared with a conventional general cargo vessel.
- In the realistic reference scenario, an emissions reduction of approximately 85% is achieved.
- Under favourable operating conditions and with very high proportions of wind propulsion, emissions reductions of up to 95% are achievable.
- Specific CO_2 emissions decrease from approx. 13 g CO_2/tkm for the reference vessel to 1.95 g CO_2/tkm in the realistic scenario.
- Comparable reduction potential is also identified for NO_x and SO_x emissions.

Key Influencing Factors

- The most important factor influencing emissions performance is the proportion of propulsion provided by engine power.
- Changes in the respective shares of wind and engine-powered propulsion have a direct impact on emissions levels.
- Vessel size influences absolute emissions per voyage but has no impact on specific emissions relative to transport performance.
- Although long transport distances result in higher absolute emissions, they also offer the greatest potential for absolute emissions savings compared with conventional transport concepts.

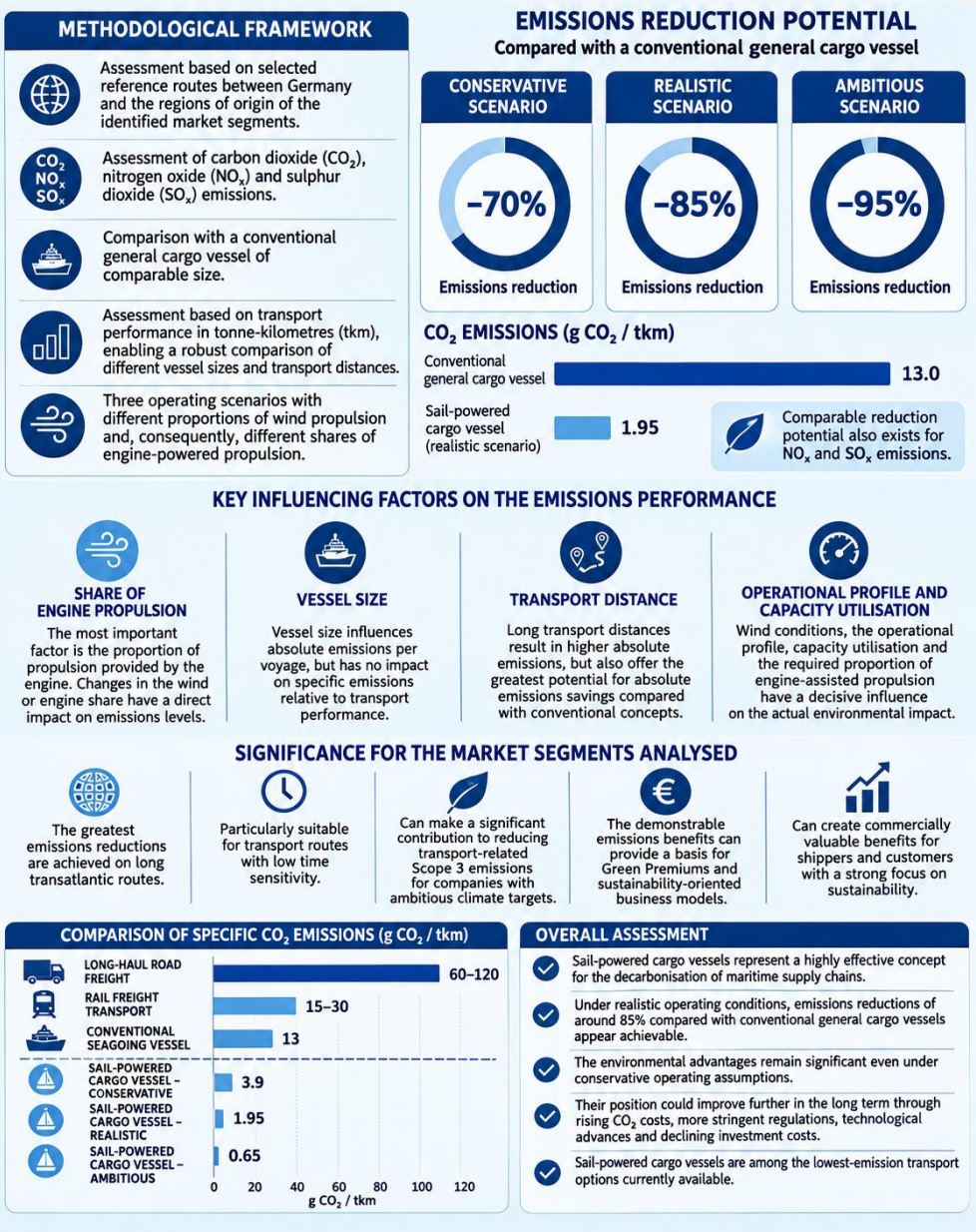
Significance for the Market Segments Analysed

- The greatest absolute emissions reductions are achieved on long transatlantic routes.
- Sail cargo ships are particularly suitable for transport routes with relatively low time sensitivity, where substantial emissions reductions can generate commercial value.
- For companies with ambitious climate targets, the use of sail cargo ships can make a significant contribution to reducing transport-related Scope 3 emissions.
- The demonstrable emissions benefits can also provide a basis for Green Premiums and sustainability-oriented business models.

EMISSIONS - SUMMARY

Overall Assessment

- The analysis confirms the considerable decarbonisation potential of wind-powered maritime transport.
- Sail cargo ships achieve substantial emissions reductions compared with conventional general cargo ships without having to dispense entirely with auxiliary propulsion systems.
- The environmental advantages remain significant even under conservative operating assumptions.
- However, the actual environmental impact depends largely on wind conditions, the operational profile, capacity utilisation and the required proportion of engine-assisted propulsion.
- Overall, sail cargo ships represent one of the lowest-emission options currently available for intercontinental maritime transport and can make an important contribution to the decarbonisation of maritime supply chains.





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STAKEHOLDERS

Objectives of Stakeholder Mapping

The successful establishment of sail cargo ships as a sustainable transport alternative depends on a wide range of stakeholders across the maritime value chain. Unlike established shipping segments, the market for sail cargo ships is still at an early stage of development. Consequently, in addition to companies directly involved in the transport process, numerous supporting institutions, networks and political stakeholders also play an important role. Systematic stakeholder mapping serves, among other things, to:

- Identify relevant stakeholders,
- Understand their roles within the value chain,
- Analyse their interests and potential influence,
- Identify potential cooperation partners to support the market development and scaling-up of sail cargo ships.

