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Exploring the potentials of electrical waterborne transport in Europe: the E-ferry concept

Eliza Gagatsi [a]*, Thomas Estrup [b], Aristos Halatsis [a]

[a]*Hellenic Institute of Transport, 6th Km, Charilaou- Thermi Rd, Thessaloniki, 57001, Greece*
[b]*Aero Kommune, Statene 2, 5970 Ærøskøbing, Denmark*

Abstract

This paper presents the concept of a fully electrified ferry that aims to support and promote energy efficient, zero GHG emission and air pollution, free waterborne transportation for island communities, coastal zones and inland waterways in Europe and beyond. Existing state-of-the-art ferries with 100% electric drive train systems are suffering from major limitations in range and are thus only being built and applied for very short ferry connections. The E-ferry, goes beyond this limitation targeting medium range connections and aims to become the ferry with the largest battery pack ever installed on a vessel. Other state-of-the-art solutions are based on retrofit, integrating hybrid or 100% electric systems in existing ferries suffering from lack of energy efficiency due to an existing energy inefficient vessel design. The E-ferry concept also differs from all other known projects by a record breaking high charging power of up to 4 MW allowing for short port stays. This is important for the operational profile of most ferry routes. Starting from a state of the art analysis on the use of alternative fuels in EU ferries, the paper presents the barriers that currently exist in Europe preventing the successful implementation of electrical ferries and how the proposed E-ferry aims to address them. It also reports on the competitive advantages of E-ferry in terms of cost efficiency, speed, trip frequency, capacity, dependability and overall environmental performance. Finally, the market penetration potential of this innovative ship is assessed.

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Keywords: Ferry transport; electric ferry; ship design; coastal transportation

* Corresponding author. Tel.: +30-2310-498464; fax: +30-2310-498269.
E-mail address: lgagatsi@certh.gr

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1. Alternative fuel and energy use in the EU Ferry market

Maritime transportation is an important sector of the European economy, strongly dependent on a dynamically changing environment comprising of internal as well as external to the system, parameters and market dynamics. Further to Europe's strong presence in the international maritime scene (the EU holds 34.55% of the world's tonnage[1]), an important part of the European maritime economy is related to Short Sea operations covering both freight and passenger transport. The total number of passengers embarking and disembarking in the EU-28 ports was estimated at 400 million in 2013. Europe is an extremely ferry-intensive area, with two main markets – Northern Europe and the Baltic, and the Mediterranean. The extended coastlines (more than 68.000 km length) and the strong islander character of Europe (5,116 EU islands) makes ferry transportation a critical link, ensuring connectivity, securing economic and social cohesion and, as the 2015 Mid-Term Review of the EU's Maritime Transport Policy highlights, bridging existing gaps, preventing isolation and offering equal growth opportunities to small and remote islands, as well as insular Member States and promoting coastal tourism.

Despite the importance of the EU ferry market, the European ferry fleet remains old and in need of newer, more energy efficient and less CO_2 emitting and polluting vessels. The majority of European ferries are older than 20 years (Papanikolaou A. et al, 2001). Europe has around 900 ferries for both cargo/cars and passengers which accounts for 35% of the world fleet and 71.5% of the world trips (ESPO, 2006). Including passenger only ferries the total number is around 1,350.

Shipping in general is highly fuel-efficient, but its sheer volume and rapid growth makes it a major consumer of energy and source of carbon air-polluting emissions. Global shipping, with just tens of thousands of vessels, is the next largest energy consumer and carbon emitter after road passenger and commercial vehicles. Maritime shipping uses about 11% of the global transportation sector's petroleum (about 5 million barrels per day) equating to 1 Gt CO_2 emissions annually. In the EU context, it is worth noting that, without further action, the continued growth in SO_2 and NOx emissions from the European maritime sector has been predicted to surpass total emissions of these pollutants from all land-based sources by 2030 (EC, SEC (2005) 1133).

