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Thesis

FERRY FLEET MODERNIZATION: A COMPARATIVE ANALYSIS OF ENVIRONMENTAL PRACTICES

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Abstract

As we transition into a more environmentally conscious era, the imperative for the maritime industry to adopt greener practices is undeniable. The ferry sector, which serves millions of passengers, should prioritize safety and efficiency and ensure that travelers can be confident that their journeys do not contribute to environmental degradation. Embracing sustainable technologies and low-emission solutions is essential for minimizing the ecological footprint of ferry transport while maintaining high standards of reliability and passenger security. This study aims to assess whether the ferry fleet has undergone modernization and to evaluate the extent to which ferry companies comply with environmental standards and policies. This thesis examines technological advancements in the sector, the implementation of sustainable practices, and the alignment of ferry operators with regulatory frameworks designed to reduce emissions and enhance environmental performance. The hypothesis is that most of the ferry fleet is aligned with international environmental standards, incorporating sustainable technologies and practices. Despite the assumption that full compliance with the ferry fleet with international environmental standards remains a challenge. Concluding that the modernization of the ferry fleet is essential for achieving a more sustainable maritime industry, significantly reducing emissions and improving operational efficiency, although challenges related to investment and regulatory support remain. The paper is separated into 6 chapters: 1) Introduction; 2) The importance of ferry fleet modernization; 3) Ferry fleet modernization in different countries; 4) Environmental Impact; 5) International Environmental Standards; 6) Concluding Remarks and recommendations.

Key words:

ferry, modernization, countries, and policy

Contents:

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Abbreviations

GHG: Greenhouse gas

PM2.5: Fine particulate matter (PM2.5)

eBC: Equivalent BC

PN: Particle number (PN) emissions

VOCs: are common groundwater contaminants, Volatile organic compounds (VOCs)

LOA: Length overall

FTA: Federal, Transport, Authority

MVA: Megavolt-Amperes

MW: Megawatt

Chapter 1: Introduction

Coastal ferry services have existed for thousands of years, dating back to ancient civilizations. The earliest forms of ferry transport can be traced to Ancient Egypt, Mesopotamia, and Greece, where small boats were used to carry people and goods across rivers and coastal areas. The Romans further developed ferry systems, building extensive networks for military and trade purposes (Nikel David, 2023).

In medieval Europe, ferry routes became essential for connecting trade hubs, and by the 19th century, the Industrial Revolution led to the introduction of steam-powered ferries, significantly improving speed and capacity. The 20th century saw the rise of diesel-powered vessels and the expansion of large-scale ferry networks, especially in island nations such as the UK, Japan, and Greece (Wikipedia).

Ferry transportation has its roots in ancient times, when it served as both a legally sanctioned public service and a practical means of traversing bodies of water. Ferries were typically created by official grants or long-standing use, and they were usually safeguarded by monopoly rights, as described in Storey's (1915) study of ancient ferry rights. The critical public need for dependable watercraft transit, particularly during times when bridges and other land routes were scarce or nonexistent, served as justification for these rights. In the past, ferries were regarded as extensions of the public highway system, and laws were in place to guarantee their functioning for public access, defense, and commerce. Tolls, or "passage," were imposed as payment for the services rendered, highlighting the crucial role ferries played in social and economic mobility. The long-standing value of ferries as a means of bringing people, products, and communities together is demonstrated by this legal and infrastructure basis. This value is still present today, especially in geographically fragmented locations like islands or coastal districts.

Today, modern ferries use advanced propulsion systems, including LNG, hybrid, and electric power, as part of a shift toward green shipping technologies aimed at reducing environmental impact.

Ferries primarily navigate marginal seas and connect islands, running on fixed schedules and often operating as shuttle services between two ports (Burke et al,2016). Well-established ferry routes continue to function in the Baltic and North Seas, the Mediterranean, and the Black Sea, as well as along the coastlines of other continents. These ferries typically accommodate both commercial vehicles and passengers traveling with their private cars, classifying them as passenger and car ferries, commonly known as Ro-Pax ferries (Kotowska,2015).

In addition to ferries that transport both passengers and cargo, many routes also operate ferries dedicated solely to freight. These vessels typically provide limited accommodation for truck drivers, restricted to 12 berths for classification purposes. If they exceeded this limit, they would be categorized as passenger vessels, requiring specific design modifications and enhanced safety equipment. Several well-established ferry routes connect the UK with mainland Europe, including short crossings over the English Channel. However, longer ferry routes to the UK also serve a practical purpose, allowing truck drivers to take extended rest breaks. Since 2000, Germany’s Flensburger Schiffbau-Gesellschaft (FSG) has specialized in ferry construction, delivering over 50 vessels and establishing itself as a global leader in this sector (Kotowska,2015).

This research aims to discuss how and if it is important for the ferry fleet modernization, though mentioning environmental practices and regulations. Chapter 1 examines the importance of ferry fleet modernization and the problems of achieving sustainable ferry fleet modernization. Through this chapter, the importance of ferries in global transport and commuting will be understood. Chapter 2 presents the literature review and provides an overview of the key perspectives and arguments that will be further analyzed throughout this study, along with the main authors whose contributions are from the theoretical foundation of the research. Chapter 3 constitutes the core section of the present dissertation. It provides an in-depth analysis of fleet modernization across various countries and examines the role of leading companies in this process. The chapter explores, in detail, the innovations implemented in each country and by each company, culminating in a comprehensive conclusion. Chapter 4 aims to enumerate the established regulations that contribute to the sustainability and modernization of fleets, as well as to outline the methods for achieving fleet modernization on a broader scale. Concluding by summarizing both the positive and negative aspects of fleet modernization, identifying which countries have successfully modernized their fleets, and ultimately assessing whether the modernization of the coastal shipping fleet is a necessary step.

1.1 The importance of ferry fleet modernization

For years, vessels were constructed to transport passengers and cargo simultaneously; however, the advent of aviation significantly transformed this practice. Subsequently, specialized ships were employed for the independent transport of individuals and goods. A limited number of combined cargo and passenger vessels continued to operate under European shipping companies during World War II, particularly for colonial services. Nevertheless, initiatives aimed at reconciling cargo and passenger transportation, as well as equipping dedicated cargo and passenger ships with appropriate cabins and lounges, ceased even before the decline of pure liner shipping in the 1960s (Kotowska, 2015; Witthohn, 2022).

1.2 The importance of ferries to the cities

Cities around the world are getting more crowded, so more public transportation is needed to ease the pressure and meet future travel needs. Many riverfront and coastal cities are turning into urban water transit as a solution. High-speed ferries that run on scheduled, linear routes with multiple stops are becoming a more popular type of public transportation (Tanko & Burke, 2016).

Linear transport ferries are a relatively recent development in urban transit, apart from exceptions like Venice. Historically, ferries primarily provided cross-river transport, for example, the Hudson River. (The Hudson River is a 315-mile (507 km) river that flows from north to south primarily through eastern New York, United States. Wikipedia). As more bridges and tunnels were built, though, many of these ferry routes went away, leaving only a few in some places. Since the 1980s, urban structures in many cities have undergone significant changes. Ports have relocated downstream, while inner-city waterfront areas have seen increased commercial, retail, and residential development. This shift has also led to a renewed interest in water-based passenger transport (Tanko & Burke,2016). Several key factors have contributed to this trend. For example, waterfront redevelopment, state-led urban renewal and tourism promotion, technological advancements, public transport demand, and traffic congestion (Wu & Xu, 2024).
With globalization and environmental sustainability gaining relevance, the sustainable development of sea transportation, which is the primary means of international trade, is especially important (Wu & Xu, 2024).

1.3 Why do we need ferries

Around 73% of ferry and Ro-Ro routes in Europe are required, with the majority serving islands without land alternatives 63% connect islands to the mainland, while 10% lack road infrastructure entirely. These routes are critical for meeting residents' transportation needs, promoting tourism, enhancing regional safety, and facilitating socioeconomic development, even if they do not directly reduce external transportation costs.
The remaining 27% are optional routes, classified as bridge, transverse, or longitudinal lines. These routes frequently compete with road transport and have varied environmental impacts. Some minimize external expenses by shortening

routes, whilst others provide minor environmental advantages while reducing traffic congestion and accidents (Kotowska,2015).

Sustainable development can be achieved through 1 Sustainable development can be achieved through green shipping technology, which encompasses inventions and practices designed to mitigate the environmental impact of maritime transportation. These technologies aim to reduce greenhouse gas (GHG) emissions, enhance fuel efficiency, and diminish pollution from vessels (Wu & Xu,2024; Witthohn,2022).

2 Maritime security relates to the methods and tactics adopted to safeguard vessels, ports, and maritime infrastructure from threats. It includes various actions designed to protect maritime assets, ensure the safety and security of trade routes, and prohibit illegal activity at sea. Dealing with marine challenges and vulnerabilities involves coordination between governments, international organizations, and maritime industry stakeholders. Maritime security encourages secure transportation, trade, and the preservation of nature in waterways worldwide (Windward;IMO).

3 "*Port sustainability is the business strategies and activities that meet the current and future needs of ports and all stakeholders, while protecting and maintaining natural resources and the welfare of humanity*" (Conreras Lisperguer, 2010). In other words, a port that has made significant efforts to minimize negative environmental externalities such as emissions and energy consumption, as well as investing in innovative technology to improve environmental performance, is on its way to becoming a green port (RedMamla;Bandara et al,2021).

In conclusion, these three themes not only expose the most recent technologies and methodologies in the field of sustainable maritime transportation but also emphasize the necessity of technological innovation and legislative changes in reaching sustainability goals in this business.