The following section identifies the key stakeholders along the maritime value chain for sail cargo ships and analyses their functions, interests and contributions to the implementation of such transport concepts. The value chain encompasses all activities, from the provision and operation of the vessel through to the organisation and execution of transport services, as well as the marketing and use of the transported goods by the end customer. In addition to stakeholders directly involved in the transport process, supporting institutions and regulatory bodies also play an important role, as they help establish the economic, technical and regulatory conditions necessary for the deployment of sail cargo ships. The following figure provides an overview of the value chain and the relevant stakeholders.



Overview of Relevant Stakeholders

At the centre of the value chain are shipowners, investors and vessel operators. They provide the capital required to build or acquire vessels and bear the financial responsibility for their operation. Shipping companies are responsible for technical and nautical management, organising crews and maintenance, planning routes and marketing the available transport capacity. As sail cargo ships often represent innovative vessel concepts and are still at an early stage of market development, these stakeholders play a key role in developing viable business models and operational structures.

On the demand side, shippers and cargo owners constitute the central stakeholder group. These include producers, traders, importers and brand owners that require transport services and provide the goods to be transported. Their willingness to integrate sail cargo ships into existing supply chains is a fundamental prerequisite for the economic viability of such concepts. Of particular interest are companies whose products have a strong sustainability focus or for which longer transport times are less important than the environmental benefits of low-emission transport.

Logistics and service providers fulfil an important intermediary and integration function between shippers and shipping companies. Freight forwarders and other logistics service providers organise transport operations, consolidate shipments from different customers and undertake tasks such as documentation, customs clearance and shipment tracking. They make a significant contribution to integrating sail cargo ships into existing transport networks and coordinating the interfaces between different modes of transport. Port and terminal operators also play a central role. They provide the infrastructure required for cargo handling, storage and onward transport, ensuring that sail cargo ships are integrated into existing port operations.

Smaller and medium-sized ports, in particular, may offer promising opportunities for cooperation, as they often have greater flexibility in accommodating new transport concepts. At the same time, port authorities and customs offices are responsible for ensuring compliance with regulatory requirements and facilitating the movement of goods across international borders.

At the end of the transport chain are importers, trading companies and, ultimately, end customers. They benefit from the transported goods and can indirectly influence the development of the market for sail cargo ships through their demand for sustainably produced and transported products. Particularly in market segments where sustainability is becoming increasingly important as a purchasing criterion, the use of sail cargo ships can generate additional value and contribute to product differentiation.

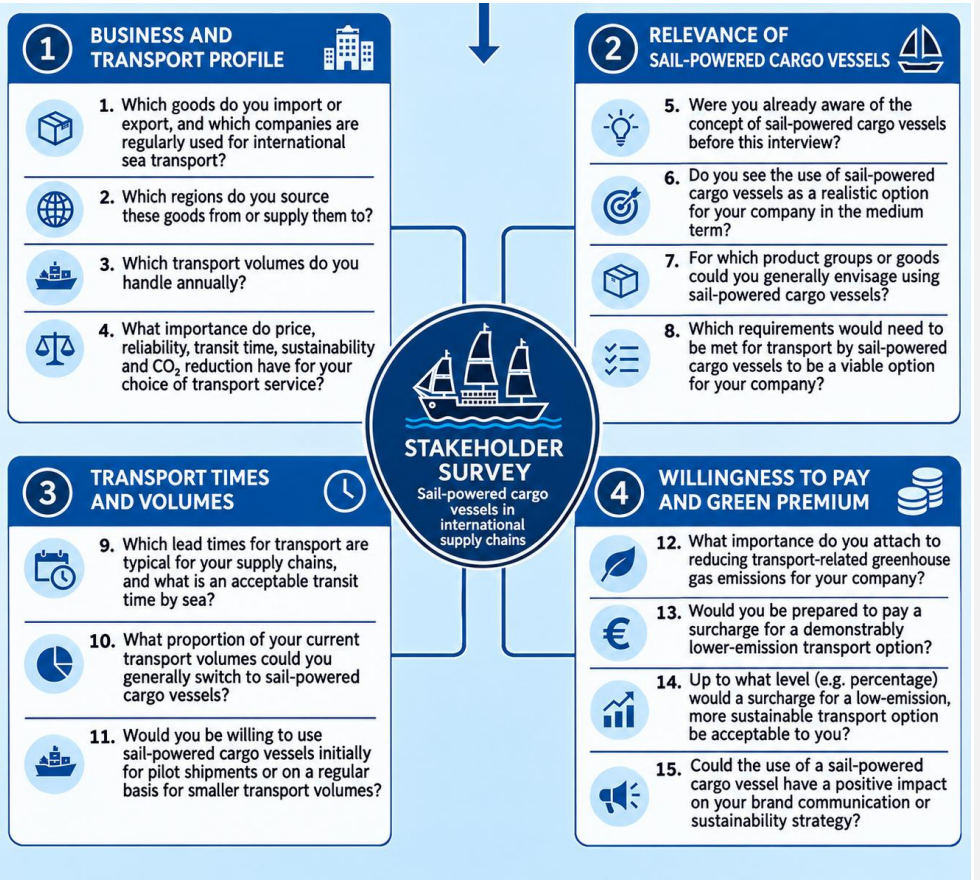
The value chain itself is complemented by various supporting stakeholders and institutions. These include political decision-makers and regulatory authorities, which influence market conditions through legislative frameworks and funding programmes. Research and educational institutions support the technological development and assessment of new vessel concepts. Industry associations and networks promote knowledge transfer between the stakeholders involved and help raise awareness of the concept. In addition, classification societies, certification bodies and insurance companies perform important functions in ensuring safety, regulatory compliance and risk management. Finally, banks, funding institutions and private investors play a crucial role in financing new vessel construction and scaling up innovative business models.

STAKEHOLDERS

As part of a more detailed stakeholder analysis, various stakeholder groups along the value chain for sail cargo ships were identified and systematically examined. The aim was to include potential users of wind-powered cargo transport services, as well as vessel operators, intermediaries and institutional stakeholders responsible for shaping the regulatory and market framework. To this end, a longlist of potential contacts was compiled and continuously expanded. Several companies or organisations were identified within each stakeholder group and included in the analysis.

