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REISFER – REDUCING CO_2 EMISSIONS IN ISLAND FERRY TRAFFIC

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Report on the setup of island ferry transport in the Central Baltic Region

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List of Acronyms

BBAB	Blidösundsbolaget
CB	Central Baltic
CO_2	Carbon Dioxide
EEXI	Energy Efficiency Existing Ship Index
ETS	Emissions Trading System
EU	European Union

EV	Electric vehicle
GHG	Greenhouse Gas
GoA	Government of Åland
GT	Gross Tonnage
HELCOM	Baltic Marine Environment Protection Commission
ICE	Internal Combustion Engine
IMO	International Maritime Organization
NM	Nautica Mile
NO_x	Nitrogen oxides
PM	Particulate Matter
SECA	Sulphur Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SLL	Suomenlinnan Liikenne OY
SO_x	Sulphur oxides
WP	Work package

Keywords List

- Carbon emissions
- Decarbonization
- Island ferry
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Background and REISFER introduction

The REISFER project specifically focuses on the CB region, encompassing Estonia, Finland, Åland, and Sweden where the island ferry network plays a crucial role in facilitating both passenger and freight transport.

Its focus is on international shipping, more specifically, addressing climate change which is central to the European Union (EU) Green Deal, and the integration of these objectives into national policies aiming to significantly reduce greenhouse gas (GHG) emissions in the transport sector.

The REISFER project aims to significantly reduce the carbon footprint of island ferry transport, which is vital for connecting mainland areas with islands in the Central Baltic (CB) region – specifically in Estonia, Finland, Åland, and Sweden. The primary objective is to achieve a 10-20% reduction in CO_2 emissions from selected island ferry routes by introducing a mix of technological and operational innovations.

The project's work plan is divided into two (2) work packages (WPs), each focused on delivering outcomes that contribute to lowering CO_2 emissions in key ferry transport areas:

(1) WP 1 – CO_2 reduction possibilities and potential in CB island ferry traffic
(2) WP 2 – CO_2 emission abatement methods and technologies on ferries

This report falls under WP1.

Purpose of the report

The Baltic Sea, as one of Europe's busiest maritime areas, features a dense network of ferry routes connecting islands and mainland ports. These ferry services are essential for both passenger and cargo transport, particularly in heavily trafficked areas like the Gulf of Finland and the northern Baltic Proper. Ferry services are considered the backbone of transport in the Baltic region, with major routes experiencing constant, year-round demand. This includes large vessels over 5,000 gross tonnage (GT) on routes such as Tallinn – Helsinki, and smaller vessels under 5,000 GT operating in the Central Baltic (CB). Major ferry routes between mainland ports and islands handle millions of passengers annually, underscoring their importance for both tourism and local commuting.

The purpose of this report is to provide a comprehensive overview of the current setup of the island ferry transport in the Central Baltic region. It aims to describe and assess the existing routes and infrastructure, geographic, climatic and operational characteristics and constraints. It examines the characteristics of ferry traffic in fours selected nodes: EE. FI. AX, SE, including the typical vessels in operation, types of operation, age, structure, and technology used.

The report also explores opportunities for improving ferry transport through energy efficiency measures, alternative fuels, and industry stakeholders making informed decisions based on existing knowledge and practices in the region and beyond.

The findings will contribute to the evaluation of the role of ferry services in the regional connectivity, economic development, and social inclusion; and serve as a base for discussions on sustainable island transport frameworks and policies in the Central Baltic region.

1. Characteristics of ferry operations in the CB

Ferry operations in the CB region, covering Estonia, Åland, Sweden, and Finland, serve as essential lifelines for both residents and businesses, ensuring the movement of passengers, goods, and services across the islands and coastal areas. However, these operations are shaped by a complex interplay of environmental, economic, and logistical factors that determine efficiency, reliability, and sustainability. Understanding these influences is crucial for improving service quality, optimizing vessel performance, and reducing environmental impact.

The region's geographic and climatic conditions play a fundamental role in shaping ferry operations. Winter ice formations, whether level ice in sheltered waters or unpredictable drift ice in open sea routes, pose significant navigational challenges, affecting fuel consumption and emissions. Also, seasonal wind and wave patterns, as well as varying water depths between routes, influence vessel speed, energy efficiency, and overall service planning.

In addition to environmental conditions, the frequency and capacity of ferry services are influenced by economic factors and demand dynamics. The transport needs of passengers and transport fluctuate throughout the year, requiring a balance between high-demand periods and off-peak operations. Public transport agreements, typically spanning 5 to 10 years or more, provide stability for operators and encourage investments in new technologies and infrastructure. However, ensuring optimal vessel utilization remains a key challenge, as underloaded ferries lead to inefficiencies in energy consumption and cost distribution.

Operational constraints further add complexity to ferry management. The time spent in ports, dictated by the loading and unloading process, influences overall scheduling. Adjusting travel speed to optimize fuel efficiency, considering both sea conditions and route distances, becomes a strategic decision for operators. The selection of vessel size also plays a crucial role, larger ferries may improve efficiency on busy routes, but smaller vessels offer flexibility and better adaptability to varying demand levels.

With the growing focus on sustainability, technology and innovation are becoming central to the future of ferry operations. The transition towards hybrid propulsion systems, expanded shore power infrastructure, and potentially hydrogen-based fuels, presents both opportunities and challenges. The integration of technology providers, universities, and research institutions is crucial to developing solutions that not only reduce emissions but also ensure practical implementation across different ferry routes.

This chapter explores these diverse conditions, highlighting their impact on ferry operations and identifying pathways for a more efficient, flexible, and environmentally responsible maritime transport system in the CB region. By examining both the challenges and opportunities within this sector, it aims to provide insights that support sustainable investments, smarter operational strategies, and long-term improvements for ferry services that remain a backbone of regional connectivity.

1.1. Geographic and climatic conditions influencing ferry operations

The Baltic Sea, a semi-enclosed body of water in Northern Europe, plays a vital role in regional connectivity, with extensive ferry operations linking Estonia, Finland, Sweden, and the Åland Islands. The CB region is particularly important for passenger transport, cargo logistics, and economic integration, ensuring mobility between islands and the mainland. Figure 1 presents the passenger vessel traffic in the region in 2022.

Ferry operations in this region are heavily influenced by geographic and climatic conditions. The Baltic Sea's shallow waters, particularly near archipelagos and coastal areas, impact vessel navigation and fuel efficiency. Seasonal ice coverage, especially in winter, requires ice-class vessels, increasing fuel consumption. Winds and waves vary throughout the year, affecting ferry schedules and operational speeds. Strong winds and rough seas in autumn and winter often lead to route adjustments or speed reductions for safety.

To ensure efficient and sustainable ferry transport, operators must continuously adapt to these environmental conditions. Investments in modern vessel technology, optimized routes, and alternative fuels are key to maintaining reliable ferry services across the CB.

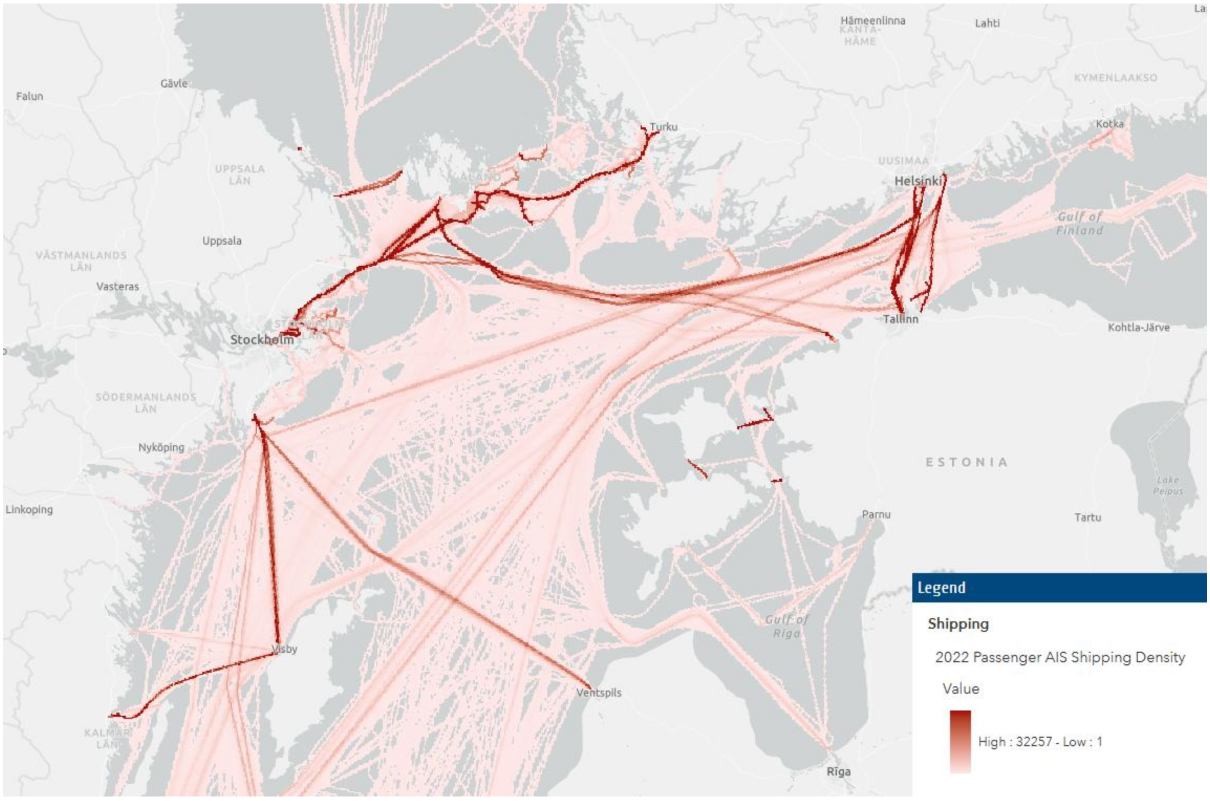

Figure 1. Passenger traffic density in the region in 2022. Source HELCOM (2022)

1.1.1. Deep and shallow waters

Island ferry services in regions such as Estonia, Finland, Åland and Sweden operate under a variety of water depth conditions. Both deep and shallow waters present distinct challenges and benefits that directly affect vessel performance, safety, fuel consumption, and emissions.