1.4 Where are ferries also important?

Ferries are an essential element of transportation infrastructure in numerous areas. Ferries provide substantial environmental benefits, particularly with new technological advances. Traditional ferries frequently run on marine diesel, contributing significantly to air and water pollution. Electric and autonomous ferries, such as those created by the Norwegian business Zeabuz, have zero emissions and highlight the sector's ability to shift to sustainable transportation. The introduction of electrified maritime transportation assists global efforts to minimize carbon emissions following environmental laws such as MARPOL Annex VI (IMO).

Furthermore, ferries are affordable and scalable. They use existing waterways, eliminating the need for additional infrastructure like highways, tunnels, and bridges. According to Carl Petersson, Autonomy Engineer at Zeabuz, ferry systems are "*a very cost-effective way*" for communities to satisfy both transportation and sustainability objectives (Tanko & Burke, 2016).

Ferries also play an important role in connecting remote and island communities. In many parts of the world, ferries are the primary or only link between remote areas and mainland services such as healthcare, education, and markets. Their operation ensures connectivity and supports local economies by facilitating both passenger and freight movement (Kotowska, 2015). The global relevance of ferries is highlighted by their passenger volume. Every year, ferries transport nearly as many passengers as airlines, demonstrating their extensive reliance and importance in national and international transportation systems. To summarize, ferries are more than just an alternate mode of transportation; they are an essential component of accessible, sustainable, and efficient transportation. With improvements in electric and autonomous ferry technology, their importance will only grow in the global push for greener cities and better public transportation networks (Wu & Xu, 2024).

Table 1. Positive aspects of ferries

Category	**Positive aspects of Ferries**
Sustainable urban mobility	Helps relieve congestion in crowded cities
Environmental Sustainability	Reduce maritime emissions and align with global frameworks
Territorial Cohesion and Accessibility	Links remote areas and islands to the mainland
Economic and Regional Development	Boost local economies and support tourism
Maritime and strategic security	Provide strategic redundancy in transport networks, aiding in emergency logistics, disaster resilience, and reinforcing national maritime infrastructure

Table 1 Author

Table 2. The Economic Impact of the Global Ferry Industry in 2019

The Global Ferry Fleet in Numbers	15,400 vessels 31 million gross tons
Transported Traffic Volumes in 2019	4.27 billion passengers 373 million vehicles (cars, buses, trailers)
GDP Contribution (2019)	$60 billion total contribution - $17 billion direct - $25 billion supply chain - $18 billion worker spending
Employment Contribution (2019)	1.1 million jobs globally - 218,000 direct

	- 460,000 supply chain - 422,000 workers are spending
Comparison Note	Airlines carried 4.5 billion passengers in 2019 (ATAG report)

Table 2. The Economic Impact of the Global Ferry Industry in 2019.

Chapter 2 Literature Review

Methodologically, the present dissertation adopts a qualitative research approach. Data were collected from a variety of secondary sources to draw well-founded personal conclusions regarding the ferry industry. The main keywords used during the material collection process were “ferry transport” and “innovations.” The primary sources of information included ScienceDirect and Google, which were used to identify relevant and up-to-date articles and news on this continuously evolving topic.

It is important to note that the availability of scientific literature on the subject was relatively limited. Earlier academic contributions on ferry transport appear to be scarce, which significantly constrained the breadth of the research. As a result, the comparative analysis over different periods was not feasible due to the lack of sufficient historical data from peer-reviewed sources.

The present dissertation is theoretical. All numerical data, statistics, and comparative insights presented, although they may resemble a quantitative research approach, are in fact derived exclusively from secondary sources. Consequently, the conclusions drawn are based on the critical analysis and synthesis of existing material, rather than on any form of primary data collection. The only exception to this is where personal commentary or reflection is explicitly provided.

Given the limited number of academic sources dedicated to ferry fleet modernization, this field presents a valuable opportunity for researchers to invest in further study and critically engage with the unique characteristics of this specific maritime sector.
As already mentioned in the main text, ferry transportation has its roots in antiquity. Significant academic contributions on the subject can be found across various scholarly platforms. This research began by searching for academic texts and peer-reviewed articles through ScienceDirect, using the keywords “ferry fleet” and “ferry fleet modernization.” Afterward, it searched on Google Scholar, Academia.edu, and all the recent articles. The official IMO (International Maritime Organization) website, as well as daily news outlets. These sources played a central role in supporting the analysis and enriching the academic foundation of the study.

2.1 Historical Data

To be exact, Historical data was retrieved by David Nikel, who provided historical context and modernization efforts of Norway's ferry services, and his article was published in Forbes magazine. M. Tanko & M.I. Burke explored transport innovations and their worldwide impact on urban ferry systems. This article was found on Academia.edu. Furthermore, Izabela Kotowska discussed the role of ferry and Ro-Ro shipping in sustainable transport development on Research Gate. Ralf Witthohn analyzed the role of sea transport in the global economy, focusing on ferry traffic on Science Direct. Lastly, Xianhua Wu, Jian Wu, and Lang Xu conducted advanced research on sustainable maritime transportation on Science Direct as well.

2.2 Case Studies for each country

Country-specific data were gathered in Norway, covered by Niels Anner and others, analyzing emission reduction strategies on the Siemens Website. France Brittany Ferries’ fleet upgrades to hybrid battery vessels are featured in multiple sources, including Cruise Mapper and the company’s official sustainability reports on the

Cruise Mapper website. Also, in Greece, the ONEX–Attica Group collaboration is reported in Ekathimerini and Ship & Offshore, detailing a €1 billion modernization plan. USA: The Federal Transit Administration's $300M grant for green ferry upgrades is highlighted in AASTHTO and WSDOT publications. China and Russia's electric ferry deployment and low-emission vessels have been documented in Plug boats and Baird Maritime.

2.3 Technological Innovation and Electrification

Modernization strategies center around the adoption of hybrid-electric propulsion systems, as shown in the work of Annie Kortsari et al. (2022), who compared the performance of electric and diesel vessels in Denmark's E-Ferry project. David Cord (2024) discusses the Finnish innovations contributing to greener maritime solutions, while TELE2 (2024) presents the world's first autonomous electric passenger ferry, incorporating 5G and IoT technologies. The importance of electrification is also addressed by Siemens in its analysis of Europe's transition towards battery-powered fleets.

2.4 Environmental Sustainability and Policy Compliance

Sustainability-oriented articles from DNV, IMO, and the European Union's Fit for 55 framework provide foundational regulatory insights, outlining emissions standards and compliance mechanisms for maritime operators. Izabela Kotowska (2015) frames ferry operations within broader sustainability goals in her work on Ro-Ro and ferry shipping. Further, Ralf Witthohn (2022) explores the macroeconomic role of ferry transport in the global economy in International Shipping (Springer).

2.5 Safety, Risk, and Challenges

Concerns about safety and resilience are raised in the RAND Corporation's work by Greenberg et al. (2006) regarding terrorism threats to passenger ferries. The

SuperFerry 14 bombing is discussed as a case study on the vulnerability of maritime infrastructure. Technological, regulatory, and environmental obstacles to modernization, such as underwater radiated noise and hazardous airborne emissions, are explored by multiple authors, including Vakili, White, and Turnock (2023–2025).

The outcomes of this study highlight the critical need for coordinated action: a joint effort by governments, ferry operators, shipyards, and regulatory organizations. A well-supported modernization process not only improves environmental performance and energy efficiency, but it also promotes economic growth, regional connectivity, and social cohesion.

Finally, ferry fleet modernization should be considered a strategic priority in global maritime policy. By investing in green technologies and complying with international standards, the sector may position itself as a significant driver of long-term transportation sustainability.

2.6 Limitations

Like any research project, this study also had its limitations. One of the main challenges was the limited availability of primary data, such as interviews or first-hand operational information from ferry companies. As a result, the analysis had to rely mainly on secondary sources like academic papers, news reports, and official announcements. Another limitation was the scarcity of academic literature that deals specifically with ferry fleet modernization, especially in countries where maritime transport is prominent but under-researched. Also, because each country follows different reporting practices, it was sometimes difficult to make direct comparisons between them. Lastly, while the study aimed to give a global overview, it did not go deep into local realities like port conditions, crew training, or regional funding mechanisms.

2.7 Research Questions

1. To what extent has the ferry fleet been modernized?

2. How do different ferry operators implement modernization strategies to reduce environmental impact?

2.8 Aim

This paper aims to explore the effectiveness of various strategies that ferry operators adopt to reduce emissions, improve energy efficiency, and comply with global environmental regulations. Additionally, through a literature review, it conducts a comparative analysis of environmental practices within ferry fleets.

2.9 Hypothesis

Modernizing ferry fleets through sustainable environmental practices is likely to reveal differences in policy implementation, technological innovation, and public acceptance across different regions, emphasizing the importance of socio-political, economic, and geographic factors in shaping effective green maritime legislation.

2.10 Suggestions for Future Research

There is room for future research to take this topic further. For example, more in-depth case studies could focus on how individual countries or companies approach modernization, what they do not, and why. It would also be helpful to include quantitative data collected through surveys or interviews with industry professionals, shipbuilders, or port authorities. Another interesting direction would be to examine how digital technologies (like automation or real-time emissions tracking) are affecting ferry operations. Also, future studies could look more closely at the human side of modernization, how it affects workers, passengers, and island communities. And finally, as regulations and technology continue to evolve, tracking these changes over time could offer valuable insight into long-term trends and impacts.