Stakeholder Group	Stakeholders Included
Vessel Operators and Shipping Companies	Reederei F. Laeisz, Ahlmann Zerssen, Amadeus Schiffahrts- und Speditions GmbH, Reederei M. Lauterjung (Sunship Schiffahrtskontor KG)
Shippers and Cargo Owners	Cooko (cocoa), Sport Thieme (sports equipment), Bay City Textilhandel (clothing), Louis Dreyfus Company (coffee), Tchibo (coffee), Patagonia (clothing)
Logistics and Service Providers	H.D. Cotterell (cocoa and spice storage and logistics)
Investors and Financing Institutions	MPC Capital (investment manager)
Industry Associations and Multipliers	German Coffee Association (Deutscher Kaffeeverband), German Shipbrokers' Association (Zentralverband Deutscher Schiffsmakler)
Universities and Educational Institutions	Emden/Leer University of Applied Sciences (Hochschule Emden/Leer)

The questionnaire framework developed was primarily designed for companies involved in shipping goods as potential users of wind-powered cargo transport services. However, due to the different roles of the stakeholders interviewed along the value chain, not all questions could be answered by every stakeholder. The main reasons for this were the limited relevance of certain topics to specific stakeholder groups and the confidentiality of internal company data. The questionnaire framework was therefore adapted to the specific circumstances of each interview.



STAKEHOLDERS

The following section summarises the key findings from the stakeholder interviews conducted. The analysis focuses on overarching insights gained from discussions with representatives of various stakeholder groups. The findings provide an understanding of shared perspectives and the key technical, economic and organisational requirements for the deployment of sail cargo ships.

In addition to the overall analysis, detailed case studies were prepared for selected shippers. These case studies examine company-specific conditions and illustrate the circumstances under which sail cargo ships could be considered a viable transport solution for individual market participants.

To complement the primary research, secondary research was also conducted. This involved analysing publicly available statements, pilot projects and practical examples from companies that already use wind-powered cargo vessels, are trialling their deployment or have publicly expressed their commitment to sustainable maritime transport solutions. The insights gained from this research were also incorporated into the analysis.

An overview of the companies identified and their key statements is provided in the following table.

Company	Industry	Key Statement on the Use of Wind-Powered Cargo Ships
Café William	Coffee	Uses sail-powered cargo vessels to reduce emissions and aims to achieve coffee logistics with as close to zero emissions as possible.
Origin Coffee	Coffee	Regards sail-powered transport as part of a responsible and sustainable sourcing strategy.
Yallah Coffee	Coffee	Uses sail-powered cargo vessels to reduce the climate impact of international transport and improve supply chain sustainability.
Shipped by Sail	Coffee	Actively markets coffee transported by sailing vessel as a distinctive sustainability feature.
Belco	Coffee	Uses sail-powered cargo vessels to transport speciality coffee, significantly reducing transport-related emissions.
Expocacer	Coffee	Uses sail-powered transport as part of a transparent, low-emission export concept for high-quality coffee.
Café d'Oriant	Coffee	Considers sail-powered transport an effective way to reduce the carbon footprint of coffee.
WAY Gent	Coffee	Uses sail-powered transport as point of differentiation for sustainable speciality coffee.
Chocolarder	Chocolate	Uses cocoa transported by sailing ship to improve the carbon footprint.
Port O'Bristol / Xisto Wines	Wine	Uses sail-powered cargo vessels to import wine into Europe with lower transport-related emissions.
New Dawn Traders	Food	Aims to make international trade flows more sustainable through wind-powered transport.
Cémoi	Cocoa	Supports the use of low-emission transport for high-quality cocoa products.
Ethic Drinks	Wine	Uses sail-powered ships as part of a sustainable supply chain strategy.
Longueteau	Spirits	Regards sail-powered cargo vessels as an opportunity to improve the sustainability of premium spirits throughout the supply chain.
Drappier	Champagne	Uses sail-powered transport to reduce transport-related emissions in a premium segment.
Boisson Delame	Wine	Integrates sail-powered transport into its logistics operations to reduce the environmental impact of wine transportation.
Molienda Real	Raw sugar	Trials sail-powered transport as a low-emission alternative for high-quality agricultural raw materials.
Hennessy	Cognac	Uses wind-assisted shipping to reduce transport-related CO_2 emissions in its export operations.
Manitou Group	Vehicles	Uses sail-powered shipping to reduce the climate impact of transatlantic transport.
Michelin	Tyres	Uses wind-assisted cargo vessels as part of its efforts to decarbonise international supply chains.

Structured Analysis of the Interview Findings

The qualitative interviews reveal a broadly consistent picture regarding the market potential and challenges associated with sail cargo ships. Across almost all stakeholder groups, there is a shared understanding that the decarbonisation of maritime transport will become increasingly important in the future. At the same time, it is evident that sail cargo ships are currently regarded not as a replacement for conventional maritime shipping, but rather as a complementary solution for selected market segments. The assessments provided by the interviewees can be divided into four key areas: market potential, economic requirements, operational requirements and regulatory framework conditions.

Sail Cargo Ships are Predominantly regarded as a Niche Solution

A key finding from the interviews is the largely shared view that sail cargo ships will only be economically viable in certain market segments in the long term. The main reasons cited are their comparatively limited transport capacity, longer transit times, lower schedule reliability and higher transport costs compared with conventional maritime shipping. Consequently, their potential for use in the mass market, particularly in container shipping and traditional bulk cargo transport, is considered limited.

Greater potential is identified for high-value products with substantial added value and relatively low time sensitivity. Frequently mentioned examples include coffee, cocoa, tea, wine, spirits, spices, high-quality textiles and artisanal products. In these segments, the transport method itself can become part of the product promise and create additional value for customers. Low-emission transport is therefore regarded not merely as a logistics service, but also as an integral element of brand positioning and sustainability communications.

Several interview partners emphasise that companies with close relationships with end consumers, in particular, may be more willing to adopt such transport concepts. However, this depends on end customers recognising the sustainability benefits of the transport method and being willing to accept higher product prices to reflect the additional value created.

Willingness to Pay as a Decisive Success Factor

The willingness of shippers and end customers to pay a premium is regarded as a key prerequisite for successful market entry. Almost all interviewees point out that, due to their more limited economies of scale, sail cargo ships will continue to incur higher transport costs than conventional ships, even in the long term. Such concepts will therefore only be economically viable if customers are willing to accept this additional cost in return for a demonstrably lower-emission transport solution.

At the same time, there is uncertainty regarding the actual level of willingness to pay in the market. Although many companies express a general interest in sustainable transport solutions, they frequently refrain from providing specific figures regarding the additional costs they would be prepared to accept. This makes it more difficult to develop robust business models and increases the investment risk for potential service providers.

