OVERVIEW OF THE TRENDS IN ELECTRIC PROPULSION ON RO-PAX FERRIES IN EUROPE

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ABSTRACT

Considering the extensive initiatives intended towards sustainable transport development and the latest adoption of the European Green Deal, more shipping companies are investing in alternative propulsion on Ro-Pax ferries. This paper provides an overview of the alternative electric propulsion systems on Ro-Pax ferries indicating the industry's best practices in Europe. A viable model of the electric Ro-Pax ferries has already been utilized in Norway and Denmark exploiting the specific shape of the coastline and adequate, short shipping routes. The application and use of electric propulsion on Ro-Pax ferries correspond to the significant decline in emissions of harmful exhaust gases and particles and overall cost-savings compared to the standard diesel propulsion. Based on the qualitative and quantitative data on specific Ro-Pax electric ferry examples, an overview of the sector trends considering the fundamental characteristics of the route and technology is presented. These components comprise the data on route length, passenger and cargo capacities, battery capacity, charging options, speed of the ferries, and other performance features.

Keywords: Electric propulsion, sustainability, Ro-Pax ferry, Europe

1. INTRODUCTION

Ferry transportation plays a vital role in short sea shipping connecting the coast and islands. With the indented coastline in several European countries, ferry routes and transportation represent a vital line in socio-economic relations. Currently, there are hundreds of Ro-Pax ferries operating in Europe and thousands of other types of vessels. By carrying over 80% of global freight, the maritime industry is burdened with high pollution levels [2]. Marine industry and shipping have a considerable impact on climate change with hazardous gases emissions such as SO_X, NO_X, CO_2, and particulate matter. These emissions directly impact the human health and quality of life in the adjacent areas of vessels operations such as ports. Many incentives are provided by the International Maritime Organization to reduce emissions from the vessels and to promote greener and sustainable shipping. European Union also encouraged limitations in the use of fossil fuels with several directives and legislative decisions which aim to reduce the pollution from vessels. The most contemporary one is the Green Deal promoting drastic changes in the maritime industry and shipping, further introduction of alternative fuels, and sustainable renewable energy sources [15].

The ferry industry is quite significant for the European economy, and most ferries are still using fossil fuels for their propulsion systems, so the optimization of the industry is obliged. It should include renewing the outdated ferries with inadequate propulsion systems emitting substantial quantities of greenhouse gases and building new modern ships [2].

Several initiatives of alternative propulsion systems in Ro-Pax ferries have been realized already, especially in Northern Europe. Denmark and Norway are leading in implementing fully electric ferries into their fleet. Ferries usually operate on short routes connecting islands and the mainland, where the battery-powered electric propulsion implementation is feasible. With the technology innovation, the batteries became more powerful and more durable. Their implementation on short ferry routes is the first step in introducing electric propulsion in the commercial shipping industry [21]. Fully electric ferries charged with an onshore battery facility need enough power from the electrical grid to make charging operations efficient. If the charging station provides electricity generated from renewable sources thus further contributes to the reduction of pollution [32].

Even though the electrification of the ferry's propulsion systems is a big step toward sustainable technologies, issues are emerging from the implementation of e-ferries. Challenges and barriers that need discussion are technical, operational, legislative, and human nature [21, 2].

2. EUROPEAN FERRY MARKET

Maritime ferry transport plays an essential role in the integration and connectivity of the European Union, making it the most suitable passenger and freight transport system on short-sea routes [21]. Although ferry connections are significant for the European Union, their outdated propulsion systems represent a growing threat to the current environmental challenges.

2.1. Current state

In the European Union, the ferries run among ports of the same country or connect two or more European countries. Approximately 58% of the passengers travel by the ferry routes of the same country [3]. Europe is a notably ferry-intensive area due to the specific shape of the coastline and islands [21]. The European coast is 68,000 km long [19] and has around 2,400 islands [22]. The principal regions of the ferry transport routes are the Baltic, Northern Europe, and Mediterranean [21]. The Mediterranean area has the highest number of passengers transported by ferries compared to the other ones (around 450,000 passengers). The Baltic region has the highest share in vehicles regarding ferry transportation (approximately 93,000). More than half of the routes are managed in the Mediterranean area [3].