In deep water, ferries benefit from reduced bottom friction since the seabed does not interfere with the hull, which can enhance fuel efficiency under calm conditions. However, deep waters expose ferries to more open-sea dynamics, where strong winds and powerful waves are common, especially during adverse weather. These larger waves and high-energy conditions force vessels to increase engine output to maintain stability and safe navigation, thereby elevating fuel consumption and emissions despite the inherent efficiency benefits of operating in deeper water.

When a vessel transitions from deep to shallow water, it experiences significant changes in hydrodynamic behaviour that impact its efficiency and manoeuvrability. The most noticeable effect is increased resistance, as water flow accelerates under the hull, making movement more challenging. This leads to speed reduction, requiring additional engine power to maintain cruising speeds. Additionally, vessels experience the squat effect, where the ship sinks slightly and trims forward, which can affect manoeuvrability, particularly in narrow or constrained waterways. Wave resistance also increases, as shallow waters alter wave patterns, leading to higher hydrodynamic drag that opposes the vessel's motion.

These effects have practical operational consequences. Higher frictional and wave resistance mean that more energy is needed to overcome the increased drag, which in turn leads to higher fuel consumption and greater environmental impact. Advanced hydrodynamic estimation methods, such as Schlichting’s method, can help predict resistance levels and improve vessel performance by optimizing operational parameters. For ferry operators, these conditions highlight the importance of route planning, vessel design, and propulsion efficiency to mitigate fuel costs and emissions in shallow water environments.

In Estonian island routes, deep water is typically encountered in the open channels adjacent to the mainland and around larger islands. Under calm conditions, these deeper waters offer reduced bottom friction that can enhance fuel efficiency. However, when weather is getting worse, the open deep-water environment exposes vessels to stronger, more persistent wave action, which forces ferries to operate at higher engine outputs. This increased engine load leads to higher fuel consumption and increased emissions, thereby offsetting the potential efficiency benefits in adverse conditions.

Finnish island routes, such as those connecting urban centres to historic sites or remote island communities, often cross deep-water passages, particularly near major ports like those serving Suomenlinna or between Korpoo and Houtskär. In these areas, the benefits of lower hydrodynamic drag are evident during mild weather. However, during periods of storm or high-energy conditions, the deep water amplifies the effects of wave impact, requiring vessels to use additional power to maintain stability and course. This operational demand results in increased fuel consumption and emissions, making fuel efficiency highly dependent on prevailing weather conditions.

Within the Åland archipelago, deep water segments occur between the islands, especially on routes that extend toward the open sea. While some deep-water channels are sheltered by the surrounding islands, allowing ferries to benefit from reduced friction, others are more exposed. In the exposed channels, the open deep water can generate significant wave energy, particularly when winds are strong. This forces vessels to counteract higher wave forces by ramping up engine performance, which leads to increased fuel consumption and emissions. The overall impact is highly variable, with deep water offering efficiency gains only under optimal weather conditions.

In Sweden's Stockholm archipelago and surrounding regions, ferries sometimes encounter deep water near the outer reaches of the archipelago. Here, the deep-water environment, while reducing bottom friction under calm conditions, also subjects vessels to the full force of open-sea dynamics when weather conditions worsen. Strong winds and large waves in these deep channels compel operators to use additional engine power for maintaining safe navigation, thus increasing fuel consumption and emissions. The net effect is that, despite the potential for improved efficiency in calm conditions, the variable weather in deep water areas often leads to a higher environmental impact during challenging conditions.

Deep and shallow water conditions each present unique challenges to island ferry operations in the CB region. Deep waters offer lower hydrodynamic drag but expose vessels to more severe wave action, while shallow waters increase friction and require careful navigation around submerged obstacles. Both scenarios necessitate increased engine power under certain conditions, leading to higher fuel consumption and emissions.

Based on the power prediction, the water depths on routes should be taken into account together with the hotel load, leading to energy consumed during one crossing. Harbor consumption must be included from the study of power prediction. Shallow water areas in routes to be considered in powering.

1.1.2. Ice coverage and winter operations

During the winter months, ferry routes in the CB region face distinctive geographic and climatic challenges that directly affect navigation, fuel efficiency, and emission levels. Although the ice conditions vary depending on the specific area of navigation, more is expected in coastal and island regions – the focus of the REISFER project. Figure 2 presents the average ice conditions in the Baltic Sea.

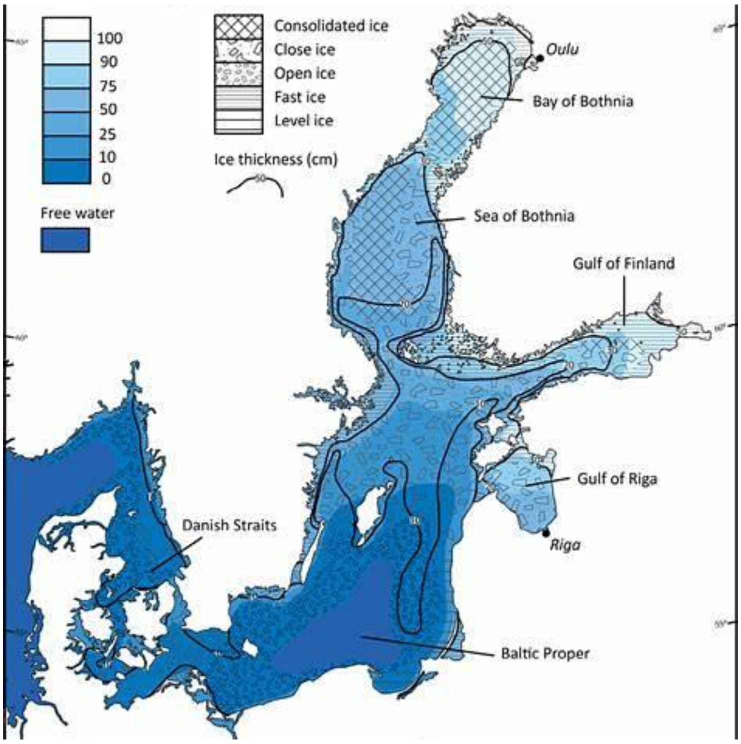

Figure 2. Average ice conditions in the Baltic Sea. Source: Lépy (2012)

In Estonia, in sheltered coastal areas, such as those serving Ruhnu, Laaksaare, or Piirissaare, relatively uniform level ice may form during calm weather. On routes crossing more open or exposed waters, such as those connecting Hiiumaa with Saaremaa or the mainland with Prangli, the formation of drift ice is more likely. Drift ice is characterized by fragmented, moving ice floes that require constant monitoring and dynamic navigation.

Ferries must be designed or retrofitted with ice-strengthened hulls and, in some cases, utilize icebreaking support when entering or departing port. The need to overcome the resistance of level ice results in higher engine loads. The unpredictable movement of drift ice forces vessels to frequently adjust their course and speed. This unstable navigation often leads to slower transit times and additional fuel usage. Both level and drift ice conditions elevate the engine power required for safe operations. The extra fuel burned to overcome ice resistance or to perform frequent course corrections results in increased CO_2 and emissions compared to operations in open water.

In Finland, the route to Suomenlinna, though relatively sheltered by the island fortress's natural harbour, still encounters level ice along port approaches that demand extra power during manoeuvring. The route between Korpoo and Houtskär is more exposed, making it susceptible to the formation of drift ice. The dynamic nature of drift ice in these waters results in unpredictable navigation conditions.

In sheltered routes, even with level ice, the requirement for additional engine output increases fuel consumption during critical phases such as departure and docking. In more exposed areas, the necessity for constant adjustments due to drift ice leads to operational inefficiencies, prolonged journey times, and higher fuel consumption. The additional energy expended in overcoming ice resistance, whether level or drift, directly contributes to increased fuel usage and higher emissions, particularly during extended periods of ice navigation.

Due to the complex network of islands, ferry operations in Åland are subject to both level ice in more sheltered passages and drift ice in exposed channels. The multiplicity of stops on routes like those of M/S Alfågeln, Viggen, and Gudingen means that vessels often operate in varying ice conditions over short distances. The need for rapid and frequent adjustments when encountering drift ice across several legs of a journey increases the strain on vessel engines. In areas where level ice forms, the predictable resistance still demands additional energy for safe navigation and docking. Frequent stop-and-go operations combined with the extra power required to break through or manoeuvre around ice (both level and drift) significantly elevate fuel consumption. Consequently, emission levels increase, especially over the course of multiple short routes where ice navigation is consistently challenging.

The Stockholm archipelago is partially sheltered, which may favour the formation of level ice in port areas and along some routes. However, routes that extend further into the archipelago, especially those serving smaller, more exposed islands, are likely to encounter drift ice. Level ice in the sheltered areas necessitates careful manoeuvring during port entry and exit, while drift ice in open areas forces vessels to reduce speed and frequently adjust their navigation. These operational adjustments often result in delayed schedules and increased transit times.

The extra engine output required to overcome both forms of ice leads to higher fuel consumption. The prolonged operation under suboptimal conditions (e.g., lower speeds and frequent course corrections) contributes to elevated emissions, particularly in routes that frequently transition between ice conditions.

For the island ferry routes across Estonia, Finland, Åland, and Sweden, winter operations are significantly affected by both level ice and drift ice conditions. These conditions require the use of ice-strengthened ferries and sometimes external icebreaker support. The additional engine power required for safe navigation under such challenging conditions leads to higher fuel consumption and, consequently, increased CO_2 and other pollutant emissions. Operators must constantly balance safety, efficiency and environmental impact, often using advanced monitoring techniques and adaptive routing strategies to mitigate these challenges during winter.