Some companies are already pursuing internal approaches to integrating sustainability-related costs more closely into economic decision-making, for example through internal carbon pricing. This could make lower-emission transport options more economically attractive in the future. However, only a limited impact is expected for sail cargo ships in the short term.

Economic Viability Requires Stable Cargo Flows

Several interviewees pointed out that investments in sail cargo ships or specialised vessel concepts are only economically justifiable if transport volumes are secured over the long term. Particularly in the tramp shipping market, stable trade flows and multi-year transport contracts are considered essential to recover the substantial investment costs.

At the same time, it was noted that many shippers now enter into integrated logistics contracts covering the entire transport chain. Integrating individual sail cargo ships into these existing supply chains is often difficult unless transport capacity can be made available on a permanent basis.

Requirements for Reliability and Logistics

In addition to economic considerations, operational requirements were identified as a major challenge. Predictable arrival times, high reliability and stable schedules are crucial for many industrial supply chains. Weather-dependent transit times are therefore widely regarded as an obstacle, although modern weather-routing systems and hybrid propulsion concepts can reduce some of these uncertainties.

Additional challenges were raised regarding port operations and cargo handling processes. In container shipping, in particular, sailing rigs could complicate cargo handling or interfere with existing port infrastructure.

By contrast, greater advantages are seen in the bulk and general cargo sectors, where more flexible cargo handling processes are possible and there is less dependence on standardised terminal operations.

The sailing systems themselves must also meet stringent requirements. They must not interfere with port operations, must function reliably over the long term, should ideally require no additional crew training and must achieve a service life comparable to the operational lifespan of the vessel.

Wind-Assisted Propulsion Is Viewed Much More Positively Than Primary Wind Propulsion

While primary wind-powered cargo ships are predominantly regarded as a niche solution, wind-assisted propulsion systems receive a considerably more positive assessment. Several interview partners see significantly greater market potential in wind-assisted propulsion concepts, as these can complement existing vessel concepts and be deployed without fundamental changes to logistics operations.

The main advantage is that the economies of scale offered by modern cargo vessels can be maintained while simultaneously reducing fuel consumption and CO_2 emissions. Nevertheless, it was noted that some companies have already investigated such technologies but have not pursued them further due to insufficient economic viability or technical limitations.

Regulatory Framework Conditions Determine Market Development

Another key finding concerns the importance of regulatory framework conditions. There is broad agreement that sail cargo ships will only be able to establish themselves on a larger scale if low-carbon transport solutions receive significantly greater regulatory support. Rising CO_2 prices, stricter emissions requirements or targeted funding mechanisms could substantially improve their competitiveness compared with conventional cargo ships.

However, several interview partners point out that regulatory uncertainties currently make investment decisions more difficult. At the same time, external events – such as geopolitical crises, rising energy prices or disruptions to global trade routes – could significantly alter the economic viability of alternative propulsion concepts in the short term and increase their attractiveness.

Strong Openness to Pilot Projects – Scaling Up Is the Decisive Factor

Several companies report a generally high level of openness towards pilot projects involving low-emission maritime transport. Such demonstration projects are regarded as an important opportunity to gain practical experience and support technological developments. At the same time, it is emphasised that pilot projects alone are not sufficient. The decisive factor is the transition of successful concepts into economically viable, long-term commercial operations with sufficient transport volumes and reliable business models.