2.2. Environmental determinations and incentives

Considering the transportation of goods and people, the ferry market in the European Union plays a significant role. The European ferry fleet remained outdated. Most ferries are more than 20 years old [21]. Due to the vessels' age, the modernization of the European ferry fleet is necessary to install sustainable technologies available on the market. It is also important to note that European vessels and ferries do not have adequate specifications to reduce the growing environmental concerns [2]. According to the research by [18], Europe has around 900 ferries for cargo/cars and passengers, while the authors in [3] state that 671 ferries operate in Europe. Additionally, the authors in [3] state that 206 ferries operate in the Baltic area, 121 in the North Sea area, and 344 in the Mediterranean area. Furthermore, Clarksons Research Services Ltd. claims there are 117 Ro-Pax ferries and 3,029 ferries of other types in Europe[1].

Over the past few decades, the concernment regarding the environmental issues associated with the maritime sector and pollutions from the vessels gained significant attention worldwide. Maritime transport emits around 940 million tons of CO_2 annually and is responsible for about 2,5% of global greenhouse gas emissions. Shipping emissions are a cause of around 13% of the overall EU greenhouse gas emission from the transport sector [14]. Fossil fuels are mostly used in ferries. Vessels using fossil fuels generate a range of pollutants such as [31]:

- greenhouse gas emitted by the vessels is carbon dioxide (CO_2), which is one of the main factors associated with global warming,
- sulfur oxide (SO_X) and nitrogen oxide (NO_X) are highly dangerous due to their effects on human health and nature,
- particulate matter (PM) also has a toxic impact on human health.

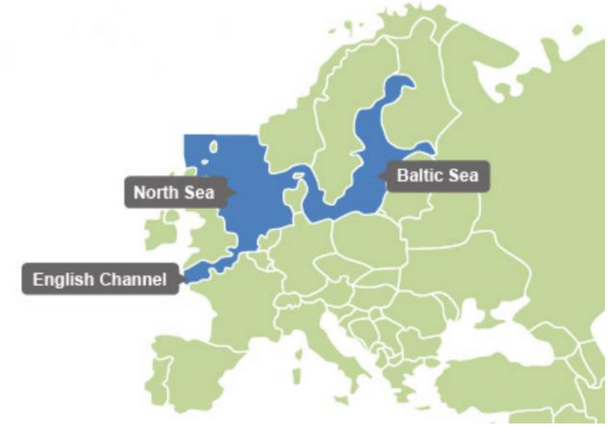
These emissions have a severe impact on health while ship is in the port. The emission of hazardous gases due to the ferry's operation in the port area is significantly higher compared to other types of vessels [2]. European Commission predicted that the growth of hazardous gases will exceed the total emission due to the fossil fuels being used in the shipping industry by 2030 if no further action is taken [28].

Due to the significant number of vessels operating in Europe, measures are introduced to eliminate hazardous environmental pollution. The shipping industry is moving towards totally eradicating greenhouse gases emissions. Several global and European directives have already been implemented in the past few years to tackle pollution from the maritime industry, especially shipping. International Maritime Organization (IMO) introduced new legislation to reduce CO_2, NO_X, SO_X, and particulate matter pollution within the MARPOL Annex VI on the Prevention of Air pollution from Ships [23]. The New IMO strategy set a target to reduce greenhouse gases emission from international shipping by at least 50% by 2050 with the encouragement to fully decarbonize the industry by the end of the century [10]. The strategy can be realized by the already available methods with short and mid-term measures. Measures include lower speeds of the vessels, improvements in operational efficiency using data analytics, limited use of low-carbon fuels, energy-efficient designs, and other provisions [17]. In 2013, European Commission already implemented a strategy with the principal goal to reduce greenhouse gas emissions from the shipping industry within the three main steps [14]:

- monitoring, reporting, and verification of the CO_2 emissions from vessels using EU ports,
- greenhouse gas reduction targets for the maritime transport sector,
- market-based measures in the medium and long term period.

EU Sulphur Directive 2012/33/EU was introduced in 2015 with the incentive to reduce sulfur emissions from all vessels that operate in the English Channel, Baltic Sea, and North Sea (Figure 1) [21]. In 2019, European Commission presented the European Green Deal, a strategy for the sustainability achievement of the European economy by turning climate and environmental challenges into opportunities in all policy areas and ensuring a fair and inclusive transition. For these goals, the EU plans to make significant investments with more than 260 billion euros [15]. The initiative of implementing the decarbonization process mentioned in the Green Deal requires drastic changes in the maritime industry and shipping, which has to undergo a global transition to alternative fuels and energy sources [17].