Chapter 3 Ferry Fleet Modernization Across Countries

A vital component of international trade and transportation, the marine sector facilitates the movement of people and goods across the world's waterways. Ferry services are essential in this industry for tying communities together, especially in areas with intricate coastlines and archipelagic topography. Modernizing the ferry fleet is becoming more necessary as environmental concerns grow and regulatory frameworks tighten. In section 1 of this chapter, European countries (Norway, France, Greece, Denmark, Germany), in section 2, the United Kingdom, the USA, and Washington, and in section 3, Russia and China.

Section 1, 3.1.1 European Countries

The modernization of ferry fleets throughout the European Union (EU) is a key element of the maritime sector's transition to sustainability, driven by a need to reduce greenhouse gas emissions, improve energy efficiency, and adhere to tight environmental regulations. Europe is a highly ferry-intensive region, comprising two primary markets: Northern Europe and the Baltic, as well as the Mediterranean; EU ferries represent 35% of the global fleet.

3.1.2 Norway

Norway has an extensive and well-developed ferry network, essential for connecting its coastal communities, islands, and fjord regions. The Norwegian ferry system includes both state-subsidized public routes and privately operated services. Major ferry companies include Hurtigruten, which operates coastal voyages from Bergen to Kirkenes, and Fjord1, Norled, and Boreal, which manage many domestic routes.

Norway is generally regarded as a global leader in the decarbonization of maritime transportation. The Norwegian government has adopted strong environmental restrictions, demanding that all new public ferry contracts prefer low- or zero-emission vessels (Norway’s Climate Action Plan Annual Report, 2021)

The world's first all-electric ferry, Ampere, was introduced in Norway in 2015, marking a major shift towards sustainable maritime transport. Today, many routes are operated by battery-powered ferries, aligning with the country's commitment to green energy.

Norway, Europe's largest ferry nation, is already seeing the benefits of replacing its outdated diesel fleet with electric and hybrid ferries (Wikipedia).

In Europe, there is enormous potential for the use of electric and hybrid ferries, with investments in shore power, hybridization, and completely electric ferries for certain routes, reducing carbon dioxide (CO2) emissions by 800,000 tons (Anner Niels, 2022).

Battery-Powered Double-Ended Ferry GLOPPEFJORD

On November 30, 2017, Turkey's Tersan Shipyard in Altinova/Yalova handed over one of the first battery-powered vessels to the Norwegian shipping company Fjord1. The 106 m length and 16.8 m breadth hybrid ferries are equipped with the Siemens BlueDrive PlusC system of 2 × 520 kWh output. The electrical energy drives two azimuth propellers from Rolls-Royce; Royce gives the ship speed of 13.5 knots. The batteries are recharged after each crossing on the 2.4 km long route by an automated system of the German company Stemmann. At 590 V/1650 A, it has a power of 1.5 MVA. The ferries can carry 349 passengers, 120 cars, and 12 trailers. Their mooring is done automatically by a vacuum system, and the navigation of the ferries is automated. The optimal crossing speed is based on wind and current conditions and the loading state of the ship.

In February 2024, Türkiye’s Tersan Shipyard continues its collaboration with Norwegian ferry operator Fjord1 AS, having secured a shipbuilding order for four battery-powered autonomous double-ended ferries, which are claimed to be the first of their kind in the world. These zero-emission ferries are set to begin operations between Lavik and Oppedal in Norway on September 1, 2026. According to Fjord1, the vessels will feature autonomous navigation and extensive automation of onboard functions, reducing the need for manual operations. The integration of automation functions and autonomous systems, such as auto crossing and autodocking, is scheduled for 2027, while full autonomous navigation is expected to be implemented by 2028.

In 2023, Zeabuz and Norwegian operator Torghatten will open the MF Estelle in Stockholm, Sweden. The ferry is remarkable for being the world's first driverless, electric passenger ferry powered by 5G and Internet of Things (IoT) technology. The MF Estelle, designed primarily for short urban excursions, represents a new paradigm in aquatic transportation. The ferry presently functions between Kungsholmen and Södermalm in Stockholm, with a duration of merely 7 minutes, significantly swifter than terrestrial options (Tele2 IoT., n.d.)

Norway leads in this initiative, having replaced a significant portion of its aging diesel fleet with over 70 electric and hybrid ferries, with more under construction. The success of Norway's electrification efforts serves as a model for other European nations. Bjørn Einar Brath describes how Norway's industrial fundamentals make it an ideal climate for decarbonizing shipping. However, progress surged only once the government prioritized sector change and mandated corporations to achieve climate goals. Government funding provides essential investments in ferry modernization and decarbonization, allowing shipyards and suppliers to produce a lot of local know-how and jobs. For operators, the shift means more energy-efficient vessel designs and a significant reduction in fuel use. Factors that help both decarbonization goals and local economies are, of course, highly valued in other nations (Siemens Energy, n.d.).

3.1.3 France

France boasts a comprehensive and efficient ferry network that connects its mainland to neighboring countries. Due mainly to regulatory pressure and the business goals of major marine operators, France's ferry fleet is modernizing gradually. Businesses like Brittany Ferries have been at the forefront of alternative fuel investments, particularly with the launch of hybrid-electric and LNG-powered ships, and various islands, facilitating both passenger and freight transportation.

France's Brittany Ferries is also contributing to fleet modernization with the introduction of the Guillaume de Normandie, a ferry equipped with multi-fuel engines and a 12 MWh battery-hybrid system, the largest of its kind globally (Brittany Ferries, n.d.).

The 195-meter-long (LOA) vessel is the fifth E-Flexer unit delivered to French operator Brittany Ferries as part of a long-term charter deal with STENA. Guillaume de Normandie is expected to start operation on the Portsmouth–Caen (UK–France) route in April 2025. It will take the place of the MS Normandie, which has been operating the route since 1992. With an 8 MW output, the shore connection guarantees a completely fossil-free presence in port and enables high-speed battery charging. The ship can reach up to 18 knots (32 kph/20 mph) on battery power alone thanks to its modular propulsion system, which can also support future improvements for full battery operation or combined fuel consumption. The Guillaume de Normandie has a certified capacity of 2410 lane meters (wheeled cargo), including 176 lane meters for private vehicles, and can accommodate 1310 passengers. With a larger size and more flexible configurations than conventional RoPax ships, its design embodies the E-Flexer series' renowned flexibility. This vessel is part of Brittany Ferries' fleet renovation initiative, which began with MS Galicia in 2020 and will continue with Salamanca (2021), Santona (2022), and Saint-Malo in 2024. Stena RoRo has delivered all five ships as part of the series ' 15 confirmed orders from CMI Jinling, Weihai. Twelve of these vessels have already been completed, with three more on the way, and two new Max RoRo vessels are currently on order (Cruise Mapper, 2024).

In 2012, STX France in Lorient, part of Korea's STX Group, collaborated with Stirling Design International (SDI) to develop the first fully electric port ferry. Named AR VAG TREDAN (meaning "electric ship" in Breton), this 100% electric catamaran was constructed entirely from aluminum by STX. Measuring 22.10 meters in length and 7.20 meters in width, it can accommodate over 100 passengers and bicycles while reaching a maximum speed of 10 knots.

The vessel was designed with innovative "overcapacity" technology, enabling it to operate regular crossings between Lorient and Locmiquélic with zero CO_2 emissions and in complete silence. Thanks to STX's advanced electric propulsion system, AR VAG TREDAN can complete crossings independently and recharge in just four minutes, the duration of a stop.

Classified by Bureau Veritas as a "Green Ship," this ferry represents a major step forward in sustainable maritime transport (Almet Marine, n.d.).

3.1.4 Greece

The Greek ferry system is one of the world's most extensive and critical, linking the mainland to hundreds of islands in the Aegean and Ionian Seas. It is vital to transportation, tourism, and the local economy. The fleet includes a variety of vessels, including high-speed catamarans, traditional ferries, and smaller local boats. Major ports such as Piraeus, Rafina, and Thessaloniki serve as centers for both local and international travel.

In recent years, modernization initiatives have been centered on increasing efficiency, lowering emissions, and introducing hybrid or LNG-powered vessels. However, obstacles such as aging ships, high fuel prices, and seasonal demand swings persist. Despite this, Greek ferries continue to provide vital services to people, businesses, and millions of tourists every year (Αθανασίου, 2024).

Greek ferry operator Attica Group has entered a Memorandum of Cooperation (MoC) with ONEX Group, a New York-based company, for the €1 billion modernization of its 45-vessel ferry fleet. ONEX manages two Greek shipyards: Elefsis Shipyard, situated on the mainland near Perama, and Neorion Shipyards on the island of Syros. Elefsis Shipyard is currently undergoing restoration to resume full operations, focusing on shipbuilding and repairs, while Neorion Shipyards is one of Greece's most prominent ship repair facilities. The fleet modernization initiative is expected to span a decade and covers 45 ferries operated by Attica's subsidiaries, including Superfast Ferries, Blue Star Ferries, Hellenic Seaways, ANEK Lines, and Africa Morocco Link. The fleet serves 52 destinations and connects 67 ports both within Greece and on international routes, consisting of Ro-Pax and high-speed ferries. Blue Star Ferries, Hellenic Seaways, and ANEK Lines primarily operate on domestic routes to destinations such as the Cyclades, Northeast Aegean, Saronic Gulf, Sporades, and Crete. Superfast Ferries and ANEK run international services linking Greece (Patras, Igoumenitsa, Corfu) with Italy (Ancona, Bari, Venice). Meanwhile, Africa Morocco Link facilitates crossings between Algeciras (Spain) and Tanger Med (Morocco) via the Strait of Gibraltar.Under the newly signed MoC, ONEX's shipyards will take full responsibility for the maintenance and repair of Attica's fleet, as well as any additional vessels acquired or managed during the ten-year modernization program (EKathimerini, 2023).