1.1.3. Wind and waves

Island ferry services operating across Estonia, Åland, Sweden, and Finland face variable wind and wave conditions throughout the year. Unlike the seasonal challenges posed by ice in winter, winds and waves are a constant factor in maritime operations. Their influence is felt both during calm summer days and under stormy conditions in winter and transitional seasons.

Winds in the CB region can range from light breezes (Beaufort 0–3) during calm summer days to strong gales (Beaufort 7–8 or higher) during storms or cold fronts in winter. High wind conditions increase vessel drift and may require constant course corrections, leading to deviations from planned routes. The Beaufort scale helps operators gauge when winds are strong enough to necessitate route adjustments.

When faced with strong crosswinds or headwinds (typically Beaufort 5 and above), vessel operators may need to alter routes to maintain stability and safety. This can result in longer travel times and increased fuel usage. High winds can affect vessel stability, particularly for smaller or older ferries. Operators may temporarily suspend services or implement reduced speed limits during severe wind events to ensure passenger safety and vessel integrity. Operating against strong winds requires additional engine power to maintain speed and course. The extra fuel burned in these conditions not only raises operational costs but also results in higher CO_2 and pollutant emissions. Frequent course corrections and the need to maintain stability against gusts lead to less efficient engine performance, further increasing fuel consumption over a voyage.

Waves in the CB region are influenced by wind strength, fetch (the distance over water that the wind blows), and seasonal weather patterns. In calmer periods (Beaufort 0–3), waves are small and manageable; however, during storm events (Beaufort 7–8 and above), larger and more powerful waves can form. Rough seas and high waves can significantly affect vessel stability, leading to uncomfortable or unsafe conditions for passengers and crew. Ferries may need to reduce speed to minimize the impact of waves, and in extreme cases, services may be delayed or cancelled. Large waves require more careful navigation. Vessels might have to alter their heading to ride the waves effectively, which can complicate manoeuvring, especially in constrained waterways or near ports.

Operating in rough seas typically leads to increased resistance against the hull. As vessels slow down or maintain higher power settings to counteract the impact of waves, fuel consumption rises. The inefficiencies introduced by continuously adjusting speeds and headings in heavy wave conditions result in higher emissions. Prolonged periods of operation in rough seas, therefore, contribute to an elevated carbon footprint.

Estonian island routes such as those connecting Ruhnu to Pärnu or Hiiumaa to Saaremaa are sensitive to wind and wave conditions. Operators monitor the Beaufort scale closely, when winds exceed moderate levels (Beaufort 4–5), increased fuel burn and emissions are noted due to required course corrections and power adjustments.

Finnish routes, whether near urban centres or serving remote islands, experience variable wind and wave conditions. Operators use the Beaufort scale to determine when conditions transition from calm (Beaufort 0–3) to rougher seas (Beaufort 5 and above), which directly correlates with increased fuel use and emissions during adverse conditions.

In the dense Åland archipelago, localized wind patterns often yield varying conditions. Sections of a route might experience mild conditions (Beaufort 2–3) while others face more challenging conditions (Beaufort 5 or above), causing fluctuations in fuel efficiency and emission levels.

In the Stockholm archipelago, sheltered routes may experience lower Beaufort scale readings, but routes to more remote islands can be exposed to stronger winds and larger waves. These conditions necessitate operational adjustments that increase fuel consumption and emissions.

Across all regions, the year-round influence of winds and waves requires that island ferry operators maintain a high degree of operational flexibility. Advanced weather forecasting and real-time monitoring systems are critical to adjust routes and speeds in response to changing conditions.

1.2. Operational conditions

This section describes how time in ports, traveling speed choices (influenced by fuel consumption and sea conditions), operation frequency, and vessel size collectively define the operational constraints of island ferry services in CB region. Each factor interacts with others, requiring operators to adopt flexible strategies to maintain efficiency, ensure safety, and mitigate environmental impacts.

Ferry operations are critically influenced by the time spent in ports. Efficient turnaround times are essential to maintain a tight schedule, especially on high-frequency routes serving both passengers and cargo. However, operational constraints such as loading and unloading procedures, customs or security checks, and passenger boarding can extend port dwell times. In regions where port infrastructure is limited or where weather conditions (like high winds or icy conditions) slow down docking procedures, ferries may experience delays. Consequently, operators must balance the need for rapid turnaround with the safety and efficiency of port operations.

The choice of traveling speed is a key operational parameter influenced by several factors. Vessels often adjust their speed based on fuel consumption considerations; operating at optimal speeds minimizes fuel burn and reduces emissions. However, environmental factors such as sea depth also play a role (as described in above chapter). In contrast, in shallower waters, increased bottom friction and the risk of encountering underwater hazards can necessitate slower speeds (as described in above chapter). Additionally, adverse weather conditions (including high winds and large waves) may force operators to reduce speed for safety, even if this results in longer transit times and higher fuel consumption per unit distance (as described in above chapter).

Number of operations per day or week is another critical value. The frequency of ferry operations is closely tied to the travel demand, both passenger numbers and cargo volumes. Routes with high demand often see multiple daily sailings to accommodate peak travel times, which requires careful scheduling and coordination. For instance, commuter routes serving urban centres may operate many trips per day and use schedules and timelines, while routes connecting remote islands might run less frequently due to lower demand and provide traveling as full loaded. High-frequency operations also place greater pressure on maintenance schedules and crew availability and may lead to increased cumulative fuel consumption and emissions if vessels are not optimized for continuous operation. In terms of the number of operations per day or week, the utilization rate factor is a critical determinant of operational efficiency. Even when vessels adhere to a strict, scheduled timeline, if they are not fully loaded, meaning that the number of passengers or cargo units is significantly lower than the vessel's capacity, the efficiency per cargo unit or passenger decreases. This underutilization leads to a scenario where fixed operational costs, including fuel consumption, crew wages, and maintenance, are spread over a smaller load. As a result, the cost and environmental impact (in terms of emissions) per unit of cargo or per passenger are higher. In essence, even with a high frequency of trips, low occupancy levels reduce overall efficiency, making it crucial to optimize the number of operations to better match demand and improve the utilization rate for both economic and environmental benefits.

Vessel size also presents operational implications. Whether small or large, it has a significant impact on operational constraints. Smaller vessels typically offer greater manoeuvrability and can access ports with limited infrastructure, making them well-suited for short, inter-island hops or routes with narrow channels. However, they may have lower fuel efficiency and reduced capacity, which limits the number of passengers or the volume of cargo they can carry per trip. Conversely, larger vessels can transport more passengers and cargo and often benefit from economies of scale regarding fuel consumption over longer distances. Yet, they are usually less agile, require deeper ports for safe docking, and may have longer turnaround times. These differences necessitate tailored scheduling and operational strategies to optimize performance, reduce fuel consumption, and minimize emissions across diverse routes.

For the CB region, under similar operating conditions, a smaller vessel consumes less energy per trip compared to larger ones due to lower displacement and reduced resistance in certain conditions. However, this can vary depending on factors such as vessel design, load factor, route characteristics, and prevailing weather conditions.

Increasing the sea time can contribute to reduced energy consumption, and thus lower emissions, in all scenarios, provided that the energy consumed by propulsion at minimum operating speed does not fall below the energy consumption for accommodation. In cases where accommodation and propulsion energy consumption are similar, the sea time should be optimized so that the energy used for both functions is balanced.

When considering ferry decarbonization, shore power connections are of significant importance. For battery or hybrid ferries with partial battery propulsion, a shore power connection (in kilowatts) is needed to fully recharge the batteries before the next trip. Ideally, this electric shore connection should be available at both ends of the route. Alternatively, increased battery capacity may allow for sufficient charging at only one port, especially in scenarios where a failure in charging at the other end is possible. An evaluation of optimal charging ratios can be conducted once the operational profile is optimized. In practice, partial charging during operation is possible, with full charging occurring during non-operational hours at night or during extended stops in the daytime.

Port stays can be arranged to provide full shore power for all types of ferries, ensuring zero emissions while in harbour.

1.3. Economic factors and demand for ferry services

The economic viability of island ferry services is shaped by a combination of factors, including the type of cargo transported, passenger demand, the capability of port and onboard infrastructure, and the availability of additional services. These elements, in turn, influence operational scheduling, vessel utilization, and ultimately, the efficiency and profitability of the ferry services.

Ferry routes in this region serve a dual role by transporting both cargo and passengers. The type of cargo varies widely across routes. For example, on Estonian routes, ferries carry essential goods such as agricultural products, consumer goods, and other supplies that support island economies. Conversely, routes serving more urban or tourist-focused regions, such as those in Sweden and the Åland Islands, often transport a mix of high-value merchandise alongside regular freight.

Passenger demand also plays a critical role. Routes that cater to daily commuters require frequent, reliable services, while tourist routes may see seasonal peaks with additional voyages to cater the demand. A high frequency of operations may be necessary to accommodate these varied needs, yet underutilization – where vessels do not reach full capacity – can lead to decreased efficiency per cargo unit or passenger. In such cases, fixed operational costs, including fuel consumption and crew wages, are distributed over a smaller number of passengers or cargo, thereby increasing the per-unit cost and environmental impact.

The efficiency and reliability of ferry services are heavily dependent on the infrastructure at both the port and onboard levels. Modern port facilities equipped with efficient loading and unloading systems, secure cargo storage, and amenities for passengers can significantly reduce turnaround times and enhance overall service reliability. For instance, well-equipped ports in Stockholm or Helsinki allow for more streamlined operations, which in turn facilitate a higher frequency of departures and quicker transits.

Onboard, the availability of advanced features such as shore power connections is crucial, particularly for battery-powered or hybrid vessels. Shore power enables ferries to recharge fully during port stays, thereby reducing reliance on fuel and cutting emissions. Furthermore, robust onboard infrastructure – ranging from comfortable seating and catering services for passengers to specialized cargo handling facilities – can generate additional revenue streams and improve the overall attractiveness of ferry travel.