[1] Data provided via e-mail correspondence with Clarksons Research Services Limited



Source: [3]

Figure 1: SO_X emission control areas

New technologies in propulsion systems and alternative fuels should become available globally to reduce the carbon footprint of the maritime industry. It needs to incentivize the industry stakeholders to transition to new technologies, propulsion systems, and alternative fuels [10]. European institutions and stakeholders point to the significant role of synergy to fully facilitate the goals set to achieve in the Green Deal. Thus, institutions could not discuss the Green Deal without consultation with the stakeholders or shift to alternative fuels without significant cooperation with the European and governmental institutions. Arguably, stakeholders have to make substantial efforts to implement new technologies and fuels. Many ship owners could face potential issues to finance new technologies in propulsion systems and alternative fuels because of the unpredictability of the necessary infrastructure still being constructed, the availability of alternative fuels in the future, and legislative support. Their motivation for green transition is mainly growing competitiveness due to fuel efficiency and cost-benefit effectiveness, branding, and innovation. The main potential barriers are the installation cost of new equipment, day-to-day cost operations, the complexity of operations, the reliability of new facilities (being installed onboard or onshore/berth - charging station), lack of market incentives, crew and ship safety, and maintenance [21].

3. ELECTRIC FERRY – ALTERNATIVE FUEL MARKET IN EUROPE

Recently, the academic community has focused its research on the technical aspect of the ship system, which should strive to modify the conventional diesel propulsion with more environmentally friendly fuels. The objective is to meet the latest regulations and directives of the European Union and the International Maritime Organization to tackle greenhouse gas emissions from vessels. One of the technologies that have gained increasing attention over the past decade in promoting alternative fuels and environmentally friendly technologies is utilizing electrical energy as the primary source of propulsion on ships. Usage of battery-operated electric propulsion on ferries has become available with the transition to green technology bearing in mind the objective of reducing the emissions from vessels [32]. An alternative electric propulsion system has been adapted for some vessel types. Numerous researchers also studied the effect of applying electric propulsion to commercial, naval, and cruise vessels, which provides more efficient operation at a low speed [1].

The electrical propulsion system has already been in use by some companies which integrated this type of alternative fuel in their ferries [3] while at the same time battling the environmental issues with battery innovations which finally led to designing and building fully electric ferries. Installing the alternative electric propulsion system into ferries is possible by either integrating the electric propulsion completely or combining the diesel-electric propulsion. Compared to the ocean-going vessels, the ferries are potentially more feasible for introducing the electric concept [21] in line with routes determined in advance and relatively short voyages [9]. The experience with electric ferries is precious for the further introduction and development of electric propulsion technology in shipping.

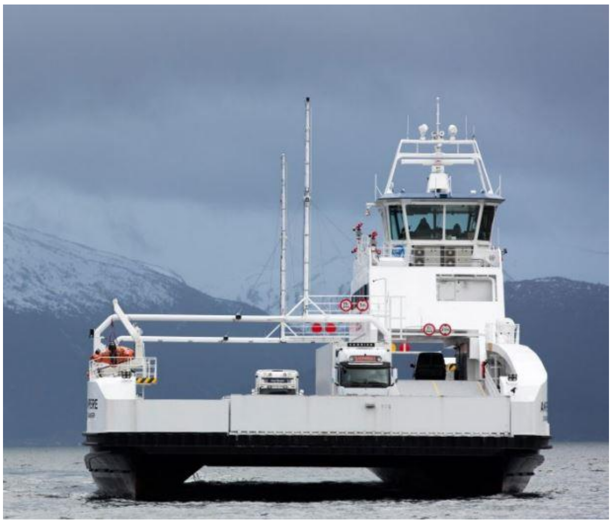
Several Ro-Pax ferries were designed and built with fully electric propulsion, and they have already been in commercial use in the Scandinavian countries. Table 1 shows the fully electric Ro-Pax ferries currently in use in Europe. It also shows the routes of the ferries and the beginning year of operations. The ferries considered in the research were exclusively designed and built for battery-powered electric propulsion and capable of carrying passengers, cargo, and vehicles (Ro-Pax ferries).