Over the past few years the issues of social and corporate responsibility and the safeguarding of the environment have seen great rise with a variety of new measures being taken to eliminate the inconsiderate pollution of the environment. In the area of maritime transportation, the IMO (International Maritime Organization) has been introducing new and stricter legislation since 2003, with MARPOL Annex IV on the Prevention of Air Pollution from Ships aiming to reduce CO_2, NOx and SOx levels.

In force from 1 January 2015, the EU Sulphur Directive 2012/33/EU requires a drastic cut in sulphur emissions from all vessels operating in the Baltic Sea, the North Sea and the English Channel. In these so-called Sulphur Emission Control Areas (SECA's), ships must use fuel with a maximum of just 0.1% sulphur content or adopt alternative solutions that achieve an equivalent effect. From 2020, the global sulphur limit will be further reduced and set at 0.5%. While this limit may be postponed to 2025 outside the EU, it will apply in EU waters (outside ECAs) from 2020. For passenger vessels operating on regular service in the EU, the Sulphur limit outside ECAs is 1.5% until 2020 while there are still discussions on further reduction of these emission levels by 2020 and 2025. The above reduction of SOx is expected to impact fuel prices implying extra cost for shipping that varies depending on the vessel type, trip and cargo. According to the assessment of different impact studies implemented by EMSA in 2010[2] the most sensitive vessels to the higher fuel prices appear to be the general cargo and the containerships and also those carrying low-value cargo. Although Ro-Ro and ferries are expected to be affected less, the increased fuel prices will surely have a negative impact on their profit margins. Given the highly competitive and low-margin structure of the sector, the problems may go well beyond higher operating costs and will definitely have an impact on the fares putting at the same time in risk the viability of different ferry operators which could result in service discontinuation – notably on long distance and/or low volume trades - and reduced frequency on marginal routes.

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[1] UNCTAD, 2014, Review of Maritime

[2] The 0.1% sulphur in fuel requirement as from 1 January 2015 in SECAs- An assessment of available impact studies and alternative means of compliance EMSA,2010

The above changes have pushed the shipping industry to look for new and “greener” solutions for their vessels. Nowadays, ship owners, operators and designers are beginning to seriously consider the emissions generated out of their operations as they take note of the political shift towards reducing impacts on climate change (Landamore, M. & Campbell, D. (2010)). However, meeting NOx and SOx requirements can prove to be very costly (DNV, 2014). For many ship-owners finding the necessary capital to finance new technology comprises an important challenge hindered by different uncertainties such as the appropriate infrastructure, the long term availability of the alternative fuel, etc. According to a survey undertaken by DNV with 23 shipowners, the main motivations for green solutions are: compliance to current/future rules and regulations, improved competitiveness resulting from fuel efficiency and cost effectiveness, trade flexibility (ECA friendly vessels) and (with a quite low score) the branding, innovation and first mover perception. On the other hand, the main barriers are: the cost of installation/purchase, the cost of operation, the technical maturity/reliability/experience of the new solutions, the lack of competitive (market, financial) incentives, crew and ship safety, the complexity of operations, and the required crew now- to operate/maintain etc.

In general, the ferry market appears more flexible towards the introduction of alternative fuels compared to the ocean going sector. This applies especially to ferries operating on local routes where fuel availability can be secured with less risk while in several cases local market conditions can favour the implementation of some fuel types (eg LNG). Ferry operators can operate 100% in ECA therefore the risk of future fuel availability or its supply on another geographical area does actually not comprise an issue. LNG, electrification, biofuels, Methanol and LPG are some of the most popular existing options in the EU ferry market.[3]

Table 1. “Green” EU ferries.