When the overland routes between Central and Southeastern Europe were disrupted by the Yugoslav Wars starting in 1991, Greece's Attica Group, owned by the Panagopoulos family, commissioned the Schichau Seebeckwerft shipyard in Bremerhaven to design a fast Ro-Pax vessel capable of completing the Adriatic route between Greece and Italy within a single day.

Attica's fleet expansion strategy was driven by the success of the fast ferry concept on the Adriatic route. This approach, initially developed out of necessity, was later envisioned for broader application on ferry routes in the North Sea and Baltic Sea, including the Rostock-Helsinki connection.

Saronic Ferries aims to operate a 100% electric fleet by 2040, replacing all existing vessels with zero-emission ships over the next two decades. Collaborations with organizations such as DNV are underway to create fully electric ferries for short-sea trips in the Argosaronikos area, with the first scheduled to be operational in 2026.

Blue Star Ferries and Superfast Ferries have both received ISO 14001 Environmental Management System accreditation and are active members of HELMEPA, demonstrating their dedication to environmental conservation. They have implemented initiatives such as increasing engine performance to reduce fuel consumption and emissions, lowering solid waste through plastic usage, and building oil separation equipment to prevent sea contamination. And the Environmental Management System of Minoan Lines, which has earned ISO 14001:2004 certification, complies with international standards like MARPOL and follows procedures including routine environmental controls and waste sorting for appropriate disposal (Ship & Offshore, 2024).

3.1.5 Denmark

Denmark serves as the principal ferry nexus for travelers connecting mainland Europe, Norway, and Sweden (FerryGogo, n.d.).

Ellen is the world's first fully electric ferry, developed as part of the Horizon 2020 Project E-Ferry. Since August 2019, it has been operating between the Danish ports of Fynshav, on the island of Als, and Søby, on the island of Ærø.

Designed to carry around 30 vehicles and 200 passengers, Ellen is powered by the world's largest battery for a ferry. This advanced battery system enables it to cover longer distances than any existing electric ferry, reaching up to 21.4 nautical miles (nearly 38 km) before requiring a recharge. A total of €21.3 million was allocated for the ferry's development under the EU Horizon 2020 program, of which €15 million came from EU money. It was built in Poland by Spawrem and put into service by Søby Shipyard, fostering innovation and jobs in the area. The project's objectives were to evaluate the economic and environmental viability of electric ferry transportation in addition to proving its technological viability. Significant environmental advantages of the EF Ellen include the removal of local pollution, a 2,000-ton yearly decrease in CO_2 emissions, and around 50% energy savings as compared to traditional diesel ferries. It also saves around a quarter of the journey time. All things considered, EF Ellen establishes a standard for sustainable marine solutions of the future and provides insightful information for the deployment of zero-emission ships in comparable island and coastal communities around Europe (CINEA, n.d.).

To sum up, the E-ferry has a five to eight-year payback period because of its much lower operating energy expenses, despite its higher starting costs. Infrastructure for charging and battery systems is the primary cost factor. When compared to diesel vessels, the potential annual CO_2 cost savings can reach about 500,000€, indicating significant environmental benefits. It is anticipated that electric ferries will become more economically and environmentally feasible as battery prices drop and support incentives rise (Kortsari et al., 2022).

3.1.6 Finland

With more than 180,000 islands and a strongly indented coastline, Finland is a nation that depends significantly on ferries for both domestic and international trade. For island communities, ferries act as lifelines, providing access to logistics, tourism, and necessary services (Tarkowski, 2021).

The world's largest passenger ro-ro vessels, COLOR MAGIC and COLOR FANTASY, maintained a daily connection between Oslo and Kiel, until in March 2020 the COVID-19 pandemic stopped, as most other passenger ferries, the ships, which resumed service in February 2022 after another suspension in December 2021 (Ralf Witthohn)

Ro-Pax Ferries

A Ro-Pax ferry is a vessel that blends the characteristics of a cruise ship, including night cabins, with the functionality of a roll-on/roll-off (RoRo) ferry. These ferries, known as Ro-Pax due to their combined Ro-Ro and passenger design, are conventional ferries featuring a spacious garage capacity and relatively high passenger accommodation. They typically operate with conventional diesel propulsion and can reach speeds exceeding 25 knots (46 km/h; 29 mph). While cabins, when available, are generally smaller than those on cruise ships, the hull of a Ro-Pax ferry is divided into multiple (10+) watertight compartments, secured by automatic watertight doors. At sea, the bow visor and ramp are locked in place using hydraulically operated cleats, with watertight seals created through the compression of heavy rubber gaskets. The ship's watertight integrity is continuously monitored from the Bridge (GRS Shipbrokers, n.d.).

World's Largest Combined Passenger and Car Ferries on the Finland Route

M/S Finnsirius is Finnlines' largest Ro-Pax. She is a stunning hybrid vessel, outfitted with cutting-edge technology to reduce emissions. The vessel blends climate-friendly operations with a sophisticated interior design, a wide range of services, and efficient cargo handling.

In April 2021, Helsinki-based Finnlines announced the initiation of the first of three 5800 lane meter hybrid Ro-Pax vessels, designated FINNECO I, FINNECO II, and FINNECO III, at China's Nanjing Jinling shipyard. The EUR 500 million new building work will begin in late 2021. In February 2022, the series had not yet been commissioned. The ro-pax vessels FINNSIRIUS and FINNCANOPUS will operate on the Finland-Sweden route commencing in 2023.

The sun deck below the bridge serves as a landing pad for helicopters weighing up to 8.6 tons, including Super Puma. All public places are monitored with video cameras.

The ships adhere to the SOLAS requirements of the "Consolidated Edition 2001". Sufficient rescue equipment is required for 540 individuals (500 passengers and 40 crew members). There are 300 available seats in the partially closed lifeboats, with two on each side and a capacity of 150 people (Finlines Plc, 2023).

Finland aims to lead the Baltic Sea region in clean maritime transport, with a broader goal of becoming carbon-neutral by 2035.

The goal is to eliminate CO_2 emissions. This is possible with fully electric vessels, provided that their batteries are charged by renewable energy sources such as wind, solar, or hydroelectric power. Wärtsilä has previously supplied electric propulsion systems for numerous all-electric ships and is currently designing a 130-meter high-speed ferry to connect Argentina and Uruguay. Once completed, it will be the world's largest electric vessel, powered by a 40-megawatt battery system.

Alternative approaches to zero-emission shipping include the use of biofuels and synthetic fuels. According to Büssow, a sustainable marine future would most likely rely on a mix of fuels and technologies rather than a single universal solution. However, given the severity of the climate catastrophe, there is little time to respond (Cord, 2024).

3.1.7 United Kingdom

The UK ferry network is a vital part of the country’s transport infrastructure, connecting the UK to neighboring countries and islands. Major operators include P&O Ferries, Stena Line, DFDS Seaways, and Brittany Ferries, offering routes to France, Ireland, Belgium, and the Netherlands.

In the United Kingdom, companies like Stena Line are modernizing their fleets by introducing larger vessels that offer increased passenger and cargo capacities. (“ *Stena (UK) Limited and its subsidiaries are part of the Stena AB Group and have been present in the UK since the mid-60s. Through organic growth and acquisitions, the*

group has expanded its business activities in the UK substantially throughout the years, especially in the areas of Ferry Operation, Offshore Drilling, and Shipping. ")
Stena Line's E-Flexer vessels are designed and manufactured in partnership with its sister firm Stena Ro-Ro. Among their features are efficient loading and unloading with drive-through lanes on two levels. Because of the optimal design of the hulls, propellers, bulbs, and rudders, the new vessels can be up to 30% more energy efficient than the old fleet. All five vessels are delivered gas-ready, allowing for conversion to methanol or LNG fuel (Blenkey,2020).

Caledonian MacBrayne is the largest ferry operator in the UK. ("*Caledonian MacBrayne started life in 1851 as a steamer company under the name of David Hutcheson & Co. The main sphere of operation was from Glasgow through the Crinan Canal to Oban and Fort William and then on through the Caledonian Canal to Inverness*"). Their environmental goals for the period 2024-27 are significant (Dalton,2025). As for fleet modernization, their goal is to efficiently sail schedules, enabling vessels to operate at optimal fuel consumption for most of their service tenure. Ports and vessels will collaborate to minimize departure delays, reducing the need to boost speed to make up time. Over the following three years, they will assist and facilitate the launch of six new, upgraded big vessels. Selective catalytic reducers, which lower nitrogen oxides discharged into the atmosphere, are used in the construction of four of them. Two more ships are LNG/MGO dual fuels. They want to launch these dual fuel ships at a time when, in their opinion, LNG was one of the most environmentally friendly ways to power the shipping sector. They will do this and anticipate a 25% reduction in CO_2 emissions as compared to ships that use comparable MGO fuel (CALMAC,2024).