Table 1: Fully electric Ro-Pax ferries in the EU

Ro-Pax ferry	Routes operated	Year
Ampere	Lavik-Oppedal (Norway)	2015
Kommandøren	Halhjem – Våge (Norway)	2018
Ellen	Soby - Fynshav (Denmark)	2019
Bastø Electric	Moss – Horten (Norway)	2021
Grotte	Esbjerg – Fanø (Denmark)	2021

Source: [5,6,7,25,27]

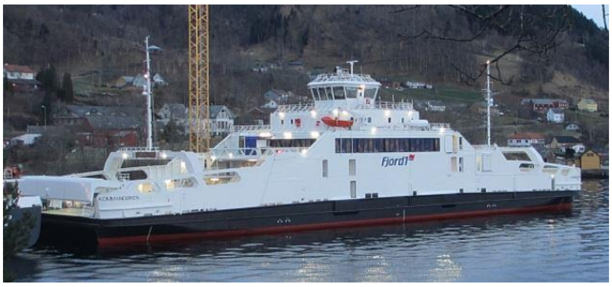
The first emission-free Ro-Pax ferry Ampere (Figure 2) was built by a consortium of Ferry Company Norled AS, shipyard Fjellstrand and Siemens [4]. Ampere's route is six kilometers long across the Sognefjord between Lavik and Oppedal. It crosses the distance in 20 minutes, 34 times per day, and operates 365 days a year. Ferry's dimensions are 80 meters long by 20 meters wide. Ampere was constructed in aluminum with two electric engines of a maximum total power of 900 kW. The lithium-ion batteries facility fuels the engine with a total capacity of 1,000 kWh giving the ferry enough energy to make up to two round trips across the Sognefjord. The estimated lifetime of the batteries is ten years [32]. At each dock, Siemens installed a 260-kWh battery plant to recharge the vessel's battery where the ferry can recharge in ten minutes during unloading and boarding operations. Ampere consumes approximately 200 kWh on each crossing [30]. If the electrical energy for charging is obtained from a fossil-free power plant, the ferry runs on fossil-free energy, which is still cheaper than diesel. A diesel-powered ferry of the same capacity and size would consume about 1 million liters of diesel and emit 2,680 tons of CO_2 and 37 tons of NO_X per year [25]. Research has shown that the electric ferry reduces carbon emissions by 95% and costs by 80% compared to oil-powered ferries [24]. Ampere Ro-Pax ferry can take 120 vehicles and 360 passengers and has a maximum speed of 14 knots [30].



Source: [25]

Figure 2: Ferry Ampere

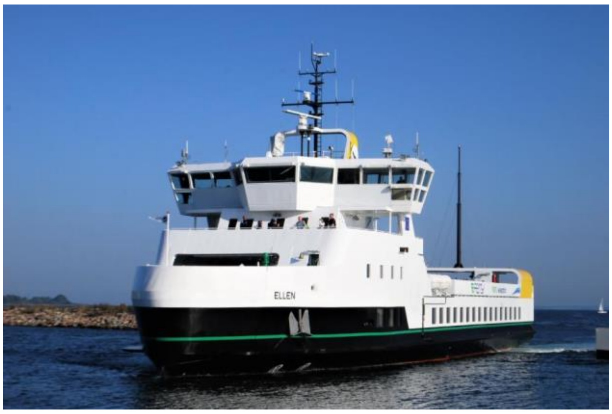
A larger and more advanced version of the e-ferry Ampere is the Kommandøren (Figure 3) fully electric ferry delivered in 2018. The ferry designed and built by Fjellstrand operates the route between Halhjem and Våge in Norway. Compared to the Ampere's voyage, the Kommandøren route is more than two times longer (12.5 kilometers), with a crossing time of 35 minutes and a battery capacity of 2,938 kWh. The annual savings in diesel fuel are estimated at more than 2.5 million liters and a reduction of more than 7,197 tons of CO_2 emission [6]. This ferry is 87.5 meters long and 20.8 wide, and it can carry 120 cars, 12 trucks, and 350 passengers. Like the Ampere, Kommandøren was also built of aluminum with a catamaran hull [20].



Source: [6]