Beyond transportation, additional services onboard are increasingly important in enhancing the economic model of ferry operations. Services such as onboard restaurants, cafes, retail outlets, and entertainment options not only contribute to passenger comfort but also serve as additional sources of revenue. These services make ferry travel more competitive relative to other modes of transport by improving the overall customer experience and encouraging higher occupancy rates.

Regarding market dynamics and operational integration, the overall success of inter-island ferry services in the CB region is determined by how well these economic factors are integrated into operational planning. Operators must carefully balance the frequency of departures with actual demand. Underutilized vessels, even if operating on a strict schedule, can lead to higher fuel consumption per cargo unit or passenger, thereby reducing overall efficiency. Conversely, optimizing vessel size and schedule to better match demand can lead to improved fuel efficiency and reduced emissions, as fewer trips with fuller loads are generally more economical. With island ferry traffic, where the service is operated based on a procurement contract, the voyage frequency is usually set, fare prices not dependent on demand and fuel consumption per transported unit is not calculated that strictly.

Economic considerations also extend to investments in infrastructure, both at ports and on vessels. Modernizing port facilities to support faster turnaround times and installing energy-efficient systems onboard are critical steps toward reducing operational costs and minimizing environmental impacts. Additionally, implementing operational strategies, such as energy monitoring systems that enable the tracking of fuel consumption at all times, supports making data-driven decisions and helps ferry services remain competitive while ensuring sustainable practices.

Economic factors and demand for ferry services in the CB region are multi-dimensional, involving the type of cargo and passenger demand, the quality of infrastructure, and the provision of additional services onboard.

1.4. Home port philosophy and facilities in the CB

Efficient ferry operations in the CB region require careful management of round trips and port stays, ensuring optimal fuel efficiency and minimal environmental impact. As the region transitions towards sustainable maritime practices, strategies must balance current operational needs with future emissions reduction goals.

A round trip encompasses departure from the home port, transit to the destination, docking, passenger and cargo handling, and the return journey. Each phase influences fuel consumption and operational efficiency, and with increasing pressure to decarbonize, adopting low-emission technologies has become imperative. The rapid emergence of hybrid- and full-electric ferries, and upcoming developments in hydrogen-based fuels, including green hydrogen, green methanol, and other sustainable alternatives, requires adjustments in operational planning, energy storage, and bunkering infrastructure.

Port stays duration plays a significant role in overall emissions. Extended port stays lead to increased auxiliary engine usage, contributing to emissions. To mitigate this, optimizing loading and unloading procedures, integrating shore power, implementing auto-mooring systems, and ensuring efficient scheduling are essential. Shore power, or cold ironing, allows vessels to draw electricity from the grid while docked, eliminating the need for auxiliary fuel combustion. Auto-mooring technology further reduces emissions by minimizing engine use during docking and departure, while also improving cost-effective operational efficiency.

In the CB region, ports are increasingly adopting shore power to reduce emissions. Although experiencing remarkable difficulties in islands, where energy supply and security is weaker, over 90 shore power facilities are already operational across the Baltic Sea, with major ports like Stockholm, Helsinki, and Tallinn leading efforts to standardize onshore power connections. With rapid developments also in smaller ports servicing the island ferries these initiatives significantly cut greenhouse gas emissions by reducing auxiliary engine use during port stays (PTR Inc., 2023; Seatrade Cruise News, 2023(1); Seatrade Cruise News, 2023(2)).

Charging infrastructure for electric and hybrid-electric ferries is also expanding. Sweden has introduced its largest hybrid-electric car ferry, using both overnight onshore charging and onboard diesel generators. Estonia is advancing its electric ferry operations with plans for a fully electric vessel serving Saaremaa by 2026, supported by new charging stations. Additionally, operators are integrating onboard EV charging for passenger vehicles, further supporting the shift toward sustainable maritime transport. (Danfoss, 2023; TT-Line, 2023)

The home port serves as the primary hub for maintenance, bunkering, and crew management. It must be equipped with appropriate charging and bunkering infrastructure. Similarly, full-electric ferries need high-capacity fast-charging stations to maintain operational reliability. The selection of home port is important to consider on routes with multiple stops. For that, one must consider not only operational efficiency but also environmental factors, ensuring proximity to renewable energy sources to support green bunkering initiatives.

In the CB region, ferry routes differ in their energy requirements based on distance, passenger volume, and seasonal ice conditions. Short-distance commuter ferries, such as those in Finland, are better suited to full-electric propulsion, whereas medium-range island connectors in Estonia and Åland benefit from hybrid-electric solutions.

2. Ferries and ferry routes in the CB

The ferry fleet operating within the CB region comprises of a diverse range of vessels, each designed to accommodate specific route requirements, passenger capacity, and service frequency. These ferries vary in size, layout, and functionality, reflecting the unique operational demands of island and coastal connectivity.

This chapter gives a general overview of the different types and functions of ferries and brings out the relevance of these on different routes and service areas. Additionally, the ferry operators in the CB have been brought out with stronger focus and thorough description of the vessels and routes included in the REISFER project.

2.1. Types and functions of ferries

Ferries serve as a critical mode of transportation worldwide, facilitating the movement of passengers and vehicles across waterways where fixed infrastructure, such as bridges and tunnels, is not feasible. The global ferry industry encompasses a variety of vessel types, each designed to meet specific operational needs based on geography, passenger volume, and cargo capacity. These ferries play a crucial role in urban transit systems by integrating into city transport networks, reducing congestion in dense metropolitan areas. They provide essential island connectivity, ensuring reliable transport for remote and coastal communities. Additionally, ferries contribute to international and regional transport, linking countries and major economic hubs. Beyond their functional transport role, ferries support tourism and leisure by enabling coastal and island sightseeing services, while also facilitating heavy cargo transport in regions where fixed infrastructure is unavailable, serving as a vital link in logistics operations.

Ferries in the CB region serve a wide range of transport needs, with vessel types selected based on route characteristics, passenger and cargo demands, and infrastructure availability. This project includes several ferry types, each optimized for their respective routes across Estonia, Finland, the Åland Islands, and Sweden.

Roll-on/Roll-off (Ro-Ro) and Roll-on/Roll-off Passenger (Ro-Pax) ferries are the backbone of ferry transport in the CB region, facilitating both passenger and vehicle transport, and ensuring seamless multimodal transport integration. Within the REISFER project, M/S Viggen and M/S Gudingen in the Åland Islands operate as Ro-Pax ferries, ensuring smooth connections between Långnäs, Överö, Sottunga, Husö, Kyrkogårdsö, Kökar, and Galtby. M/S Alfågeln and M/S Knipan also fit into this category, supporting both regional logistics and mobility. In Estonia, M/S Wrangö (Kelnase - Leppneeme) is another example of Ro-Pax ferry. The M/S Koidula is not classified as a Ro-Pax ferry in the traditional sense, but small Ro-Ro ferry (limited vehicle transport capability) or as passenger and vehicle ferry.

Double-ended ferries are crucial for short-distance crossings, where efficiency in docking and turnaround times is a priority. Within this project, M/S Soela (Sõru - Triigi), M/S Ormsö (Sviby - Rohuküla), and M/S Kihnu Virve (Kihnu - Munalaid - Manilaid) in Estonia exemplify this ferry type. Their symmetrical bow and stern design eliminate the need for turning manoeuvres, reducing docking times and improving operational efficiency.

High-speed catamarans and hydrofoil ferries provide fast transport solutions for passengers. M/S Runö (Ruhnu - Pärnu) in Estonia is a high-speed catamaran, specifically designed to ensure quick transit between the mainland and Ruhnu island. With speeds of up to 24.7 knots, it significantly reduces travel time while maintaining essential connections. In Sweden, the Candela electric hydrofoil ferry (not in the scope of this project) in Stockholm showcases an emerging technology for high-speed, energy-efficient transport.

Road extension ferries, which function as floating bridges, provide vital links where fixed crossings are impractical. Within this project, M/S Stella (Korpoo – Houtskär) in Finland is an example, ensuring uninterrupted transport as part of the road network.

Pontoon and passenger ferries serve short, frequent crossings, primarily catering to foot passengers and cyclists. These ferries are an integral part of public transit networks, supporting local and regional mobility. In this project, M/S Suomenlinna II (Kauppatori - Suomenlinna) in Finland, M/S Doppingen (Åva - Jurmo) in the Åland Islands, and M/S Silverö (short routes around Vaxholm) in Sweden all fit within this category, providing reliable transport for commuters and visitors.

Fast passenger ferries operate in regional transit networks, offering efficient connections across archipelagos and coastal areas. M/S Sjöbris and M/S Sjögull (Stockholm – Blidö – Rödlöga, Vaxholm – Blidösundet - Rödlöga) exemplify this category, ensuring smooth transport across the Stockholm archipelago. M/S Sunnan (Sandhamn – Norrtälje, Tappström – Klara Mälarstrand) serves as another example of a passenger ferry. Additionally, cable ferries, guided by underwater cables, could be utilised in short routes and sheltered waters, requiring minimal onboard propulsion.

Across the CB region, ferry operations are tailored to geographic and logistical needs, ensuring that vessels match the demands of their specific routes. While Ro-Ro and Ro-Pax ferries dominate high-capacity transport, double-ended ferries and high-speed catamarans provide flexible and efficient solutions for shorter and faster connections. The diverse ferry types in this project highlight the importance of optimizing vessel design, infrastructure, and operational models to enhance regional connectivity, economic resilience, and sustainable transport solutions.

The CB region operates a combination of ferry types tailored to its unique geographic and transport demands. Ro-Pax ferries dominate longer routes, ensuring both passenger and vehicle transport, while double-ended ferries and road extension ferries are prevalent on shorter, high-frequency crossings. The region also employs cable ferries in inland and sheltered waters. Unlike many global ferry networks, the CB region has a strong emphasis on year-round operation, requiring ice-class ferries to maintain services in harsh winter conditions.