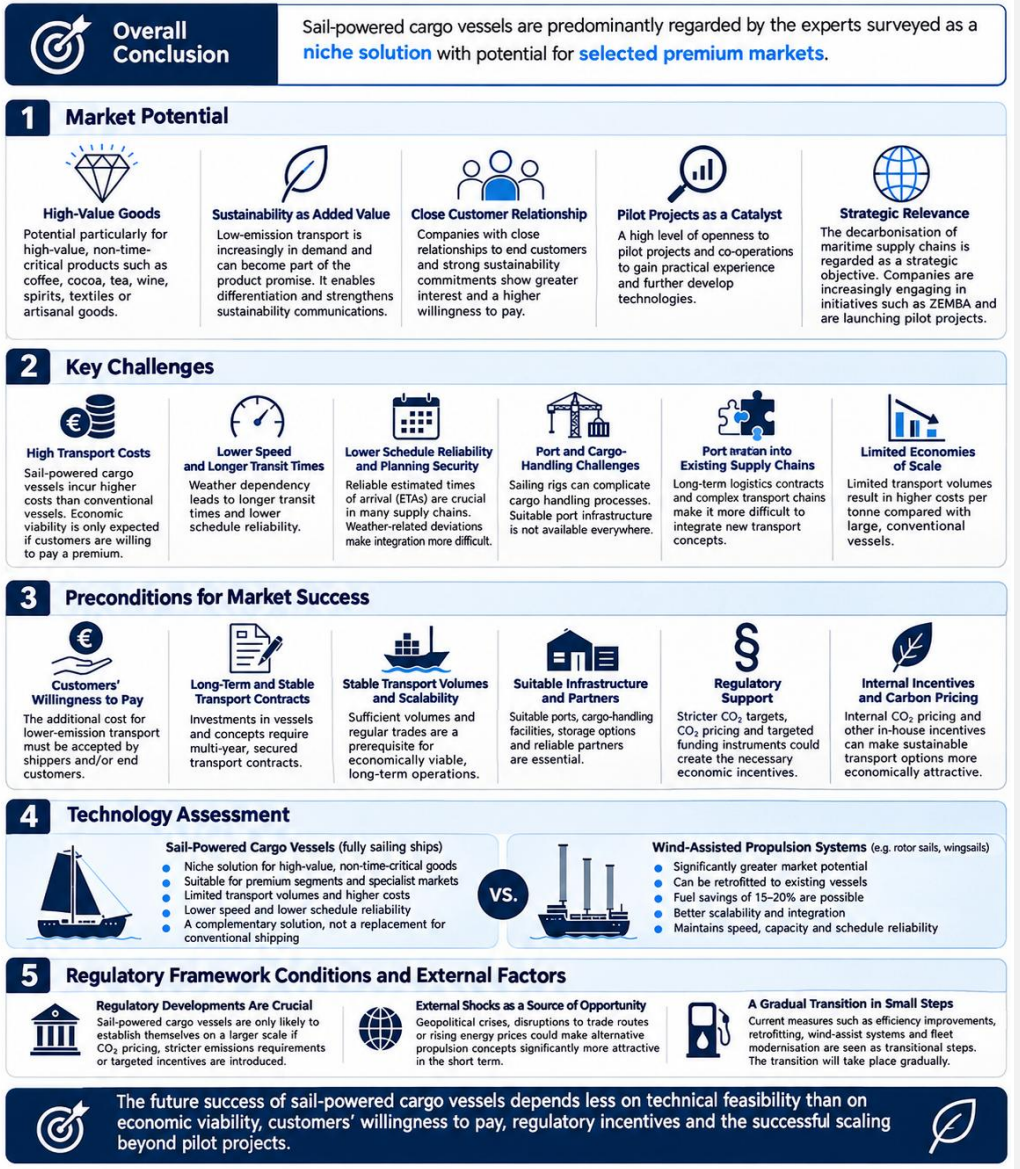
Overall Assessment

Overall, the interviews present a nuanced but consistent picture. Interest in low-emission transport solutions is high across all stakeholder groups and is further reinforced by increasing sustainability requirements and regulatory developments. At the same time, there are considerable doubts as to whether primary wind-powered cargo ships can become a significant alternative to conventional maritime shipping in the short term. The main barriers identified are economic viability, limited scalability, higher transport costs and the requirements for reliability and integration into existing supply chains.

Greater market opportunities are primarily seen in the premium segment for high-quality consumer goods and in supply chains where sustainability creates recognisable added value for customers and the transport method can become part of the product story.

For the wider maritime shipping sector, hybrid concepts incorporating wind-assisted propulsion are currently considered to have significantly greater market potential than primary wind-powered cargo ships.

In the long term, market development will largely depend on whether regulatory incentives are introduced, customers' willingness to pay increases and pilot projects can be developed into economically viable transport concepts.



Case Study: Sport-Thieme

Sport-Thieme is an owner-managed German specialist mail-order retailer of sports, therapy and exercise products based in Grasleben. The company offers a broad range of products sourced globally and supplies customers internationally. Its supply chain is strongly import-oriented, with major sources in Asia, particularly India, Pakistan, China and Taiwan.

Sustainability is embedded in the company's strategy and is driven by a clear intrinsic motivation. Its aim is to systematically reduce its environmental footprint and achieve climate-neutral operations in the long term. Sport-Thieme takes a holistic approach across the entire value chain, continuously assessing where the greatest opportunities for emissions reductions lie.

Maritime transport is operationally relevant, with around 200 TEU imported annually. Nevertheless, the company's own carbon footprint assessment shows that the greatest potential for climate action lies not in transport but in product design and the materials used, such as aluminium and recycled content. Accordingly, the strategic focus is more strongly on product-related measures than on logistics optimisation.

At the same time, Sport-Thieme actively supports the decarbonisation of maritime transport. It is a member of the Zero Emission Maritime Buyers Alliance (ZEMBA), an initiative that aggregates demand for low-emission transport solutions. Hapag-Lloyd was selected as the provider through a joint tender with other companies. The agreed solution uses vessels powered by biomethane, resulting in significantly lower emissions. For Sport-Thieme, however, this option entails substantially higher costs than conventional sea freight.

The use of such initiatives in communications is also restricted. This is due to the EU's Empowering Consumers for the Green Transition (EmpCo) Directive, which imposes strict requirements on sustainability and environmental advertising. Sport-Thieme nevertheless communicates its involvement cautiously, avoiding exaggerated marketing claims.

Against this background, the role of sail cargo ships is assessed in a nuanced way. In principle, they could contribute to eliminating emissions from maritime transport, particularly for cargo that is not time-sensitive. However, transport volumes are relatively limited, and few products in the range have sufficient willingness to pay or particular environmental sensitivity to justify more expensive transport solutions.

One example is sports balls, some of which are Fairtrade-certified and for which sustainability is especially relevant. The focus here, however, is primarily on production conditions, such as manufacturing in Pakistan, rather than transport. This product group is not currently considered suitable for sail cargo ships either.

The Sport-Thieme case demonstrates that even a strong commitment to sustainability does not remove the economic, product-specific and regulatory constraints on zero-emission transport solutions such as sail cargo ships. While the company actively supports the transformation of maritime transport through initiatives such as ZEMBA, the greatest current opportunities for reducing emissions lie in material selection and product design rather than maritime transport.

Information is based on an interview with Wolfram Nimmerrichter, CSR Manager at Sport-Thieme, conducted on 24 March 2026.

Case Study: Tchibo

Tchibo is one of Europe's largest coffee companies, combining its traditional coffee business with an extensive non-food product range. It imports around 7,000 to 8,000 TEU of green coffee annually, transported mainly to Europe by international sea freight. As a major shipper, Tchibo relies on efficient and economically viable logistics solutions. At the same time, it pursues ambitious sustainability targets and regards decarbonising its transport chains as a key lever for reducing Scope 3 emissions.

Against this background, Tchibo has been involved in the Zero Emission Maritime Buyers Alliance (ZEMBA) since its establishment in 2023, as a founding member. The alliance aims to aggregate major shippers' demand for low-emission maritime transport and thereby encourage shipping companies to invest in alternative fuels and new propulsion technologies. Hapag-Lloyd was selected as the transport partner in ZEMBA's first tender. Through a book-and-claim system, Tchibo and its partners purchase certified emissions reductions from biomethane-powered maritime transport without fundamentally changing their existing logistics processes.

Tchibo's commitment, however, extends far beyond ZEMBA. The company is examining intensively how logistics can remain economically viable not only today but also in ten or twenty years. In its view, rising energy prices, increasing CO_2 pricing and stricter regulatory requirements will substantially affect the economics of international supply chains. Tchibo therefore seeks to familiarise itself with new technologies and transport concepts at an early stage and gain practical experience rather than waiting for regulatory pressure.

Its aim is to actively stimulate the market and help shape the development of sustainable transport solutions.

The company does not limit its activities to maritime transport. Alternative propulsion systems and low-emission logistics solutions are also being trialled in land transport. Tchibo works specifically with start-ups and technology companies to assess innovative approaches at an early stage. One example is its cooperation with CargoKite, whose towing-kite technology aims to reduce fuel consumption on conventional cargo vessels through wind assistance. Such technologies are seen as a pragmatic way to make existing vessels more efficient and climate-friendly in the short term without developing entirely new vessel concepts.