Figure 3: Ferry Kommandøren

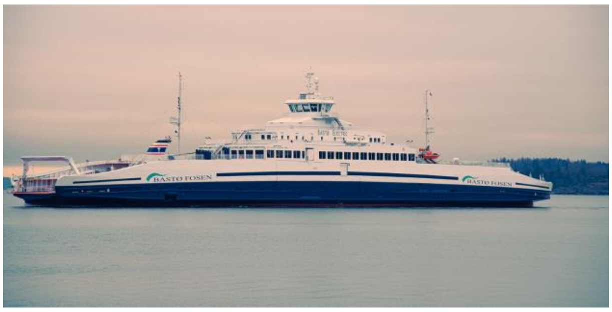
The e-ferry Ellen (Figure 4) has been in operation since 2019 crossing the route between Soby and Fynshav in Denmark three to five times a day during weekdays. Ellen was designed to meet the needs for transportation between islands and coastal zones. Dimensions of the vessel are as follows: length 59.4 meters and width 13.4 meters. Ellen is charged up to 3.8 MWh over the night in Soby. In a one-way trip, the Ellen propulsion system needs the energy of 1,400 to 1,700 kWh, depending on various variables such as weather conditions, route length, and the vessel load. The route is 22 nautical miles long (or more than 40 kilometers), which the ferry crosses in two hours. The charging point is harbor Soby where the ferry connects to the charger of 4 MW. Lithium-ion Nickel Manganese Cobalt Oxide (Li-NMC) battery system [11] has a capacity of about 4.3 MWh, and the recharge operation is between 15 to 40 minutes long [12]. The ferry is built from new lightweight materials being different kinds of carbon composites besides the more traditional aluminum lightweight composition of the superstructure, thus allowing the maximum speed of the ferry up to 14.5 knots. Ellen can also operate in ice conditions up to ice thickness of 15 to 20 centimeters. The capacity is 31 cars or five trucks on the open deck, 147 passengers in the winter and 198 passengers in the summer [13]. By introducing fully electric battery-powered e-ferry Ellen, the annual emissions will be lowered by 2,520 tons of CO_2, 14.3 tons of NO_X, 1.5 tons of SO_2, 1.8 tons of CO, and half a ton of particulate matter compared to those of traditional diesel propulsion ferries [29]. The E-ferry project that had the task of designing and building ferry Ellen was an EU-supported development project within the EU's Horizon 2020 program which successfully covered more than 15 million euros of the total costs of about 21.3 million euros [5, 16].



Source: [5]

Figure 4: Ferry Ellen

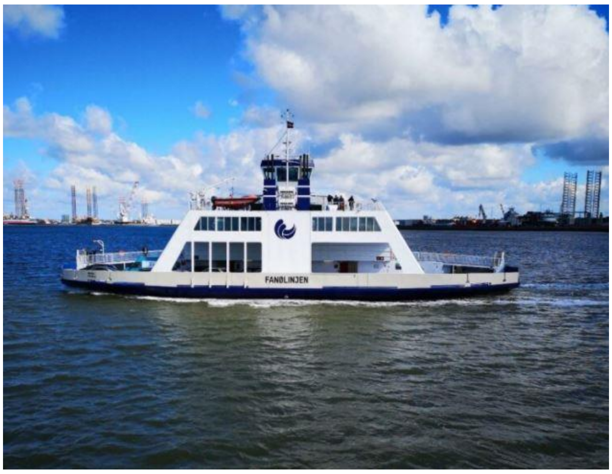
In 2021, the fully electric ferry Bastø Electric (Figure 5) was delivered to the company Bastø Fosen. The operating route is 10 kilometers long between Moss and Horten, and it takes about 30 minutes to reach another coast [9]. This electric ferry is 139.2 meters long with 21-meter width [27] and can carry 200 cars and 600 passengers [9]. The high voltage charging systems situated both in Moss and Horten have the capability of charging with a power of up to 9,000 kW. The ferry's battery system has a capacity of 4,000 kWh. The predicted reduction of greenhouse gases emissions will be about 80% compared to diesel ferries emissions [26].



Source: [27]

Figure 5: Ferry Bastø Electric

In 2021, Danish company Molslinjen introduced a fully electric ferry Grotte (Figure 6) on the ferry's route between Esbjerg and Fanø in Denmark [8]. The sailing distance is 3.5 kilometers long, which the ferry crosses in 12 minutes [7]. The batteries drive two 375 kW electric motors with an output speed of 11.5 knots. The Grotte recharges the batteries from a dual shore supply facility having 1,250 kW of power each. The charging operations take place in the port of Esbjerg during an eight-minute stay in port. The energy provided is enough for the purely electric round trip [8]. The fully-electric ferry Grotte saves annually more than 800,000 liters of diesel fuel lowering CO_2 emissions by 2,214 tons. It has a capacity of 396 passengers and 35 cars [7].