2.2. Ferry operators in the Central Baltic

The operational framework of ferry services across the Central Baltic region is defined by a diverse network of routes that connect islands and mainland ports with varying distances, transit durations, and service frequencies. Each route is shaped by geographical conditions, seasonal variations, and passenger demand, influencing the scheduling, port infrastructure, and modal integration of ferry transport. The operational parameters encompass route lengths, designated ports of call, and the applied transport models, whether structured by fixed timetables or demand-responsive services. These factors collectively determine the efficiency, accessibility, and sustainability of ferry operations within the region.

Several ferry operators serve the CB region, providing essential transport links for both passengers and cargo. While not all operators are included in this project, their collective role underscores the importance of ferry traffic as a critical component of regional connectivity and economic activity. Operators vary in size and service model, with some running fixed-schedule routes while others operate demand-responsive services tailored to specific transport needs. The route length, designated ports of call, and applied transport models all contribute to the efficiency, accessibility, and sustainability of ferry services in the region.

For a more comprehensive overview of ferry traffic organization in Estonia, Finland, Åland, and Sweden, including market structures and procurement criteria, further details can be found in REISFER D1.2.1 Road and Island Ferry Traffic Governance and Markets in the Central Baltic Region.

2.3. Ferries and routes included in REISFER

2.3.1. Estonia

The Estonian State Fleet (Riigilaevastik), established 1 July 2023, is a government body tasked with managing and operating vessels for several state agencies, such as the Transport Board, Police and Border Guard, Rescue Board, Environmental Board, and AS Eesti Loots. Operating under the Ministry of the Climate, it oversees public safety, maritime security, environmental protection, and other governmental functions. The fleet was established to streamline and unify the management of watercraft across different agencies, ensuring more efficient usage and development.

According to regulations, the Estonian State Fleet handles the management of state watercraft (excluding Defence Force and Defence League vessels), navigational markings, icebreaking, and pilotage services. Since July 1, 2023, it has been responsible for providing pilotage services for vessels in Estonian ports and sea areas, while also working with the Transport Administration to ensure water traffic safety and maintain waterway infrastructure, including navigational markings and icebreaking operations.

OÜ Kihnu Veeteed, founded in 2002, provides ferry services to four small Estonian islands – Kihnu, Manilaid, Vormsi, and Piirissaar – across five different routes, and operates a route between the larger islands of Hiiumaa and Saaremaa.

As a key player in Estonia's maritime transport, Kihnu Veeteed ensures essential connectivity for island residents, supports tourism, and contributes to the economic sustainability of these communities by offering both passenger and cargo ferry services. The company operates vessels built and owned by the Estonian State Fleet under public procurement contracts. Additionally, its fleet includes the reserve ferries Amalie and Reet, which are used for backup and commercial voyages.

The routes and ferries included in REISFER from Estonia are shown in Table 1 and Figure 3.

Table 1. REISFER ferry routes, ferries and scheduling in Estonia (Authors' representation)

Route	Vessel	Operator	Crossing time	Schedule	Capacity	Annual passenger / vehicles numbers (2023)	Annual passenger / vehicles numbers (2024)
Sõru – Triigi (between the islands of Hiiumaa and Saaremaa)	M/S Soela (double-ended ferry, built 2017)	AS Kihnu Veeteed	1 hour; 9 NM	All year round (2 times per day, more often during summer)	200 passengers; up to 30 passenger vehicles	47 989 / 23 527	51 734 / 26 214
Sviby – Rohuküla (between the mainland and Vormsi island)	M/S Ormsö (double-ended ferry, built 2015)	AS Kihnu Veeteed	45 min; 6,5 NM	All year round (up to 5 times per day)	200 passengers; up to 30 passenger vehicles	74 414 / 29 145	77 537 / 31 622
Kihnu – Munalaid	M/S Kihnu Virve (double-ended ferry, built 2015)	AS Kihnu Veeteed	1h 5min; 11 NM	All year round (2-3 times per day, more often during summer)	200 passengers; up to 30 passenger vehicles	82 353 / 23 760	87 185 / 25 237
Ruhnu - Pärnu	M/S Runö (high-speed catamaran, built 2012)	Tuuleliinid OÜ	3h 10min; 55 NM	May – October (3 times per week)	60 passengers; up to 2 passenger vehicles	8 785 / 37	8 763 / 28
Kelnase – Leppneeme (between the mainland and Prangli island)	M/S Wrangö (Ro-Pax ferry, built 2013)	Spinnaker OÜ	1 hour; 9 NM	All year round (2-3 times per day; more often during summer)	65 passengers; up to 2 passenger vehicles	29 049	N/A
Laaksaare – Piirissaare (between the mainland and Piirissaare island)	M/S Koidula	AS Kihnu Veeteed	1 hour; 8NM	2-3 times per day during summer; in winter depending on ice	50 passengers, up to 5 passenger vehicles	10 630 / 1408	11 234 / 1203

Figure 3. Estonian ferry routes included in the REISFER project

2.3.2. Finland

Suomenlinnan Liikenne Oy (SLL) was established in 1950, and Suomenlinna's ferry has been running between Kauppatori and the fortress islands since 1952. SLL is a Pääkaupunkiseudu Kaupunkiliikenne Oy (Metropolitan Area Transport Ltd) owned subsidiary. It runs ferry services between the city and Suomenlinna as part of the Helsinki region's transport (HSL) organized public transport. SLL’s ferry service was connected to the ticket system of the City of Helsinki's transport department in 1971. It manages Suomenlinna’s passenger and service traffic in accordance with the traffic plan drawn up by HSL.

The Suomenlinna ferries operate all year round, during open waters as well as in ice-conditions during the winter period. They serve the residents of Suomenlinna, people that work there and thousands of tourists interested in the fortress. SLL operates five ferries serving 1,88 million trips with 28,6 million place kilometres per year. M/S Suomenlinna II, completed in 2004, is the newest entrant in Suomenlinna ferry traffic. The ferry was built at the Polish Naval Shipyard Gdynia. The tender for the construction of the ferry was won by the Danish company Johs. Gram-Hanssen Product Ltd., which built Suomenlinna II in Poland. It can carry 395 passengers and two cars or vans.

FinFerries history extends back over 200 years as part of the Finnish Road Administration. In early 1998, the national ferry unit was founded at the National Board of Public Road's production unit, which assumed responsibility for the ferry locations throughout Finland in the nine different road district areas. The era of the National Board of Public Roads came to an end in 2001 with the permanent split of production and administration into two separate organisations: Finnish Road Administration, which had the responsibility of coordination of maintenance of public roads, and Finnish Road Enterprise, later called Destia. In the beginning of 2008, it’s name was changed to Destia Ferry Services and it became a wholly state-owned limited liability company.

Thereafter, Suomen Lauttaliikenne Oy was established in 2010 as a result of the division of Destia Ltd, and it continued the ferry traffic operations, using the short name of FinFerries. In 2012 Suomen Lauttaliikenne Oy purchased the entire stock of Arctia Archipelago Shipping, and became the only organization owned by the State that is responsible for both ferry and commuter ferry traffic. Arctia Archipelago Shipping became a subsidiary of Suomen Lauttaliikenne Oy and the name was changed to Finland Archipelago Shipping Ltd.

Currently, with the commuter ferries included, FinFerries manages and operates the ferry services on over 40 routed across Finland. The maintained connections range from minor, secluded strait crossings to demanding sea passages. FinFerries’ vessels carry around 4 million vehicles and 10 million passengers each year.

The ferry M/S Stella is considered for conducting the pilot activities. The ferry was built in 2012, and measures 65m in length, 12,8m in breath and 4,5m in free height carrying approximately 65 vehicles. M/S Stella operates on the longest route operated by FinFerries, the Korpoo – Houtskär route, which is 9,5 km long.

The routes and ferries included in REISFER from Finland are brought out in Table 2 and shown on Figure 4.

Table 2. REISFER ferry routes, ferries and scheduling in Finland

Route	Vessel	Operator	Crossing time	Schedule	Capacity
Kauppatori – Suomenlinna	M/S Suomenlinna II (passenger ferry, built 2004)	Suomenlinna Liikenne Oy	15 min; ca 2 NM	All year round (in the summer season, ferry can operate up to 4 times per hour and in the winter, 1-2 times per hour)	395 passengers; 2 passenger vehicles or vans
Finnish Archipelago, Korpoo – Houtskär	M/S Stella (road extension ferry, built 2012)	FinFerries (Suomen Lauttaliikenne Oy).	30 min; 5 NM	All year round (multiple times daily, increased frequency to accommodate higher demand in summer, and less in winter)	200 passengers; up to 40 passenger vehicles

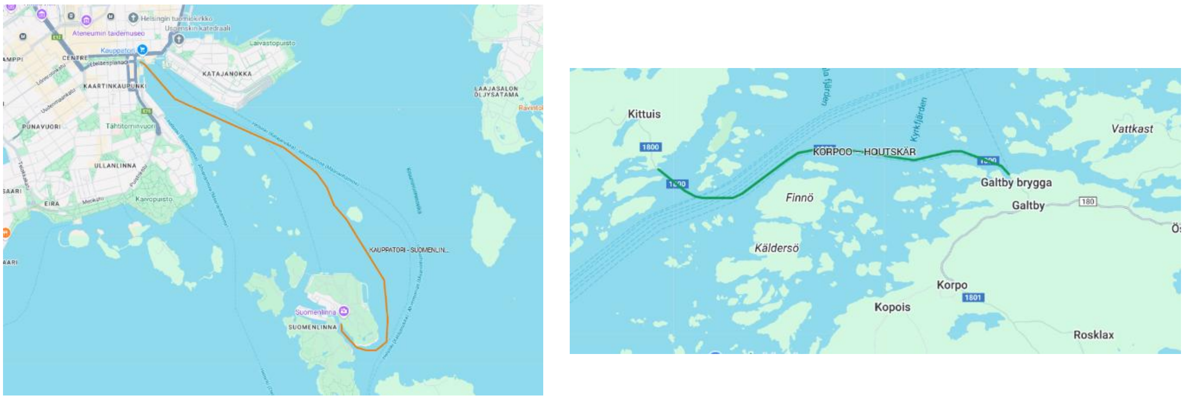

Figure 4. Kauppatori – Suomenlinna route operated by SLL, and Korpoo – Houtskär route operated by FinFerries

2.3.3. Åland Islands

The self-governing province of the Åland Islands lies off the southwest coast of Finland. Åland is an autonomous, demilitarised, Swedish-speaking region of Finland consisting of more than 6,700 islands. The current population of over 30,000 live on around 60 islands. Over 40 per cent of the inhabitants live in the only town, Mariehamn, which is one of Åland's 16 municipalities. Therefore, the ferry connections play an important role in the functioning of the region. The ferries offering the services are owned by the Government of Åland (GoA).