Tchibo is also generally open to sail cargo ship projects. It views such initiatives positively because they can diversify sustainable transport options. However, many projects are still individual demonstrations or pilots. In Tchibo's view, the real challenge is to turn successful pilots into reliable, regularly available and economically viable transport services. The main challenges for sail cargo ships are their comparatively low speed and longer transit times. These factors currently impose significant constraints on time-sensitive supply chains and standardised container shipping.

The interview also suggested that many established shipping companies have so far shown too little initiative in actively advancing alternative vessel concepts. Tchibo believes greater investment and willingness to innovate within the shipping industry are needed to bring sustainable transport solutions to market more quickly.

The company is also developing an internal carbon footprint pricing approach. The aim is to assess future transport costs not solely in monetary terms but also by including the resulting CO_2 emissions in economic evaluations. This would give lower-emission transport options an economic advantage over conventional solutions. According to Tchibo, this instrument is already creating additional opportunities for alternative land transport solutions, such as electric lorries. Its initial impact on sail cargo ships is likely to be smaller because availability remains limited, transit times are longer and costs are higher. Nevertheless, Tchibo sees future opportunities in specialised niches, such as high-value products, promotional shipments or selected sustainability-oriented supply chains, provided a reliable scheduled service can be established.

Overall, Tchibo regards sustainable maritime transport not as a short-term marketing issue but as a strategic challenge for the future. The company deliberately adopts a technology-neutral approach and supports solutions ranging from alternative fuels and wind-assist systems to new vessel concepts. In its view, widespread market adoption nevertheless depends on innovative approaches successfully progressing from pilot projects to economically viable and permanently available logistics solutions.

Information is based on an interview with Peter Maltzahn (Senior Process Manager, iLogistik / Supply Chain Management at Tchibo), conducted on 26 June 2026.

Case Study: Cooko.co

Cooko.co is a young, values-driven company in the premium cocoa segment, with a clear focus on transparency, sustainability and quality. It works closely with producers in countries of origin, particularly Cameroon, and follows an integrated approach across the supply chain. This includes processing fresh cocoa locally into dried cocoa suitable for storage and transport, establishing comprehensive traceability systems and ensuring high environmental and social standards. Cooko is positioning itself in the growing market for high-quality, sustainably produced raw materials for small and medium-sized premium chocolatiers in Europe and, prospectively, North America. Its target customers are predominantly quality-oriented artisan producers who value origin, transparency and credible sustainability concepts alongside excellent product characteristics.

Against this background, sustainable supply-chain design plays a central role for Cooko. Transport is regarded not merely as a logistical process but as an integral part of the company's identity and brand. CO_2 reduction, transparent supply chains and verifiable sustainability performance are becoming increasingly important, particularly in the premium segment. Accordingly, the company is closely following alternative transport concepts such as sail cargo ships. In its view, low-emission transport solutions can create additional value and provide a credible point of differentiation for customers. Cooko is, in principle, interested in using sail cargo ships. Potential applications are seen particularly in the premium segment, among customers with strong sustainability commitments and greater willingness to pay for reduced-CO_2 transport solutions. This applies primarily to European sales markets, but potentially also to North America.

Cooko also considers sail cargo ships a possible option not only for cocoa but for other high-quality speciality products, such as rum and comparable premium goods.

However, it identifies substantial practical and economic challenges. Cocoa is a sensitive natural product whose quality is strongly influenced by transport conditions. Temperature, sunlight, humidity and total transport duration are critical factors. Longer transit times, which are often associated with sail cargo ship concepts, can increase the risk of quality deterioration. For Cooko, maintaining consistent product quality is therefore a central prerequisite for adopting alternative transport solutions.

There are also logistical challenges. International cocoa trading is largely standardised and primarily relies on containerised transport. Goods are typically traded in sacks, while procurement and consolidation are often handled by specialist traders. Economically consolidating smaller shipments is frequently difficult. At the same time, many existing sail cargo ship concepts still have only limited capability to handle standardised container shipments. This creates additional requirements for cargo handling, securing loads and preserving quality. In the company's view, future sail cargo ships would therefore need greater carrying capacity, container-handling capability and stable transport conditions to offer a serious alternative to conventional solutions.

A further major obstacle concerns economic viability and the associated risk. The value of a single container of high-quality cocoa products can reach EUR 100,000. As payment is often made only after the goods arrive successfully, longer transit times directly increase the amount of capital tied up.

Currently high cocoa prices further amplify this effect. Against this background, any additional costs of wind-powered transport must be clearly offset by environmental benefits, marketing effects or corresponding customer willingness to pay.

The Cooko.co case illustrates both the opportunities and limitations of sail cargo ships in the premium agricultural and speciality food sector. On the one hand, these ships offer considerable potential for credible sustainability marketing, storytelling and reducing transport-related emissions. On the other hand, technical, logistical and economic challenges currently hinder wider adoption. In particular, long transit times, limited scalability, quality risks and the lack of container-handling capability in many concepts currently restrict practical deployment.

Overall, the case study shows that market interest in sail cargo ships exists, particularly for high-value products with a strong sustainability focus. However, broader deployment will only become realistic when modern sail cargo ships offer container-compatible transport solutions, achieve competitive transit times and reliably maintain quality standards. Under these conditions, an attractive niche market could develop in the long term, in which sustainable transport itself becomes part of product value and brand communications.

Information is based on an interview with Silke Elwer (Cooko.co), conducted on 25 March 2026.

Case Study: Reederei Laeisz

Reederei F. Laeisz is an internationally active Hamburg-based shipping company specialising in bulk carriers, gas tankers and specialised shipping. It pursues a sustainability strategy aimed at reducing fleet emissions through efficiency measures, fleet modernisation and alternative fuels.

The interview made clear that sustainability is becoming increasingly important for the shipping company and its customers. However, it was also noted that the new IMO Net-Zero Framework had recently slowed market development, as stakeholders were waiting for clarity on regulatory conditions and the resulting investment decisions. The company's current strategic focus is less on sail cargo ships and more on alternative propulsion concepts and fuels, particularly ammonia.

The company is generally very open to wind assist shipping concepts. Wind-propulsion technologies such as Flettner rotors or rigid sails are regarded as realistic options that could achieve fuel savings of approximately 15–20%, depending on the operating area. Transatlantic routes with favourable wind conditions appear particularly suitable, for example for ammonia transport. These systems must meet the highest standards of operational safety, reliability and suitability for carrying dangerous goods. Primary wind-powered cargo ships, by contrast, are viewed more critically and considered a niche solution.