Ferry Operator	Country	New technology vessels (fleet)
Scandlines Denmark A/s	Denmark	2 (9)
Viking Line ABP	Finland	1 (8)
Scandlines GmbH	Germany	6 (9)
Norled	Norway	(80)
Fjord1 Nordvestlandske AS	Norway	12(60)
Stena Line Scandinavia	Norway	1 (35)
Cal Mac	Scotland	2+1(27)
Green City Ferries	Sweden	1 (1)

Source: Authors' research

In total 13 ‘green’ ferries operated by European ship-owners and 10 more expected to be delivered in the next years have been identified in a survey based on internet and business publications that took place by the authors in July 2015. Table 1, presents an overview of the main European ferry operators that introduced new technology green ferries to their fleets.

2. Electric ferries sailing the European waters

Ferry services in the EU and around the globe are facing (among others) the challenges of increasing energy prices, and of the demand for renewable energy-efficient sources. In other words, they have to provide affordable, sustainable and low-emission transport services. These challenges are particularly acute in the cases of islands and other isolated communities. As ferries have a long life span and since energy efficiency has not been a focal area until recently, many energy inefficient ferries are currently in operation in Europe.

[3] Currently, the available fuel options for ferries are: LNG, LPG,Methanol/Ethanol, DME, Synthetic Fuels (Fischer-Tropsch), Biodiesel, Biogas, Hydrogen and Nuclear.

The environmental considerations coupled with battery innovations and increased fuel prices were proven to be catalysts of a new trend towards ferry electrification in Europe. This led to building several new electric vessels and retrofitting existing ones. An overview of the electric ferry market is provided in the next paragraphs focusing on the existing electric and hybrid-electric ferries operated in EU waters and also on vessels to be delivered in the next few years. The market includes a limited number of fully electrified and several hybrid-electric ferries.

Leaders of this newfound market in Europe are the Scandinavians, with Norway playing the prime role introducing the first fully-electric ferry using Li-ion batteries, Ampere, awarded as 'ship of the year' in 2014.

Another purely electric ferry is the Ar Vag Tredan that was built in France and is operated by Lorient Agglomération. It uses 128 super capacitors provided by Batscap and is also made of aluminium. It is quite smaller than the Ampere and doesn’t have the ability to transport vehicles.

The Movitz ferry is another case in point, considered to be the world’s first super charging battery-powered ferry. It was retrofitted into a super charging electric ferry, both built and operated by Green City Ferries in Sweden, using Nickel-Metal-Hydride (Ni-MH) batteries. Its operation is expected to reduce CO_2 and NOx emissions (by 130 and 1.5tons yearly respectively) cutting at the same time operating costs by 30%. Its size is also small and it has the ability to operate at 9 knots for an hour after ten minutes of supercharging.

On the contrary to the limited number of the fully electric ferries there are several Hybrid Diesel-Electric ferries in operation. MV Hallaig and MV Lochinvar are two pioneering sister vessels both operated by CalMac and built by Ferguson. They are 43 meters long and 12 meters wide and both operate in Scotland at 9 knots. They have the capacity to transfer 150 passengers and 23 vehicles each. The ferry hybridization is expected to lead in around 20% fuel reduction resulting among others from the overnight charging and the fact that their machinery runs more efficiently, using the battery as a buffer. The same company has also on order another hybrid Diesel-electric ferry with a Li-ion battery. An interesting example of green ferry transportation is Prinsesse Benedikte, refitted into a hybrid diesel-electric ferry in 2003. Operated by Scandlines, it is the biggest retrofit from diesel to hybrid vessel, capable of transferring 1,140 passengers and 364 vehicles. Servicing the route of Rødbyhavn - Puttgarden, at 18.5 knots service speed, Prinsesse Benedikte is also one of the fastest hybrid ferries, recharging in 30 minutes by renewable, shore or generator power. Prins Richard, sister vessel to Prinsesse Benedikte, also got retrofitted into a hybrid diesel-electric ferry in 2003. Operating at the Puttgarden, Germany- Utrodbyhavn, Denmark route at 10 knots, it carries 1,140 passengers and 364 vehicles. M/F Deutschland, operated by Scandlines, is another ferry turned into a battery-electric hybrid one in 2004. It is 131 meters long and 25 meters wide, operating at 16 knots, with a 900 passengers and 292 vehicles capacity. The same company plans to renew its fleet with two new electric vessels (M/V Copenhagen and M/B Berlin).