Source: [7]

Figure 6: Ferry Grotte

4. CHALLENGES OF IMPLEMENTATION OF FULLY ELECTRIC FERRIES

Introducing electric propulsion in the maritime industry and shipping is a significant step in line with the EU transport policy. Some companies have already adopted this form of green and sustainable technology. However, some possible challenges and barriers need additional explanation and research. They include technical, operational, and legislative issues, and they are related to the sailing range covered by the fully electric ferries, charging stations, and electricity, the composition from which the vessels are built [21], and the human factor [2]. Beneficial to the electric ferry's total cost reduction are the electric energy price and charging stations. Charging stations are expected to be implemented in many ports as common infrastructure and thus the application of the economy of scale with further adoption [12]. However, possible port electric energy charging fees are still to be discussed if the e-ferry technology is implemented on a larger scale. The electric energy price issue for the charging of the e-ferries depends on the spot prices of the electricity for each country and electric energy taxes.

4.1. Technical issues

Technical issues emerge from the daily use of the fully electric ferry. The vessel consumes electrical energy stored in the batteries for propulsion and other purposes. The ferry consumption depends on several factors as weather conditions, e.g., wind and currents, speed, load, and possible formation of an ice layer on the sea in harsh cold conditions in Scandinavian countries [2]. With the external effects defined, fully electric ferries are designed and built to have a surplus of energy stored in case of challenging situations that could potentially emerge in day-to-day operations. The technical challenge is the onshore charging stations and the electrical grid, which needs to provide enough power to charge the vessel's battery station in a reasonable time until the next scheduled trip. Preferably, the charging speed should enable the ferry to make a round trip [32] with surplus energy.

Somewhere, filling the batteries in poor conditions, e.g., bad weather, is also a point of concern. [21]. To optimize the sustainability of electric ferries, the electricity from the grid used to charge the onshore battery systems should origin from renewable sources that also provide appropriately more energy than was used to build the ferries [32]. Materials from which the green ferry has been built are also delicate issues bearing in mind that the additional weight requires more power that burdens the batteries. Designing and building ferries with lightweight materials such as aluminum is a good solution for new ferries but limits the possibility of building-in electric propulsion on the existing ones [21].

4.2. Operational issues

The battery technology that enabled the transformation from conventional fuels to green energy is accomplished by using various types of lithium batteries. The materials used to build batteries are available, but their inherent toxicity, the possibility of sudden shortages of starting materials, and limited lifespan depending on the charge cycles are of concern. Another important factor is the battery's energy density, although battery technology has improved over the last few years. Increasing the number of battery units onboard the ferry deems unpractical due to the size and weight issues. Furthermore, efficient transmission charging cable is compulsory to deliver high voltages without problems of overheating either the charging infrastructure or batteries themselves [2]. Operational cost savings derive from notably lower energy costs due to the improved energy efficiency of the fully electric ferry when average energy prices of electricity and bunker fuel are compared [12].

4.3. Legislative issues

The legislative and advisory bodies haven't yet recognized considerable electric energy application in the maritime industry. Present regulations from the International Maritime Organization increases the complexity of the active implementation of electric energy in the maritime and shipping industry [2]. An example is in the case of tax-free hydrocarbon fuels, while electricity, which represents a greener energy source, is taxed. Furthermore, the payback period of electric ferry investment would be much shorter if new legislation gave the electricity the same tax privilege as fossil fuels [21].

5. CONCLUSION

The sustainable development policy in the maritime industry of the European Union and International Maritime Organization and the contemporary Green Deal resulted in the introduction of fully electric battery-powered ferries. It presents a first step in reducing air pollution from vessels in commercial maritime transport. It should be followed by introducing a new propulsion system in the marine industry on a much larger scale. New battery technologies are becoming increasingly popular with the efficient design and affordable price, thus encouraging the ship owners and companies to built-in them into their new builds. However, some potential barriers and challenges have to be addressed before optimizing the electric ferry industry on a larger scale. Barriers discussed in this paper are related to technical, operational, and legislative issues. Also, current innovations limit the ferries only to short route operations. Incentive from the European Commission with the E-ferry project seems successful, and several companies follow it with advanced designs and capabilities of the ferries. Although investments for the electric ferry propulsion are much higher than for the diesel ones, calculations show that the costs are compensated after 5 to 8 years, even including the costs of charging facilities and the potential replacement of batteries [29]. It means that higher investments in fully electric ferries would pay off if the prices of electric energy wouldn't change drastically. Introducing the battery-powered electric ferries, estimated savings in both commercial activity and environmental pollution are growing, thus encouraging enough to promote electric ferries even more. Besides, the electrification of the propulsion systems in the maritime industry is solely one of the ways to tackle environmental pollution from the vessels. Other incentives related to alternative propulsion like hydrogen, biofuels, methanol, and other environmentally friendly alternatives, are also gaining worldly attention. Their advantages and disadvantages need to be further discussed.

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