Economically viable applications are seen primarily for high-value goods or where customers have a high willingness to pay, such as sustainably produced coffee or cocoa and, potentially, green energy carriers in the future. Companies with close relationships to end customers, for example in grain trading or the automotive industry, were identified as potentially receptive customer groups. By contrast, conventional B2B bulk commodities such as coal are expected to generate only limited demand for such transport solutions.

Customer willingness to pay was highlighted as the decisive success factor. Additional investment in wind propulsion technologies would have to be recovered through higher freight rates. At the same time, the economies of scale of conventional shipping represent a significant competitive disadvantage for sail cargo ships, whose lower capacities make it difficult to compete economically with large bulk carriers. Regarding the technical requirements for wind-propulsion systems, the interview stressed that they must not interfere with normal vessel operations, either at sea or in port. In particular, port cranes and cargo handling processes must not be restricted. In addition, the systems should require little additional crew training and achieve a service life comparable to that of a vessel, approx. 25 years.

Finally, it was noted that F. Laeisz often acts as a tonnage provider or shipowner chartering out vessels, with fuel costs frequently borne by the charterer. This gives the shipping company only limited direct economic incentives to invest in fuel-saving technologies. The current focus is therefore primarily on incremental efficiency improvements, such as retrofitting existing vessels or optimising hull coatings to reduce fuel consumption.

Information is based on an interview with Hannes Thiede (Managing Director, Reederei F. Laeisz), conducted on 8 July 2026.

SWOT Analysis

The preceding analyses show that sail cargo ships should be regarded neither as a replacement for conventional maritime shipping nor as a universal decarbonisation solution. Rather, they represent a specialised transport concept with clearly defined applications. The SWOT analysis brings together the findings of the market analysis, economic viability and emissions assessments, and stakeholder survey.

The SWOT analysis on the following page illustrates that the greatest competitive advantages of sail cargo ships lie less in traditional cost or productivity criteria and more in their environmental performance and communications value. At the same time, the analyses show that economic viability can currently only be achieved under specific market conditions. The greatest market potential therefore lies in selected niche markets where sustainability creates measurable added value and longer transit times are acceptable. In the long term, market development will be determined largely by regulatory conditions, shippers' willingness to pay and the successful scaling-up of today's pilot projects. This assessment is consistent with the qualitative stakeholder interviews, in which sail cargo ships were predominantly regarded as a specialised complement to existing maritime shipping.

Deriving Stakeholder-Specific Recommendations

The results of the SWOT analysis can be used to derive recommendations tailored to different stakeholder groups.

Shipping Companies and Operators

The study findings show that, under current market conditions, sail cargo ships do not represent a competitive alternative for the volume-driven mass market in the short term. Operators should therefore focus their business models consistently on market segments where sustainability creates additional economic value and customers are willing to accept longer transit times and higher freight rates. High-value agricultural products, premium consumer goods and selected general cargo and project cargo shipments appear particularly suitable, where climate-friendly transport can become part of a brand's sustainability strategy.

To improve economic viability, operators should establish stable scheduled services on a limited number of routes with favourable winds and recurring cargo flows. Long-term partnerships with shippers and cargo owners can provide the necessary planning certainty and reduce investment risks. At the same time, existing pilot projects should be developed into permanently viable commercial transport services at an early stage to achieve economies of scale and strengthen potential customers' confidence. Operators should also systematically use modern digital weather-routing and fleet-management systems to reduce weather-related uncertainty, improve schedule reliability and optimise vessel capacity utilisation. Transparent measurement and communication of emissions reductions are equally important. Verifiable CO_2 savings and transparent sustainability reporting can make a substantial contribution to marketing transport services and attracting customers with ambitious Scope 3 reduction targets.

STAKEHOLDERS

STRENGTHS

- Very low CO_2 emissions and a high share of renewable energy (wind)
- Low dependence on fossil fuels and energy carriers, and on energy prices
- Attractive sustainability and marketing effect, particularly for premium products
- Supports the reduction of companies' Scope 3 emissions and their ESG strategies
- High suitability for high-value agricultural products, premium goods and selected general cargo shipments
- Proven technical feasibility of modern cargo sailers

WEAKNESSES

- Limited transport capacity compared with conventional vessels
- Longer and weather-dependent transport times
- Restricted schedule stability and lower reliability
- Higher transport costs compared with established bulk transport
- Limited scalability due to small transport volumes
- Restricted integration into standardised container logistics and port processes
- Still limited operating experience and restricted market availability



OPPORTUNITIES

- Increasing regulatiory requirements for the decarbonisation of sea transport (IMO, EU)
- Growing importance of Scope 3 emissions and CSRD reporting
- Rising demand for low-emission premium transport and sustainable supply chains
- Development of new business models through green premiums, long-term partnerships and brand communication
- Pilot projects facilitate market entry, build trust and provide operational experience
- Possible funding programmes and political incentives at EU and national level
- Energy price increases during times of crisis can improve competitiveness

RISKS

- A prolonged or weakened regulatory framework reduces willingness to pay and market incentives
- Alternative decarbonisation pathways (e-fuels, methanol, wind assistance) could develop more quickly
- Cost advantages of large container vessels will remain
- A lack of critical transport volumes could prevent economic operation and scaling
- High requirements for the reliability of industrial supply chains limit deployment opportunities
- Uncertainty regarding financing, investment readiness and returns
- Technological risks and uncertainties regarding port integration and operations

Another important aspect is the further development of wind propulsion technologies. The stakeholder survey suggests that wind-assisted propulsion concepts are currently considered to have greater market potential than primary wind-powered cargo ships. At the same time, the technological and regulatory framework is still evolving. Operators should therefore monitor these developments continuously and assess the future relevance of wind propulsion for different vessel types and operational profiles.

Key Recommendations for Shipping Companies and Operators

- Focus business models consistently on niche markets, particularly high-value agricultural products, premium consumer goods, and general and project cargo with low time sensitivity and high willingness to pay.
- Establish long-term partnerships with shippers and cargo owners to secure stable cargo volumes, planning certainty and investment security.
- Develop pilot projects into economically viable regular operations and establish reliable scheduled services on suitable routes with favourable wind conditions.
- Improve operational efficiency by using digital weather-routing and fleet-management systems and continuously optimising capacity utilisation and schedule reliability.
- Document and market sustainability benefits transparently, particularly by clearly demonstrating CO_2 savings as a contribution to customers' Scope 3 and ESG targets.
- Monitor technological developments continuously and consider hybrid wind assist concepts alongside primary sail-powered cargo ships as a long-term development prospect.