The Åland Islands have an extensive ferry network, ensuring connectivity between islands and to mainland Finland and Sweden. Domestic ferry routes include the Northern Line, linking Hummelvik and Osnäs with stops in Enklinge, Kumlinge, Lappo, and Torsholma, and the Southern Line, running from Långnäs to Galtby, stopping at Överö, Sottunga, Husö, Kyrkogårdsö, and Kökar. Additional cross and local routes, including cable ferries, provide vital links for residents and businesses.

International ferry connections operate between Mariehamn and Långnäs and cities like Stockholm, Turku, and Helsinki, serviced by Viking Line, Tallink Silja, Finnlines, and Eckerö Linjen. Ferry services are vital to the Åland Islands, supporting tourism, trade, and daily commuting. The extensive network ensures that even the more remote islands remain accessible, fostering economic activity and cultural exchange.

The routes and ferries included in the REISFER project are presented in Table 3 and the ferry routes of the Åland Islands on figure 5.

Table 3. REISFER ferry routes, ferries and scheduling in the Åland Islands

Route	Vessel	Operator	Crossing time	Schedule	Capacity
Hummelvik - Enklinge - Kumlinge - Lappo – Torsholma (Åland archipelago)	M/S Alfågeln (Ro-Pax, built 1990)	Government of Åland (Ansgar Ab)	several hours; 40 NM	All year round (up to 5 times per day, less often, 3 times a day, during winter)	300 passengers; up to 50 passenger vehicles and 4 trucks
Åva – Jurmo (Åland archipelago)	M/S Doppingen (Ro-Pax, built 1984)	Government of Åland (Alandia Tug Ab)	10 min; 1 NM	All year round (up to 8 times per day, less often, 4-6 times a day, during winter)	70 passengers; up to 12 passenger vehicles
Långnäs - Överö - Sottunga - Husö - Kyrkogårdsö - Kökar – Galtby (Åland archipelago)	M/S Viggen (Ro-Pax ferry, built 1998)	Government of Åland (Ansgar Ab)	5 hours; 70 NM	All year round (up to 3 times per day, less often, 1-2 times a day, during winter))	300 passengers; up to 50 passenger vehicles and 4 trucks
Långnäs - Överö - Sottunga - Husö - Kyrkogårdsö - Kökar – Galtby (Åland archipelago)	M/S Gudingen (Ro-Pax ferry, built 1980)	Government of Åland (Nordic Jetline Finland)	5 hours; 70 NM	All year round (up to 3 times per day, less often, 1-2 times a day, during winter))	250 passengers; up to 20 passenger vehicles and 4 trucks

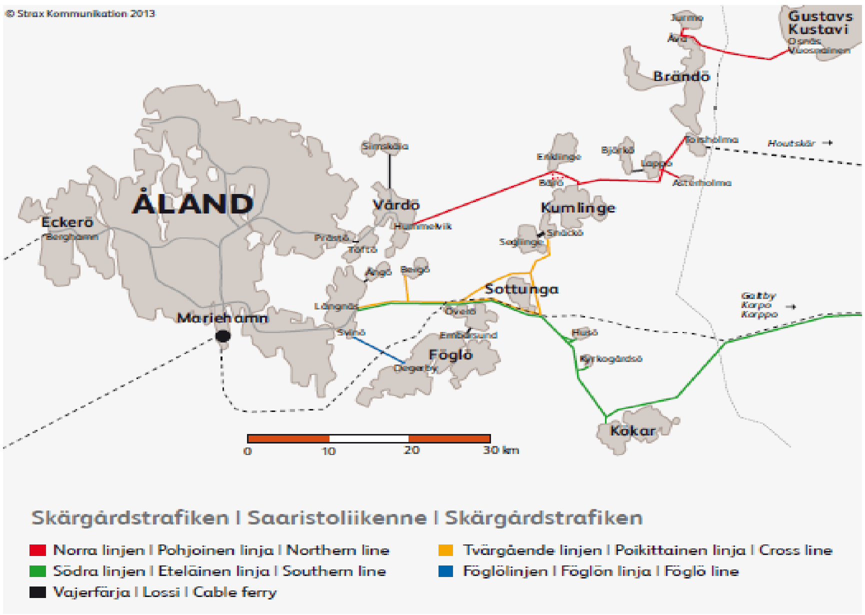

Figure 5. Ferry routes of Åland Islands

2.3.4. Sweden

Blidösundsbolaget (BBAB) is a Swedish maritime transport company that provides ferry services throughout the Stockholm archipelago, improving connectivity between the mainland and various islands such as Blidö, Yxlan, and Söderarm. The company operates a modern fleet capable of transporting both passengers and vehicles, ensuring reliable service year-round despite the archipelago's challenging conditions.

In addition to its commercial services, Blidösundsbolaget manages tasks for external ship owners, including manning and technical operations for Waxholmsbolaget, Trafikförvaltningen Region Stockholm, and SL. It operates Line 89, Ekerölinjen (Klara Mälarstrand - Tappström, Ekerö), using its own vessels on behalf of SL.

The ferries of BBAB are not fixed to a specific route and can serve different routes based on the demand. The routes and ferries included in the REISFER project are presented in Table 4 and shown on figure 6.

Table 4. REISFER ferry routes, ferries and scheduling in Sweden.

Route	Vessel	Operator	Crossing time	Schedule	Capacity	Annual passenger numbers (2023)	Annual passenger numbers (2024)
Stockholm – Blidö – Rödlöga/ Arholma	M/S Sjöbris - (passenger ship, built 1987)	BBAB	4 hours. 105 NM	All year round (once a day, less often during winter)	344 passengers	36 034	36 492
Stockholm – Vaxholm – Blidösundet - Rödlöga	M/S Sjögull (passenger ship, built 1982)	BBAB	5 hours. 105 NM	All year round (once a day, less often during winter)	340 passengers	41 964	54 758
Summer: Sandhamn – Norrtälje, Autumn/Spring: Tappström – Klara Mälarstrand	M/S Sunnan (passenger ship, built 1968)	BBAB	Sandhamn – Norrtälje 3h 35min; 89 NM. Tappström – Klara Mälarstrand 1h 55 min; 7,5 NM.	operates seasonally, 1 time per day during Summer and 3 times per day during Autumn/Spring)	198 passengers	58 475	47 470
Stockholm archipelago, short Routes around Vaxholm	M/S Silverö (passenger ship, built 1970)	BBAB	ca 10min; 0,5 NM	All year round (the number of daily trips can vary)	151 passengers;	29 425	30 852

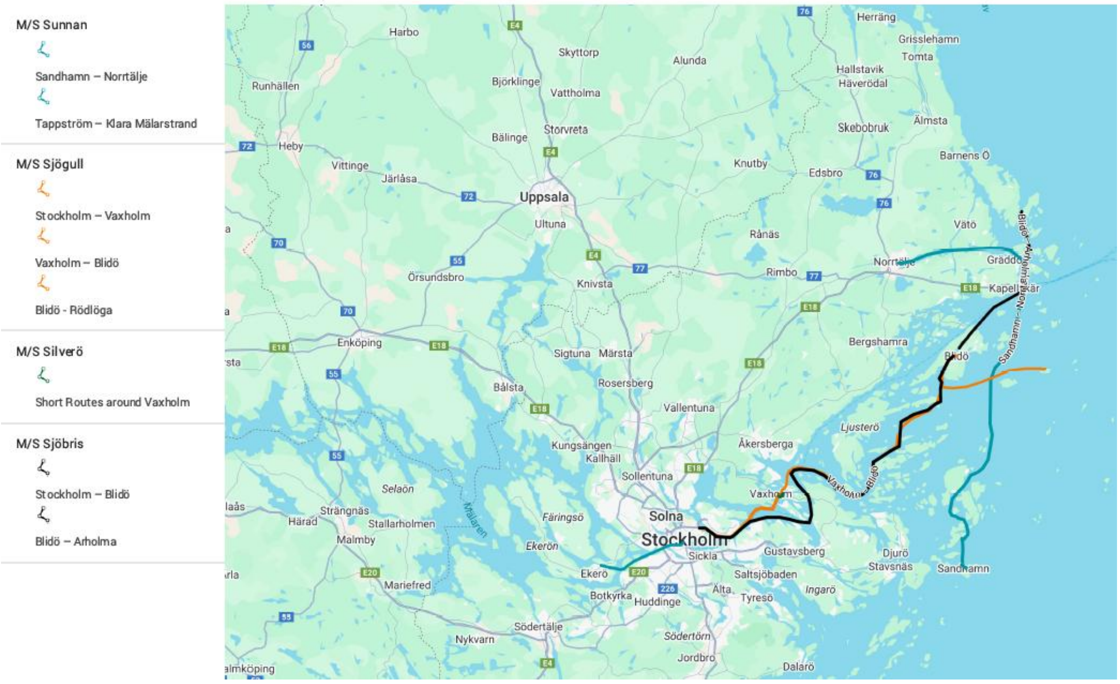

Figure 6. Ferry routes in Sweden included in REISFER.