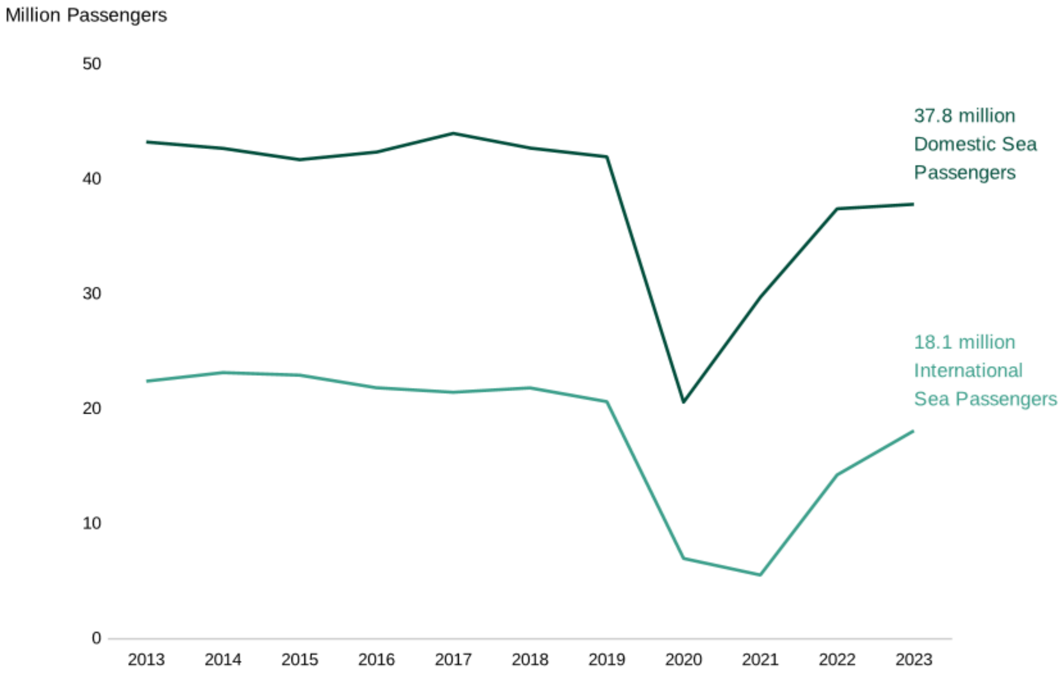

Table 3 UK domestic and international sea passengers, 2013 to 2023

Section 2

3.2.1 USA

The United States is actively modernizing its ferry fleet to enhance efficiency, reduce emissions, and improve service reliability. This initiative is supported by significant federal investments and state-level projects focusing on the adoption of advanced technologies.

Ferries play an important role in the United States by facilitating daily commuting, tourism, and access to key services for coastal and island communities. Ferry ridership has consistently increased, with a large percentage of trips used for commuting. However, their environmental impact is increasingly being studied, as maritime transport accounts for a significant share of global GHG emissions. As a result, there is a rising drive for sustainable ferry procedures, backed by legislative efforts and public money.

The Federal Transit Administration has allocated nearly $300 million in grants to support 18 ferry projects across 14 states. These projects focus on replacing outdated vessels, expanding ferry fleets, and constructing new terminals and docked technologies, as well as sustainable practices. The Federal Transit Administration (FTA) has allocated nearly $300 million in grants to 18 ferry projects across 14 states. Eight of these projects will receive funding specifically for environmentally friendly propulsion technologies, such as electric-powered ferries and recharging equipment. The funding is distributed through three competitive FTA grant programs: Ferry Service for Rural Communities Program: Allocates $194 million to four projects in two states. Passenger Ferry Grant Program: Provides $56.3 million to eight projects in seven states, focusing on new ferry services and the modernization of existing vessels, terminals, and facilities in urban areas. Electric or Low-Emitting Ferry Program: Grants $9 million to six projects in five states to acquire electric or low-emission ferries that reduce environmental impact. Several state transportation agencies are benefiting from these grants: Alaska Department of Transportation: Receives $106.4 million to build a diesel-electric ferry, replace a 60-year-old vessel, improve wireless connectivity, and upgrade the Alaska Marine Highway System. Massachusetts Bay Transportation Authority & City of Quincy: Awarded $4.2 million to modernize the Squantum Point Park Ferry Pier with a new pier, float, and ramp system. Maine Department of Transportation: Granted $16.5 million to upgrade rural ferry terminals in Lincolnville and Islesboro, originally built in 1959. These investments aim to enhance ferry services, promote sustainability, and improve connectivity for both urban and rural communities (AASHTO Journal, 2024).

3.2.2 Washington

Washington State operates the largest ferry system in the U.S. and is actively working to modernize its fleet after facing challenges due to aging vessels. The state has launched a national bidding process to construct five new hybrid-electric ferries, which are expected to improve service reliability and reduce emissions. Shipbuilders have been invited to submit qualifications, with contracts anticipated to be awarded later this year. The first two vessels are expected in 2028, followed by two more in 2029, and the final one in 2030.

The shift to hybrid-electric ferries is a key part of Washington's plan to cut emissions and ensure long-term financial sustainability. The new vessels will save around 240 million gallons of diesel over their 60-year lifespan, reducing annual emissions from 180,000 metric tons to 45,000 metric tons. The transition aligns with state policies, including an executive order from 2018 requiring the ferry fleet to move toward zero emissions (Jazlan et al,2025).
Washington's System Electrification Plan, published in 2020, outlines the goal of building 16 new hybrid-electric ferries and converting six diesel vessels by 2040. The total cost for fleet electrification is estimated at $4 billion, with $1.68 billion already secured through state programs like the Climate Commitment Act and Move Ahead Washington. The ferries, designed for Puget Sound routes, will accommodate 160 vehicles and 1,500 passengers. Shipyards must undergo a strict pre-qualification process before biding, and selected contractors will have one year for final planning and two years for construction. While some suggest that building diesel-only ferries would be faster, officials argue that the hybrid-electric plan is the most efficient path forward, as it already has legislative approval, funding, and designs in place. Switching back to diesel ferries would delay new vessel deployment until at least 2030 and fail to meet emissions reduction requirements (Pelley,2024).

Section 3

3.3.1 Russia

Russia's ferry network includes both internal and international lines, allowing passengers and freight to travel across multiple regions. The implementation of sustainable ferry technology in Russia is still in its nascent phase.

One significant innovation is when the first LNG bunkering was done on October 15 at the Ust-Luga harbor aboard Russia's dual-fuel ferry General Chernyakhovsky. It then traveled to Kaliningrad, carrying automotive equipment. The ferry employs LNG and low-sulfur diesel, decreasing CO_2 emissions by 20-30%, nitrogen oxides by over 90%, and eliminating sulfur oxides and soot from traditional heavy fuel use.

The ferry, which has been operating on the Ust-Luga-Kaliningrad route since October 2022, plays a critical role in a strategically significant line. A comparable vessel, the Marshal Rokossovsky, has been in service since March 2022. Both were constructed by Nevsky Shipyard (Russia) in conjunction with Turkey's Kuzey Star Shipyard. They have Arc4 ice class, ballast water treatment systems, and satisfy current environmental regulations (Habibic,2022).

Three new electric monohull commuter boats, Sinichka, Filka, and Presnya, have began operation on the Moskva River in Moscow, marking the city's first river transport service in 16 years. These vessels, built by the Russian shipyard Emperium and operated by Moscow Deptrans, are the first in a planned 20-boat fleet aimed at promoting sustainable urban transport. Each 21-meter ferry has a modular aluminium hull, can accommodate 80 passengers (42 seated), and includes Wi-Fi, USB charging, bathrooms, bike/scooter storage, and a smoker-friendly upper deck. The modular design enables disassembly for rail shipment and reassembly in seven days. The ferries, powered by 500 kWh lithium iron phosphate batteries and two 134kW motors, can reach speeds of up to 11.8 knots and have a range of 150 kilometers. The direct-drive propulsion system with twin pulling screws increases energy economy and mobility. They are ice-capable and can operate all year in mild winter conditions.

Batteries are meant to last 10-12 years and have built-in safety features (Baird Maritime, 2023).

Despite geopolitical tensions, nautical newspapers continue to cover these developments because of their importance in vessel design and urban movement. It seems that progress in ferry transport continues at a very slow pace, in contrast with the rapid development of ferry transport in European countries and the United States.

3.3.2 China

China's ferry fleet modernization is impressive. China officially complies with IMO regulations and participates actively in the organization. In many cases, especially in coastal urban areas, it enforces even stricter domestic measures (e.g., ECA zones *China established coastal emission control areas (ECA) that capped the sulfur content of marine fuels. The three ECAs are the Pearl River Delta, the Yangtze River Delta and Bohai Bay*). to reduce maritime emissions (NorthStandard,2020).

Junlyu, China's first entirely electric ferry, debuted in November 2019 and is presently running on the Yangtze River in Wuhan, a city of 11 million people that has recently seen protests over air pollution. Junlyu, a 53-meter-long, 13-meter-wide vessel capable of carrying up to 300 passengers, was built by the Wuhan Institute of Marine Electric Propulsion, a part of China State Shipbuilding Corporation (CSSC), the world's largest shipbuilder. The ferry has a top speed of 19 km/h (10 knots) and can operate for up to 8 hours at speeds below 13 km/h (7 knots). Although technical details like as motor size are unknown, the vessel incorporates modern Chinese-developed technologies, such as high-efficiency, variable-frequency drive systems. The institute is also China's exclusive provider of hydrogen and electric power systems for shipbuilding (Butler,2019).