Shippers and Cargo Owners

For shippers and cargo owners, sail cargo ships are particularly suitable as a complementary option within existing transport chains. They should not be regarded as a complete replacement for conventional sea freight, but should be used selectively where transit time is of secondary importance and environmental benefits generate additional value for companies, brands or end customers. Particularly suitable product groups include those with strong sustainability credentials, clear communication potential and sufficient value density, such as high-value agricultural products, premium consumer goods and selected specialised and project cargo.

A sensible starting point may be pilot shipments involving individual product lines or selected batches. This enables companies to gain practical experience of transit times, predictability, cost structures, interfaces with existing logistics and internal coordination processes without immediately having to restructure large parts of their supply chains. Such pilot shipments are particularly suitable for products where low-emission transport can credibly form part of the product story.

Furthermore, sail cargo ships can contribute to reducing transport-related Scope 3 emissions. This requires the emissions reductions achieved to be transparently measured, documented using robust methodologies and integrated into existing sustainability reporting. For companies with ambitious climate targets, using sail cargo ships can therefore be not only an operational logistics measure but also part of their ESG and decarbonisation strategy. At the same time, shippers should make targeted use of the communication potential of low-emission transport. Particularly for consumer-facing products, transport by sail cargo ship can create additional brand value when it is transparent, credible and not merely symbolic.

Crucially, sustainability communications must be consistently linked to actual emissions performance. To support economic viability and reliable capacity, shippers should, wherever possible, conclude long-term transport agreements with operators. Such agreements provide planning certainty for both sides: operators can better forecast capacity utilisation and investments, while shippers can secure transport capacity at an early stage and define requirements for reporting, transit times and supply-chain integration.

Key Recommendations for Shippers and Cargo Owners

- Use sail cargo ships selectively to complement existing transport chains, particularly for non-time-critical, high-value products with strong sustainability positioning.
- Carry out pilot shipments involving selected product lines or batches to gain practical experience of transit times, costs, interfaces and internal processes.
- Use sail cargo ships to reduce Scope 3 emissions, provided that emissions reductions can be measured transparently and documented robustly.
- Integrate low-emission transport into sustainability and brand communications, particularly for products where origin, transparency and climate-friendly logistics create customer value.
- Conclude long-term transport agreements with operators to support planning certainty, capacity availability and economic viability.
- Begin with smaller cargo volumes and gradually expand deployment once operational experience, customer demand and internal assessment mechanisms are in place.

Policy-Makers and Institutional Stakeholders

The study findings show that the future development of the market for sail cargo ships will depend significantly on the regulatory framework. Under current market conditions, sail cargo ships are often unable to translate their environmental advantages fully into competitive economic benefits. This is because the societal costs of CO_2 emissions from maritime transport are still only partly reflected in transport costs. Without suitable policy incentives, the use of sail cargo ships is therefore likely to remain confined to a small number of niche markets.

Policy measures should not focus on promoting individual vessel technologies, but should support low-emission transport services on a technology-neutral basis. The key requirement is for regulatory instruments to create incentives that reward actual emissions reductions economically and provide investment certainty for innovative transport concepts. This would allow other low-emission solutions, as well as sail cargo ships, to benefit equally from improved framework conditions. In addition, targeted funding for demonstration and scaling-up projects is particularly needed at the current stage of market development. Although the technical feasibility of modern sail cargo ships has already been demonstrated, the transition from pilot operations to permanently economically viable commercial services remains a central challenge. Public funding programmes can help reduce investment risks, generate practical operational experience and establish the first viable business models.

A further area requiring action is the expansion of suitable port and cargo-handling infrastructure. Modern sail cargo ships and wind-assisted ship concepts sometimes impose new requirements on port facilities and cargo-handling processes. Considering these requirements at an early stage can reduce infrastructure-related barriers and facilitate integration into existing logistics chains.

At the same time, the development of standardised methods for accounting for and certifying emissions reductions should be advanced further. Consistent and transparent assessment procedures improve comparability between different transport solutions and create the transparency required by companies, investors and funding institutions. This also facilitates the recognition of low-emission transport within sustainability reporting and climate strategies.

Finally, research, education and knowledge transfer play an important role. The further development of wind-powered shipping requires interdisciplinary expertise in shipbuilding, navigation, logistics, digitalisation and energy technology. Supporting research projects and cooperation between academia and industry can accelerate innovation and improve the conditions for long-term market expansion.

Key Recommendations for Policy-Makers and Institutional Stakeholders

- Create technology-neutral regulatory incentives that provide economic advantages for low-emission transport services regardless of the technology used.
- Further develop CO_2-based market mechanisms so that the climate benefits of low-emission maritime transport are reflected more strongly in transport costs.
- Provide targeted support for demonstration and scaling-up projects to facilitate the transition from pilot schemes to permanently economically viable business models.
- Further develop suitable port and cargo-handling infrastructure so that innovative vessel concepts can be efficiently integrated into existing logistics systems.
- Establish standardised procedures for accounting for and certifying emissions reductions to improve transparency, comparability and integration into ESG and Scope 3 reporting.
- Strengthen research, education and knowledge transfer to promote technological innovation and support the long-term development of wind-powered shipping.

Overall Conclusion

The study shows that sail cargo ships are not a replacement for conventional maritime shipping under current market conditions. Their realistic field of application instead lies in clearly defined niche markets where environmental advantages can generate economic added value. High-value agricultural products, premium consumer goods and selected general cargo services, in particular, offer suitable conditions. Successful market development will depend less on further technological progress than on stable regulatory conditions, sufficient willingness to pay among shippers and the transition from individual pilot projects to permanently economically viable business models.

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The cost, revenue, capacity utilisation and operating parameters presented are scenario-based modelling assumptions used in the study. They are based on industry benchmarks, project information and expert interviews and serve as the basis for the comparative economic viability analysis; they do not constitute a forecast of market prices.

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MOVE4WARD is an independent management and strategy consultancy specializing in transport, mobility, logistics, and infrastructure. Led by Prof. Dr. Jan Ninnemann and Torsten Tesch, we combine extensive industry experience, scientific expertise, and innovative thinking to develop tailored, forward-looking solutions for our clients. Our interdisciplinary team supports public institutions, policymakers, industry associations, and private companies in addressing complex challenges and shaping sustainable transport and logistics systems.



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