3. Emissions from ferries

Ferry operations contribute significantly to maritime emissions, with CO_2 being the primary focus due to its role in climate change. International Maritime Organization's (IMO) Fourth Greenhouse Gas Study 2020 reported that total shipping (including international, domestic, and fishing) accounted for approximately 2.89% of global anthropogenic CO_2 emissions in 2018 (IMO, 2020). In the Baltic Sea, vessels under 5000GT, i.e. including the island ferries sector, are accountable for nearly 25% of the total CO_2 emissions (HELCOM, 2024)

Current CO_2 emissions from island ferries in the Baltic Sea highlight both the critical role of maritime transport in regional connectivity and its environmental impact. Despite advancements with hybrid and electric ferries, the transition to sustainable operations remains in its early stages. Although technical and regulatory measures have led to reductions in sulphur emissions, further action is needed to achieve EU and international carbon neutrality targets.

When planning to reduce CO_2 emissions, it is essential to consider additional pollutants, such as nitrogen oxides (NO_x), sulphur oxides (SO_x), particulate matter (PM), to avoid unintended environmental trade-offs. Even while docked, ferries continue to emit pollutants due to auxiliary power use, affecting port communities and local air quality. The CB region is actively working toward CO_2 reduction, but current operations still rely heavily on diesel, LNG, and hybrid systems, each with varying emission profiles.

Gross Tonnage (GT) is a key determinant in the applicability of international maritime emission regulations, as larger vessels generally fall under stricter regulatory frameworks. In the CB region, ferries with higher GT are more affected by global and regional regulations due to their higher fuel consumption and emissions output. While current EU ETS regulations apply to ships of 5,000 GT and above, obliging them to report CO_2 emissions and purchase carbon allowances from 2024 onward, none of the CB ferries exceed this limit. However, this threshold could be revised to include smaller vessels in the future.

Calculating emissions from fuel consumption in maritime transport, particularly for ferries operating in the Baltic Sea, involves the use of various methodologies, which can be classified into top-down and bottom-up approaches. These approaches draw on different data sources and calculation techniques to estimate the GHG emissions and other pollutants. Top-down approaches generally rely on aggregated data, such as overall fuel consumption and established emission factors. In this method, emissions are estimated using national or regional fuel consumption statistics combined with emission factors that represent the amount of emissions produced per unit of fuel consumed for different fuel types. These factors are typically derived from empirical data and provide average values for specific fuel types.

In contrast, bottom-up approaches require detailed data collection at the vessel level. This includes information on specific fuel consumption rates, engine types, operational profiles, and voyage details for individual ferries. Both approaches rely heavily on emission factors to quantify the emissions produced from fuel consumption. Moreover, the accuracy of emissions calculations depends on the reliability of the data, whether it’s aggregated from regional sources or collected from individual vessels.

4. Ferry decarbonization

In recent years, several European countries have initiated projects to decarbonize their ferry fleets, focusing on electrification, adoption of green fuels, and autonomous operations. These efforts aim to reduce greenhouse gas emissions, enhance energy efficiency, and promote sustainable maritime transport. Technological innovations, together with operational measures, collectively contribute to ferry decarbonization efforts, improving efficiency, lowering emissions, and reducing operational costs. As the regulatory landscape tightens and environmental pressures increase, integrating different solutions into existing and new ferry fleets will be essential for meeting emission reduction targets. The combination of digitalization, energy efficiency improvements, and renewable energy solutions will play a critical role in shaping the future of sustainable ferry transport.

Retrofitting existing vessels with energy-efficient technologies provides avenue for reducing fuel consumption and emissions. Hybridization and electrification enable optimized engine load and energy recovery, leading to lower overall energy demand. Onboard systems, such as LED lighting, contribute to reduced electricity consumption, while enhanced cooling and heating solution reduces the use of additional fuel. Improvements in propulsion efficiency, including advanced propeller designs, hull coatings, and air lubrication systems, lower resistance and improve fuel economy. Energy management systems further optimize onboard power distribution, ensuring that energy is used only where necessary.

This chapter gives an overview of the decarbonization methods that will be implemented within the REISFER project, as well as brings out some of the most promising initiatives from Europe suitable for the ferries fleet.

4.1. Methods implemented in REISFER

The REISFER project’s ferry decarbonization efforts are tailored to route-specific conditions, using factors such as energy availability, passenger demand, and regulatory compliance. Electrification could be prioritized for short, frequent crossings like Suomenlinna, while hybridization and efficiency improvements dominate longer, less infrastructure-ready routes. Retrofitting with energy management systems and fuel monitoring is a cost-effective approach for older vessels in Åland, as well as provide valuable data for all types of ferries. The choices for the REISFER reflect a balance between technical feasibility and regulatory alignment, ensuring practical and scalable emission reductions across the CB region.

This sub-chapter will give an overview of the different methods implemented over the course of the REISFER project.

4.1.1. Electrification

Charging infrastructure for full electrification is not widely available, making hybrid solutions more viable. Most vessels are below 5,000 GT, exempting them from EU ETS but subject to regional emissions regulations. Hybrid retrofits and fuel monitoring systems are prioritized.

Since battery and hydrogen fuel propulsion are emerging as the best solutions for sustainable ferry operations in the CB region, addressing the need for zero-emission alternatives. Despite, the region still lacks the necessary infrastructure and large-scale adoption, making their full integration a key focus for the future of maritime transport. Electric ferries produce zero emissions during operation. However, the overall environmental impact depends on the energy mix used for electricity generation. Regions utilizing renewable energy sources enhance the environmental benefits of electric ferries. Despite electric ferries being zero-emission and seemingly easier to adapt, hydrogen-powered ferries remain beneficial for the CB region due to their longer range, higher energy storage capacity, and better suitability for ice-class operations, addressing the charging limitations and range constraints of fully electric ferries while still ensuring zero emissions. Common technology is available today for vessels to operate either on full electric propulsion or using hybrid propulsion and plug-in hybrid solutions.

Two project partners will be undertaking refitting of vessels to install electric infrastructure.

BBAB, operating in the Stockholm archipelago on longer inner-city require frequent stops, making hybrid power a more viable solution than full electrification, as some ferry terminals have shore power access, supporting partial electrification. Nevertheless, a full electrification is being done on a ferry operated in a suitable route.

FinFerries operated Korpoo – Houtskär is a longer route and that makes full electrification less feasible, so energy efficiency measures and fuel optimization are prioritized. Therefore, FinFerries is implementing the battery-assisted propulsion, the so-called peak-shaving technology, with installing additional battery packs to stabilize energy use and lower emissions.

4.1.2. Technological improvements

The technical improvements towards reducing CO_2 emissions from ferries include replacing conventional lighting with LED systems to reduce auxiliary power consumption, retrofitting vessels with more efficient propellers, and testing out hull coatings to improve hydrodynamics and reduce drag. Additionally, improved cooling and heating systems are implemented on board to reduce energy consumption, while not compromising passenger comfort.

Reducing hull-water resistance by using silicone-based coatings providing a smooth, non-stick surface or bottom air lubrication by introducing a layer of microbubbles beneath the hull to reduce frictional resistance could contribute to significant savings in fuel use and, therefore, CO_2 emissions.

Waste heat recovery systems capture excess heat generated by onboard engines and convert it into usable electric power. This reduces fuel dependency and improves overall energy efficiency. Additionally, conventional heat pumps could be modified to fit the onboard conditions.

These pilot activities will be partly conducted in Sweden and partly in Estonia, by BBAB, Kihnu Veeteed and Estonian State Fleet, while experiences will be discussed and shared within the partnership.

4.1.3. Operational improvements

Operational efficiency in ferry transport is a key component of reducing emissions and optimizing costs. In the context of the CB region, operational improvements focus on improvement of fuel efficiency, rationalization vessel movements, and adopting intelligent mobility solutions. One emerging concept is the economy of scale, which involves balancing fleet composition and sailing frequency to achieve lower energy consumption per transported unit while maintaining service reliability.

Fuel monitoring and energy management systems are installed on several ferries for real-time fuel monitoring and energy-saving information to optimize energy usage and improve operational efficiency. Given the age of the fleet, example in the case of GoA ferries, monitoring-based interventions like fuel management systems provide immediate efficiency benefits and for SLL provide valuable data to improve operations in ice-conditions.

Route optimization studies include not only looking into the feasibility of alternative routes but also scheduling to enable improved adaptability to seasonal variations, as well as suitability of the ferry operating the routes.

One of the most effective methods for reducing emissions is slow steaming, where vessels operate at lower speeds to maximize energy efficiency. While speed reduction and weather routing are not considered the most suitable operational measures for ferries operating on a set schedule or in narrow channels and shallow waters, optimizing engine load is still a viable option. On operating at optimal engine loads ferries can still achieve lower fuel consumption and reduced engine wear extending its lifespan and reducing maintenance requirements.

The eco-driving trainings within the REISFER project take into account general slow-steaming principles, as well as the specific energy consumption patterns from ferries.

4.2. Cases from Europe

4.2.1. Electrification initiatives

Norway leads globally in ferry electrification and innovation. The MF Ampere, launched in 2015, was the world's first fully electric car ferry. Over a decade, it has significantly reduced emissions and operational costs, inspiring the adoption of electric ferries worldwide. The Ampere's success has led to over 70 fully or hybrid electric ferries operating in Norway, with more under construction. Norway's comprehensive maritime ecosystem, supportive policies, and public-private partnerships have been instrumental in this progress.