Yaguang Technology is the supplier of the Shanghai Passenger Ferry Company's all-electric Ro-Pax ferry, the Xin Shengtai. It will connect Changxing and Hengsha islands in Shanghai's Chongming District, helping the local government achieve its objective of shifting to low-emission public transportation within five years. The steel-hulled ferry, measuring 65 meters long and 14.5 meters broad, can transport both passengers and big vehicles such as buses and lorries. Its most notable feature is the employment of two supercapacitor systems (625 kWh total), making it one of the first Ro-Pax ferries powered solely by supercapacitors. When compared to lithium-ion batteries, they charge faster, last longer, and operate quietly and cleanly. The ferry has a power output of 2,000 kW and can reach speeds of up to 12 knots while charging at a 2.5 MW DC shore power plant. Overload and short circuit warnings are included, and the ferry is designed to run securely in winds up to Beaufort force 8. Xin Shengtai is scheduled to commence service at the end of the year.

Hong Kong's ferry network connects the city to Macau and mainland China. To modernize services, operators such as Sun Ferry Services Company Limited have deployed hybrid electric ferries such as the Xin Ming Zhu VI—for routes across Victoria Harbour and to outlying islands, thereby increasing sustainability and commuter experience (Baird Maritime,2021).

China is in a strong position to lead the world in green ferry technology and sustainable marine operations if this trend keeps up.

3.4.1 Remarks

Considering the data, it is evident that all nations are actively pursuing a transition toward a more sustainable and environmentally conscious era, notwithstanding prevailing economic and geopolitical challenges.

The table below presents all the data collected to draw conclusions and address the central question of whether the modernization of the ferry fleet is a feasible objective.

Table 4 Comparison Table of Green Ferry Innovations

Innovations / Practises	Norway	France	Greece	Denmark	Finland	United Kingdom	USA	Russia	China
Fully Electric	✓			✓			✓	✓	✓
Hydrid-Electric	✓				✓	✓	✓		✓
LNG/MGO			✓	✓		✓	✓	✓	✓
Alternative Fuels	✓		✓	✓		✓	✓	✓	✓
CO_2 emissions reduction	✓	✓	✓	✓	✓	✓	✓	✓	✓
NOx/SOx reduction		✓	✓			✓	✓	✓	✓
Zero-emission target 2040			✓	✓	✓	✓	✓		✓
Public or EU finding	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 4 Comparison Table of Green Ferry Innovations (Summary)

The global shift to sustainable ferry transportation is gaining traction, with countries implementing a variety of techniques based on technological capabilities, geographical demands, and policy frameworks. Northern European countries like as Denmark, Finland, and the United Kingdom are at the forefront, pioneering electric and hybrid ferry systems that are supported by robust public funding and environmental regulations. Denmark's Ellen and Finland's Finnsirius demonstrate significant advances in battery storage and hybrid propulsion, resulting in significant reductions in pollution.

In the United States, federal investment is important for modernizing ferry fleets, with States like Washington are spearheading large-scale hybrid-electric conversion initiatives. The long-term financial and environmental benefits of electrification are clear, particularly when matched with broader state and national climate objectives. Russia is making slower progress, focusing on dual-fuel LNG vessels and urban electric ferries, reflecting its cautious but evolving approach to marine sustainability. China, on the other hand, exhibits rapid innovation by installing a variety of electric and supercapacitor-powered ferries for both urban and regional routes, frequently exceeding international standards due to stringent domestic rules.

While development varies by location, the worldwide trend is clear: ferry operators and governments are rapidly realizing that investment in green maritime technologies not only decreases environmental impact but also improves long-term economic viability. As battery costs decrease and regulatory pressure builds, sustainable ferries are poised to become a worldwide norm rather than a localized exception.

It is evident that, based on the articles and the innovations presented, definitive conclusions cannot be drawn regarding each country individually, as only the positive aspects and selected technological advancements have been highlighted. However, the only conclusion that can be made with certainty is that each country is actively striving towards the best possible outcome in the modernization of its ferry fleet.

Chapter 4 The Environmental Impact

In addition to the advantages of modernizing the ferry fleet, it is essential to acknowledge that, as in all sectors, significant challenges exist. These challenges should by no means be overlooked. Therefore, this chapter examines current global obstacles to illustrate that while the full modernization of ferry fleets is an admirable objective, it is not always entirely feasible.

Modernizing ferry fleets is essential for ensuring efficient, reliable, and environmentally sustainable maritime transportation. However, several challenges can impede this process. Ferries play a vital role in fostering community relationships and bolstering local economies, but they also pose several serious risks, especially when it comes to security. According to Greenberg (2006), "*ferries are considered high-risk targets for maritime terrorism due to their open access, fixed schedules, and ability to carry large numbers of passengers*". Particularly in contrast to the aviation industry, ferry terminals have very loose security measures, which makes it possible for possible attacks to slip unnoticed. The risk is further increased by structural weaknesses, such as the open decks of roll-on/roll-off vessels, which are prone to damage or capsize quickly. Furthermore, the risk of insider assaults is increased by inadequate personnel screening. A successful attack might have disastrous effects on both the number of people killed and the economy, as was the case with the Superferry 14 bombing. (*With 116 fatalities, the February 27, 2004, bombing of the MV Superferry 14 continues to be the deadliest maritime terrorist assault in Philippine history. A 3.6 kg TNT bomb hidden in a television set was planted by the Islamist terrorist group Abu Sayyaf Group and detonated soon after the ferry left Manila Bay on its way to Cagayan de Oro. This sad tragedy highlighted the critical need for improved safety measures in ferry operations by exposing serious marine security flaws, such as insufficient screening processes and subpar surveillance systems*) (Wikipedia,n.d.), and other similar occurrences. The possibility of psychological trauma and a consequent drop in public trust could result in fewer passengers and long-term harm to ferry operators' reputations. The flammability of materials used in high-speed ferries and the inherent problems in policing open maritime environments exacerbate these issues, making complete risk mitigation both essential and challenging (Greenberg et al,2006).

4.1 Aging Infrastructure

Older vessels may require considerable maintenance, resulting in higher operational expenses and service delays. For example, Scotland's eight largest publicly owned ferries have spent nearly £100 million on repairs over the last decade, with the MV Caledonian Isles alone costing more than £22 million. This issue has sparked criticism for relying on antiquated vessels and highlights the urgent need for fleet renewal (McKie,2025).

Financial difficulties for operators arise from the high costs of building new, eco-friendly ships (Athens Bureau, 2023). In Greece, 86% of coastal ships are more than 20 years old, with an average age of 28 years. According to the Hellenic Chamber of Shipping, €11 billion would be needed to replace the fleet entirely with zero-carbon vessels. The timely upgrading of fleets is impeded by this significant financial load (OT Editors, 2022).

Aging fleets struggle to comply with growing environmental standards aimed at decreasing greenhouse gas emissions. Without fleet renewal, complying with measures such as the European Union's "Fit for 55" package, which aims to reduce net greenhouse gas emissions by at least 55% by 2030, becomes difficult. This scenario may result in higher operating expenses due to carbon trading schemes and other regulatory actions.

4.2 Financial Constrains

Ferguson Marine, a Scottish shipyard, recently lost a vital contract to build a fleet of Caledonian MacBrayne (CalMac) ferries to its Polish competitor Remontowa. This loss calls into question the yard's viability and illustrates the competitive and financial challenges that fleet modernization projects face (Walker,2025).

In New Zealand, the government's handling of the Interislander ferry replacement project has been criticized for substantial cost overruns, which have risen from an initial NZ$775 million to a possible NZ$4 billion. This case demonstrates the financial inefficiencies and bureaucratic delays that can impede fleet modernization attempts (DrHartwich,2024).

4.3 Environmental regulations

Environmental regulations present significant challenges to ferry fleet modernization, impacting operational costs, technological adaptation, and compliance strategies.

The European Union's Fuel EU Maritime rule, which takes effect on January 1, 2025, requires emission reductions for commercial ships with a gross tonnage of more than 5,000 operating in EU ports. Compliance necessitates the use of alternative fuels such as biodiesel and liquefied natural gas (LNG), both of which are currently in short supply and would raise operational costs. These costs tend to be passed on to consumers through higher freight charges. Furthermore, the International Maritime Organization's MARPOL Annex VI prohibits sulfur oxide emissions, mandating the installation of scrubbers or the use of low-sulfur fuels, which increase operational expenses.

4.4 Technological Adaptation

Companies like Havila Voyages and Hurtigruten have invested in battery power and hybrid electric systems to align with these goals, but widespread adoption remains constrained by technological readiness. For example, Norway's mandate for zero-emission cruise ships in the World Heritage fjords by 2026 was pushed back to 2032 due to technological constraints (Towey,2024).

4.5 Compliance Strategies

Strategic planning is required when adapting to environmental rules. For example, the Greek coastal shipping industry faces the combined task of rebuilding an aged fleet while also satisfying new environmental standards for zero carbon emissions (OTEditors, 2022).

To overcome these obstacles, governments, stakeholders, and ferry operators must work together to invest in new technology, obtain financing, and create infrastructure that supports sustainable ferry operations.

4.6 Underwater Radiated Noise

Underwater Radiated Noise (URN) from vessels considerably affects marine habitats, requiring mitigation to foster sustainable shipping practices. Underwater radiated noise is recognized as a serious form of pollution due to its influence on marine life, disrupting key functions such as communication. The International Chamber of Maritime (ICS) and BIMCO created the Underwater Radiated Noise Guide to help maritime firms lower noise levels throughout their fleets (ICS & BIMCO, 2024).