Launched in 2017, Elektra is Finland's first hybrid ferry, primarily powered by battery packs charged from shore during brief port stays. Diesel generators serve as a backup, especially in challenging ice conditions. The 97.92-meter-long vessel accommodates up to 90 cars and 375 passengers, significantly reducing emissions on the Parainen–Nauvo route. (FinFerries, 2023)

In 2018, FinFerries introduced Finland's first electrically powered cable ferry on the Högsar route in Nauvo. The ferry's batteries receive energy directly from the national grid via a cable, with a diesel generator onboard as a reserve power source. This initiative aims to minimize emissions and promote sustainable operations across FinFerries' network. (Nordregio, 2019)

Entering service in 2023, Altera operates alongside Elektra on the Parainen–Nauvo route. This 100-meter-long ferry utilizes two 950 kW electric motors powered by 2 x 0.6 MWh battery packs, charged directly from shore. Diesel generators are available as a backup. Altera can carry up to 90 cars and 375 passengers, further enhancing eco-friendly transport in the region. (FinFerries, 2021)

4.2.2. Green and clean fuels

Norway is at the forefront of integrating green fuels, particularly hydrogen and methanol, into its ferry operations to achieve zero-emission maritime transport.

Launched by Norled AS, the MF Hydra is the world's first liquid hydrogen-powered ferry. Delivered in 2021, this 82.4-meter vessel accommodates up to 300 passengers and 80 vehicles. It operates using two 200 kW fuel cells, significantly reducing annual carbon emissions by up to 95%. The hydrogen fuel is produced from renewable energy sources in Germany and transported to Norway. (Norled, 2023)

Scheduled for delivery in 2026, Torghatten Nord has commissioned two hydrogen-powered ferries designed to operate on the Vestfjordstrekninga route. At 117 meters in length, each ferry will have the capacity to carry 120 cars and 599 passengers. These vessels will utilize 6.4 MW fuel cells, making them the largest hydrogen-powered ships globally. They are expected to operate on green hydrogen for at least 85% of the time, reducing CO_2 emissions on the route by approximately 26,500 tons annually. (Lloyd’s register, 2024(1))

Stena Line is retrofitting two of its ferries, Stena Superfast VII and Stena Superfast VIII, to operate on methanol dual-fuel propulsion. This project builds upon the success of the Stena Germanica, which was converted to run on methanol in 2015. The retrofitting process involves modifying two of the four main engines in each vessel to run on methanol alongside marine gas oil (MGO). This initiative underscores the growing interest in methanol as a viable alternative fuel in the maritime industry. (Lloyd’s register, 2024(2))

4.2.3. Autonomous operations

Collaborating with Rolls-Royce, FinFerries successfully demonstrated the world's first fully autonomous ferry operation in 2018. The car ferry Falco utilized advanced sensors and artificial intelligence to navigate autonomously between Parainen and Nauvo, showcasing the potential for increased safety and efficiency in maritime operations. (Rolls-Royce, 2018)

In the Nordic region, autonomous ferry operations are advancing significantly, particularly in Norway and Sweden.

Launched in June 2023, MF Estelle is an emission-free, autonomous electric ferry developed by Torghatten AS in partnership with Zeabuz. The MF Estelle operates between the islands of Kungsholmen and Södermalm in central Stockholm, this vessel utilizes Zeabuz's Smart

Navigation technology to ensure efficient and secure operations. Initially, a crew member is on board for monitoring, with plans to transition to full autonomy under remote supervision. This project aims to alleviate urban traffic congestion by utilizing waterways for sustainable transport. The ferry is equipped with advanced sensors, including LiDAR, radar, and cameras, integrated with AI-assisted software for autonomous navigation. (Torghatten, 2024)

Fjord1, a Norwegian ferry operator, has contracted Norwegian Electric Systems (NES) to develop automation and autonomous navigation systems for four zero-emission ferries on the Lavik–Oppedal route. These vessels, expected to commence operations in 2026, will feature advanced functions such as automatic fjord crossing and docking, enhancing safety and efficiency. (NES, 2024)

These initiatives demonstrate the Nordic countries' commitment to pioneering autonomous and sustainable maritime transport solutions, leveraging cutting-edge technology to enhance efficiency and reduce environmental impact.

4.2.4. Operational measures and integration with multimodal transport

Enhancing the efficiency of ferry operations requires a seamless integration with other modes of transport to create an optimized mobility ecosystem (Okushima, 2018). This includes the synchronization of ferry schedules with schedules with buses or train ensuring smoother transitions for passengers, reducing idle times and congestion in port areas. Additionally, the smart ticketing systems allow passengers to seamlessly switch between different transport modes or select the right lane in port area when travelling by car, reducing boarding times, operational delays, and congestion. The Port of Tallinn with Saarte Liinid has established a Smart Port system in routes between Estonia’s biggest island and the ports serving the lines.

4.3. Other measures

The measured described in the Chapter 4 previously form a vital, yet not comprehensive set of methods in the decarbonization process. Following, additional measures and strategies are briefly described to give a more thorough understanding of the field.

Long-term public transport arrangements in island ferry services in the CB region could be the critical component of regional connectivity and public transportation. To ensure reliable, efficient, and environmentally sustainable service, public authorities and ferry operators often enter into long-term agreements – typically spanning 5 to 10 years. However, for the adoption of green and innovative technologies, these contracts may need to extend well beyond 10 years due to the significant capital investments, to allow stakeholders the financial security to carry these investment out with confidence.

The market for **green technologies and infrastructure** is expected to grow substantially over the coming decade. Transitioning to hydrogen-based fuels requires comprehensive retrofitting or rebuilding of existing powerplant systems, the construction of dedicated refuelling stations in harbours, and the establishment of a full supply chain, from green renewable electricity production (to produce green hydrogen) to storage and transportation of the fuel. Because these changes involve substantial infrastructure investments and longer payback periods, the contractual period must be extended to secure the financial and operational commitments. Besides green fuel and electricity solutions, other innovations and technologies such as rotor sails and wavefoils utilising wind for energy efficiency or solar panels and wings for auxiliary power from sun in ferry operations could be considered. The use of auto-mooring systems minimised the energy use during docking, while shore power integration (so called cold ironing) eliminates unnecessary fuel combustion in port.

To successfully implement such transformative projects, ferry operators need to **engage with technology providers** that specialize in hydrogen systems, battery storage, hybrid propulsion, and other green technologies. These partners bring critical expertise in integrating new energy systems and optimizing vessel performance under different operating conditions.

Digital solutions such as digital twins enable real-time monitoring, simulation, and optimization of ferry operations. As a step forward from energy monitoring systems, by creating a digital replica of a vessel, operators can analyse the data on fuel consumption, engine performance, and it also supports the concept of predictive maintenance. Additionally, adaptive ice navigation, utilising real-time satellite, radar, and sensor data, help minimize ice-resistance and, therefore, fuel use. AI-driven systems enable the predicting of ice conditions, to plan for smoother sailing adjusting the speed and adjusting manoeuvring. These technologies not only enhance energy efficiency and support lower emissions but also improve safety and reliability in icy conditions.

Academic involvement through cooperation with universities and research institutions plays an essential role. This kind of collaboration enables the developing and validating new operational models, optimizing fuel consumption, and reducing emissions. Collaborative research projects can also lead to the development of performance-based benchmarks and innovative solutions tailored to the CB environment. This collaboration enhances the quality of training for the workforce and ensures that best practices in green technology deployment are shared widely across the industry.

Conclusion

Current CO_2 emissions from island ferries in the Baltic Sea highlight both the critical role of maritime transport in regional connectivity and its environmental impact. Despite advancements with hybrid and electric ferries, the transition to sustainable operations remains in its early stages. Although technical and regulatory measures have led to reductions in sulphur emissions, further action is needed to achieve EU and international carbon neutrality targets.

The REISFER project seeks to deliver proven solutions for reducing CO_2 emissions in island ferry traffic, with outcomes expected to extend beyond the project's duration, creating a lasting impact and offering potential for adoption in other regions. Future developments must focus on integrating sustainable propulsion systems with upgraded port infrastructure. As regulatory frameworks tighten and carbon reduction targets become more stringent, investments in alternative energy solutions must align with long-term regional transport strategies.

The ferries included in the pilot activities of the project are not obligated by regulations to report their emissions, such as the EU ETS. However, the REISFER project aims to seek for the most suitable method for calculating emissions from island ferries and unify the methods used in the region.

Based on the overview in this report, which considered efficiency, energy consumption, and satisfactory levels of service for both passengers and cargo, it appears that the most suitable operational model in the CB involves a combination of vessels with different capacities. This mixed fleet approach allows operators to meet varying demand levels across different routes.

It is important to note that vessel optimization should be route specific. A vessel designed for longer routes with greater capacity is typically not the most efficient choice for shorter routes. In addition, the potential for cross-use of vessels is limited; a vessel cannot simultaneously serve different cross-operated routes, which implies that, for optimal performance, an even number of vessels dedicated to each route may be necessary.

Furthermore, while smaller vessels provide flexibility and generally lower per-unit energy consumption when fully utilized, they are not universally the best solution for all routes. Each route’s operational requirements, such as the nature of the cargo, passenger volumes, and specific infrastructural constraints, demand tailored vessel solutions.

In summary, integrating vessels of varying capacities into a well-planned operational strategy can lead to high overall efficiency and lower emissions. This is achieved by aligning vessel size with route-specific demand, balancing the extended loading/unloading and charging times of larger vessels against the agility and optimized utilization of smaller vessels, and ensuring that the deployment of additional vessels is carefully managed to avoid operational overlaps across routes.

While long-term decarbonization will be achieved through alternative fuels, full-electric propulsion, and hydrogen-based solutions, immediate reductions in energy consumption and emissions can be realized through operational adjustments and efficiency upgrades. A combination of optimized sailing practices, smart energy systems, and retrofitting initiatives will allow ferry operators to transition toward low-emission operations while maintaining cost-effective and reliable services.

Keeping in mind the potential of expanding the regulative obligations regarding CO_2 emissions in shipping to the island ferry segment, as well, the industry must continue developing pathways towards net-zero. The measures include further utilising exiting technologies and develop and implement emerging innovations such as remote-controlled and autonomous transit technologies, which will enhance operational efficiency, safety, and environmental sustainability. The gradual phase-out of fossil fuel dependency will require coordinated efforts across ports, vessel operators, and policymakers, ensuring a smooth transition to low-emission ferry transport in the CB region.

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