Anthropogenic underwater noise varies by place and with time, influenced by human activities and local acoustics. Among the different causes, industrial activity and shipping contribute significantly to the rise in underwater noise levels. This increase in noise pollution raises questions about the unique impact of commercial vessels on the ocean's acoustic environment, their participation in regional noise variations, and their long-term ecological implications on marine life. Low-frequency ambient noise levels have been studied in numerous parts of the world. For example, research reveals that ambient noise increased steadily until 2019, then fell sharply in 2020 owing to the COVID-19 epidemic and has gradually increased since then. The Baltic Sea, with its shallow waters and high shipping traffic, has the highest sound energy density among Europe's seas.

The COVID-19 epidemic provided information about the potential effects of less human activity on ocean ambient noise levels. The decline in shipping activity resulted in a considerable fall in worldwide shipping noise source energy within the 63 Hz one-third octave range, bringing noise levels back to those seen in 2017. Notably, these reductions were unevenly distributed, with considerable local declines occurring in locations where transit links, such as ferries, were shut down during the pandemic, as well as along major shipping routes between China and the EU (IMO, 2023).

Operational measures such as speed decrease, sometimes known as slow steaming, have been efficient in lowering fuel usage and URN. A 10% drop in vessel speed can result in about a 2 dB decrease in URN levels. However, it is crucial to note that for vessels equipped with adjustable pitch propellers, speed reduction may not always result in a lower URN, stressing the importance of personalized approaches based on vessel specifications (Vakili et al.,2023).

While the connection of EE measures with URN reduction looks positive, some obstacles remain. For example, increasing the blade size of propellers to reduce cavitation noise will decrease propeller efficiency. Furthermore, some emissions-reducing technology, such as exhaust scrubbers, may accidentally increase industrial noise. As a result, a full assessment of each measure's influence on both EE and URN is critical (Vakili et al., 2025).

Addressing the interconnected difficulties of decarbonization and URN reduction would necessitate coordination among ship designers, operators, policymakers, and technology vendors. To address URN, the International Maritime Organization (IMO) has issued guidelines concentrating on techniques such as routing adjustments, operational changes, and improvements in ship design and maintenance. Aligning these efforts with the IMO's GHG reduction goal may result in more sustainable and ecologically friendly shipping practices (IMO,2023).

Finally, combining energy efficiency measures with undersea radiated noise abatement offers a potential path toward sustainable maritime operations. By taking a comprehensive strategy and encouraging industry collaboration, considerable reductions in both GHG emissions and URN can be achieved, benefiting marine ecosystem health and the overall sustainability of global shipping (Vakili et al., 2025).

4.7 Case study of hazardous airborne substances on passenger ships

The ferry is an environmentally friendly choice. The carbon footprint for a foot passenger on a ferry is only 19 grams per km. The ferry service in Rio de Janeiro, Brazil, is one of the busiest in the world, but it has a significant disadvantage: high emissions of hazardous compounds from diesel combustion. Researchers examined air pollutants such as fine particulate matter (PM2.5), black carbon (eBC), particle number (PN), and volatile organic compounds (VOCs) aboard double-decker ferries.

The results revealed that pollution levels were greater on the lower deck due to smoke infiltration while docked and leaks around door frames during navigation. Boarding and alighting were the most polluted phases, with significantly higher levels of eBC, PM2.5, and PN than during sailing, as engines worked harder to keep ships in position. However, the TVOCs remained stable. Naturally ventilated boats had 2.5 to 3.5 times higher particulate levels than air-conditioned ones, while TVOCs were 150 times higher on the latter, most likely due to emissions from furniture and cleaning agents. Onboard, pollution measurements frequently exceeded those on the roadside. Upgrades or retrofits to ferries, as well as the use of jet bridges, may assist in reducing harmful emissions and commuter exposure (Nogueira,2020).

While modernizing ferry fleets is critical for encouraging safer, greener, and more efficient maritime transportation, the change is far from simple. Aging vessels, high replacement costs, severe environmental rules, and technology limits all provide substantial challenges, especially in regions with older fleets such as Greece and Scotland. Furthermore, financial inefficiencies and bureaucratic delays, as observed in

New Zealand, impede modernization initiatives. Environmental rules, such as the EU's FuelEU Maritime and the IMO's MARPOL Annex VI, while vital, raise operational costs and need advanced solutions that are not yet widely available. Challenges also exist in the marine environment, with underwater radiated noise (URN) emerging as a major worry for ecosystem health. Similarly, Brazilian studies demonstrate that airborne contaminants aboard ferries can reach urban roadside levels, stressing the need for extensive onboard modifications. Finally, ferry fleet upgrading must be done holistically, weighing environmental goals against economic realities. Cooperation between governments, shipbuilders, and operators is critical for driving innovation, securing finance, and implementing sustainable practices. Though complete modernization may not always be attainable, incremental improvement linked with global environmental goals is both possible and required for a sustainable maritime future (Vard Marine Inc.,2023).

Table 5 Challenges in Ferry Fleet Modernization – Mapped to Case Studies

Negatives / Challenges	Study
Aging Infrastructure	- Scotland *(Eight publicly owned ferries spent~£100 million on repairs in a decade)* - Greece *(86% of coastal ships are older than 20 years)*
High Cost of Fleet Replacement	-Greece *(€11 billion needed to fully replace fleet with zero-carbon vessels)* -New Zealand *(Interisland ferry project rose from NZ$775 million to potentially NZ$4 billion)*
Financial Constraints	-Scotland *(Ferguson Marine lost a ferry contract to Polish shipyard Remontowa)* -New Zealand *(Cost overruns and public criticism in ferry replacement project.)*
Underwater Radiated Noise (URN)	- Global *(IMO and BIMCO guidelines issued to reduce URN_)* - Baltic Sea (Highest *sound energy density due to shallow water and heavy traffic.)* - COVID-19 (*Shipping noise dropped in 2020, showing human impact on marine acoustics.)*
Hazardous Airborne Substances on Ferries	- Brazil *(Rio de Janeiro ferry study found high levels of PM2.5, black carbon, VOCs, and Onboarding/alighting phases showed the highest pollutant concentrations.)*
Technological Adaptation Challenges	- Norway *(Zero-emission cruise ship mandate in fjords postponed from 2026 to 2032 due to technology readiness.)* - Havila & Hurtigruten *(Invested in*

	battery/hybrid systems, but widespread use is limited.)
Environmental Regulations Increasing Costs	- EU *(FuelEU Maritime requires the use of alternative fuels, which are scarce and expensive.)* - Global *(MARPOL Annex VI forces use of scrubbers or low-sulfur fuel, increasing expenses.)*

Table 5 Summary

Based on the case studies and research presented above, we can clearly understand the difficulties that the ferry industry faces in fully modernizing. There is a multitude of challenges; however, they can be addressed through proper planning by each country or individual company. They serve as a forceful reminder that achieving sustainability requires long-term commitment, ambitious regulatory frameworks, and concerted action from governments, industry stakeholders, and innovators.

Chapter 5 International Environmental Standards

This chapter will briefly present the key laws, standards, and environmental regulations relevant to maritime transport. It is well known that all international organizations maintain high standards and enforce strict regulations. This section is particularly important for understanding why the modernization of the ferry fleet is necessary and why the oversight of the following international organizations is essential. Although comprehensive data on ferry transport was limited, the information presented herein reflects the most reliable and representative findings currently available (Norton Rose Fulbright, 2025).

The ferry industry, as part of the broader maritime sector, is experiencing major regulatory shifts focused on improving environmental sustainability. These reforms are led by international and regional authorities striving to lower greenhouse gas (GHG) emissions and encourage cleaner shipping practices (The Guardian, 2024).

The ferry sector, like the shipping industry in general, is strictly regulated in terms of safety, environmental impact, and security. The International Maritime Organization (IMO) is a United Nations entity in charge of drafting worldwide maritime standards. Ships that only operate within the borders of one country are subject to that country's regulations. However, several countries base their own legislation on IMO guidelines. Some countries fully implement the IMO guidelines for their local ships. Shipping regulations often address vessel design, construction, repair, operations, staffing, training, environmental effects, security, and frequent inspections during the vessel's life. Stability, hulls, propulsion and other machinery, electrical systems, lifesaving appliances and arrangements, fire prevention and firefighting systems, navigation systems, and communications systems are all subject to inspection (Norton Rose Fulbright, 2025).

5.1 IMO

The International Maritime Organization (IMO) is a specialized agency of the United Nations responsible for regulating the safety, security, and environmental performance of international shipping, including ferries. The IMO establishes global standards to ensure safe and environmentally sustainable ferry operations, covering aspects such as emissions reductions, safety regulations, and fuel efficiency.

Passenger ships must meet IMO safety and pollution prevention criteria. The SOLAS treaty applies to vessels carrying more than 12 people on international routes, while the IMO also promotes safety improvements for non-SOLAS ships through model regulations and recommendations.

In July 2023, the International Maritime Organization (IMO) adopted a revised greenhouse gas (GHG) strategy, setting ambitious targets for the shipping industry. This strategy aims for net-zero GHG emissions by 2050, with interim checkpoints in 2030 and 2040. A key component is the introduction of a global carbon levy, scheduled for implementation in 2025, as part of amendments to the MARPOL convention. This levy is designed to incentivize emission reductions across the global fleet. Additionally, the IMO mandates the use of shore power in ports, particularly within the European Union, by 2030 to minimize emissions from ships while docked (IMO,2023).

5.2 The European Union's "Fit for 55" package

To help the EU reach climate neutrality by 2050, the "Fit for 55" package of legislative proposals aims to cut greenhouse gas (GHG) emissions by 55% by 2030 (relative to 1990 levels) (European Commission, 2024). By enacting more stringent environmental laws, this package has a substantial impact on the maritime industry, which includes ferries.

The European Union has introduced the "Fit for 55 in 2030" package, targeting a minimum 55% reduction in GHG emissions by 2030 compared to 1990 levels. This comprehensive package includes specific measures for maritime transport, such as binding emissions reduction targets for ships exceeding 5,000 gross tons. These vessels are required to decrease their GHG emissions by 2% by 2025, 20% by 2035, and 80% by 2050, relative to 2020 levels. The package also proposes a phased inclusion of maritime emissions into the EU Emissions Trading System (ETS) between 2024 and 2026, compelling ship operators to acquire and surrender emission allowances corresponding to their emissions (O'Melveny, 2023)

5.3 Norway's Zero-Emission Mandate for Ferries

Norway is a global leader in green maritime transportation, with a strong focus on zero-emission ferries. The Norwegian government has introduced regulations to significantly reduce emissions from the ferry sector, aiming for a fully electric and climate-neutral fleet.

All ferries and cruise ships using Norway's UNESCO World Heritage fjords are required by law to become emission-free by 2032. This rule, which was originally scheduled for 2026 but was prolonged because of technology limitations, demonstrates Norway's dedication to protecting its natural heritage and encouraging environmentally friendly nautical operations. To meet these strict environmental regulations, ferry operators are investing in green technologies, such as battery-electric and hybrid propulsion systems (Towey, 2024).

5.4 Industry-Led Sustainability Efforts for Ferries

Ferry operators and shipbuilders are taking major steps toward sustainability, complementing government regulations with innovative technologies and green initiatives. These efforts focus on reducing emissions, increasing energy efficiency, and adopting alternative fuels to create a more sustainable ferry industry.

Through voluntary initiatives, the ferry sector is actively seeking sustainability outside of legal structures. The San Francisco Bay Ferry, for example, has made a commitment to the Green Marine program and is carrying out thorough evaluations of its environmental policies. This program tackles several environmental issues, including waste management, ship recycling, and greenhouse gas emissions. Transparency and ongoing environmental performance improvement are promoted by the participants' biannual independent evaluations, the results of which are published annually (Kosmajac, 2024).

The convergence of international regulations, regional policies, and proactive industry initiatives signifies a transformative period for the ferry sector. The collective efforts aim to decarbonize maritime transport, enhance environmental stewardship, and promote sustainable practices. As these measures take effect, the ferry industry is poised to play a pivotal role in achieving global environmental objectives and setting a precedent for sustainable maritime operations. A system of extensive and practical laws, along with efficient enforcement, has resulted in ferry transport being one of the safest modes of transportation in the world. However, accidents do occur, and a safety system needs to guarantee that the lessons learned from incidents are carefully documented and distributed. This necessitates rigorous accident investigation protocols. The lessons must be conveyed to both operators and regulators so that prevention and reaction may be constantly enhanced. There are places in the world, particularly Asia and Africa, where ferry safety may be improved. Countries with enormous populations, such as Bangladesh, Indonesia, and the Philippines, rely heavily on boats for transportation. Interferry has established a Domestic Safety Committee whose mission is to assist developing nations in improving their safety policies (O’Melveny, 2023).

Chapter 6 Conclusion and Recommendations

Through the present thesis, the broader context within which ferry transportation operates is clearly outlined. The study aimed to present, in a concise and comprehensible manner, the composition and modernization of ferry fleets in various regions around the world, with a particular emphasis on technological innovations, environmental protection, and policy implementation. The analysis confirmed that while notable advancements have been achieved, especially in countries such as Norway, Denmark, and China, the process of modernization remains uneven and is often impeded by financial limitations, regulatory complexity, and technological challenges.

Table 6, 6.1 Summary of Environmental Actions by Country – Positive and Negative Practices

Country	**Positive Actions**	**Negative or Limited Actions**
Norway	-Over 70 electric/hybrid ferries in operation -Government subsidies for green vessels -Full automation and autonomous ferry projects	- High investment cost - Full transition still underway for remote routes

France	-Hybrid-electric vessels (e.g., Guillaume de Normandie) -Early adoption of electric ferries	- Modernization slower compared to Nordic countries - Some reliance on LNG
Greece	-€1B modernization MoC (ONEX-Attica Group) -Environmental certifications (ISO 14001) -Plans for a 100% electric fleet by 2040	- 86% of vessels over 20 years old -Funding gaps and high modernization costs
Denmark	- Ellen fully electric ferry - Significant EU investment via Horizon 2020	- High upfront cost of battery tech - Charging infrastructure limitations
Finland	- Dual-fuel LNG ferries - Efficiency-focused design (Stena Line) - Emission reduction strategies	-Limited number of new vessels -Implementation pace varies between operators
UK	- $300M federal grants for green ferries - Washington’s hybrid-electric plan (16 new vessels by 2040)	- Delayed rollout due to procurement/legislation cycles
USA	-LNG ferries (General Chernyakhovsky) -Urban electric river ferries in Moscow	-Modernization slower than global trends -Geopolitical and economic constraints
Russia	-Electric ferries with supercapacitor tech - Strict domestic emission zones (ECAs)	-Limited transparency on lifecycle emissions -Some regions lack modernization plans

China	-Electric ferries with supercapacitor tech - Strict domestic emission zones (ECAs)	-Limited transparency on lifecycle emissions -Some regions lack modernization plans

Table 6: Summary of Environmental Actions by Country – Positive and Negative Practices

The table above compares the various strategies and degrees of success in ferry fleet modernization among many prominent maritime nations. A distinct pattern emerges, with Northern European countries, particularly Norway, Denmark, and Finland, driving the move to sustainable ferry operations. Norway's significant investment in electric and autonomous ferries, combined with strong government mandates and support, places the country as a global leader in maritime decarbonization. Similarly, Denmark's Ellen project and Finland's hybrid Ro-Pax vessels demonstrate how focused innovation and EU investment may lead to substantial environmental benefits.

France and the United Kingdom are modernizing at a reasonable pace, with important breakthroughs like as hybrid-electric propulsion and dual-fuel boats, although they continue to rely on LNG or older technologies. Despite efficient ship design advancements, development in the United Kingdom is slowed by scattered adoption across operators.

Greece, despite budgetary restrictions, shows ambition with its €1 billion upgrade agreement and environmental certification programs. However, the aging fleet and restricted access to funding remain significant challenges. These challenges are especially evident in Russia, where restricted fleet improvements and geopolitical instability prevent widespread use of sustainable technologies.

In contrast, China emerges as a technologically aggressive participant, quickly building electric ferries equipped with innovative power systems such as supercapacitors. This is mostly driven by stringent local environmental legislation, while transparency and consistency across areas remain issues. The United States, with major federal financing, focuses on long-term systemic transformation, particularly through Washington's hybrid-electric project, although bureaucratic and legislative processes can cause delays.

6.2 Recommendations

Therefore, several thoughtful, context-sensitive recommendations can be proposed. First and foremost, international cooperation needs to be strengthened. Although the International Maritime Organization (IMO) has established essential legislative frameworks, additional collaboration is required, notably in the form of finance mechanisms and shared technology resources to assist countries with limited capabilities. The European Union's Horizon 2020 initiative, for example, has shown how smart investment can promote green innovation in ferry transport. At the same time, significant collaboration between the public and private sectors is critical. Ferry operators, shipyards, governments, and technology providers must collaborate—not to compete to share risk, cut costs, and streamline implementation. Public-private partnerships can be effective in changing agents, especially when combined with well-defined policy frameworks and long-term national goals. Furthermore, modernization requires going beyond the vessels themselves. It is also critical to invest in the required port and shore infrastructure, such as charging stations for electric ferries and digital connectivity that enables autonomous navigation and real-time emissions tracking. Without this enabling foundation, even the most modern boats may fall short of their full capability. In addition, decision-making deserves to be based on a thorough grasp of environmental tradeoffs. Life-cycle assessments of alternative propulsion systems, such as electric batteries, LNG, or hybrid models, can assist policymakers in selecting the most environmentally friendly option, not just in terms of emissions during operation but also during manufacture and disposal. Equally critical is the requirement for transparency and knowledge exchange.

Countries like China and Russia, which are making substantial technology gains, might help to accelerate global progress by allowing access to data on vessel performance, emissions, and operational innovations. The marine sector would benefit from a more collaborative approach to research and evaluation.

In the end, ferry fleet modernization could be socially inclusive. It should address the effects on workers, particularly in areas with aged fleets and limited training options. Programs that assist the upskilling of marine professionals and the engagement of remote island communities in modernization plans are critical to ensuring that the transition to sustainability does not jeopardize social fairness.

6.3 Concluding Remarks

As in many sectors, there is considerable scope for improvement in ferry services, particularly in enhancing environmental protection, working conditions for employees, and consumer safety. Overcoming existing barriers is therefore of paramount importance to ensure the fulfillment of environmental goals, improve energy efficiency, and guarantee the long-term sustainability of maritime transportation.

Strict adherence to all international organization-established norms and ferry operators' continued commitment to modernizing their services under these standards are equally crucial. Modernization initiatives support regional economic growth and social cohesion in addition to facilitating the reduction of greenhouse gas emissions and compliance with international standards like MARPOL and the European Union's Fit for 55 package.

In conclusion, the modernization of the ferry fleet is not only environmentally imperative but also strategically advantageous for economic resilience and social cohesion.

The author hopes that this study may contribute, even in a small way, to the ongoing dialogue around green maritime transitions and that future researchers, policymakers, and practitioners will continue to build upon this work with vision, responsibility, and determination.

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