M/S Sjovagen is an electric ferry built on composite material operated by Ballerina, making a 50-minute trip in the waterways of Stockholm, Sweden, at 12 knots. It has a relatively small dimension (24x7m) and can transfer 150 passengers and 15 bikes, but no other vehicles.

Last but not least, in this category are the La Gondole and Hirondelle ferries. Built in France, they operate in the Garonne River by Keolis and are both made of aluminium.

Apart from the above mentioned, other operators in Europe investing on diesel-electric ferries are Clyde and Hebrides in Scotland, Teso N.V. and Fjord1. Teso N.V. is sister company with Norled while Clyde and Hebrides is sister company with CalMac. Teso and Norled own in total approximately 75 vessels, 5 of which are adopting new eco-friendly technologies. Clyde & Hebrides and CalMac own around 30 vessels, 3 of which are switching to a 'greener' path.

In addition to the above new technologies (fully-electric & hybrid), it is worth mentioning the fuel cell technology and the autonomous ferry concept. The fuel cell technology has been applied on the Hydrogenesis, a small 12-passenger ferry which uses fuel cell technology, converted to electricity. This small vessel serves a three quarter of a mile route in Bristol, United Kingdom, for sightseeing purposes. The application of this newly emerging technology in the maritime sector is still under question by the research community, being considered risky especially when it involves large quantities of hydrogen used. The autonomous ferry concept is implemented in the ReVolt, a 60 meter battery powered autonomous ferry that will have little to no crew. The estimated annual savings of this new vessel reach the 1.6 million USD. It is going to operate at a speed of 6 knots within a range of 100 nautical miles and a cargo capacity of 100 TEUs.

3. Challenges towards widespread uptake of electric ferry transport in Europe

The application of electric propulsion in the maritime market has experienced significant growth in the last decade. One of the drivers of this evolution was the growth of offshore exploration. As Whitelegg et al indicate, more than 60% of the total electrically propelled surface vessels operating world-wide serve off-shore facilities while only 14% are passenger vessels) along with the advances on power electronics and the increased sensitivity of fuel costs (Pestana, H., 2014). In the case of EU coastal transport however, there is still a variety of barriers preventing the successful implementation of electrical ferries. These barriers mainly concern legal as well as technical and operational issues associated with the sailing range/distance covered by 100% electric ferries, the charging at very high power and the introduction of lightweight materials.

Present regulations on energy taxes and ferry construction do not support a paradigm shift to electrical propulsion neglecting also the need for lightweight carbon composite materials that is necessary to offset the weight of the battery packs on the electric vessels. Legislation is an important barrier, creating paradoxes by not promoting environmentally sustainable ferry operations. Such an example is the case of hydro carbon fuels for ships that are exempted from all taxes in many EU countries while at the same time, a greener type of energy, electricity, is heavily taxed. Furthermore, the present legislation and tax regime only marginally exposes traditional ferry operations to their socio-economic cost of emissions and other environmental impacts.

The absence of those socio-economic costs from the investment decisions of the ship-owners results in favour of existing, conventional propulsion solutions. The payback time of an electric ferry investment would be much shorter if / when new legislation giving electricity the same tax exemptions as fossil fuels is introduced in the near future. This recently happened in Denmark by amending the Electricity Supply Act, the Natural Gas Supply Act and the Energinet.dk Act (No. 575 of 2012) with regard to the promotion and marketing of energy supply in Denmark, a country that strongly supports the exploitation of RES. Moreover, the estimation of the overall impact of a particular fuel on the environment should not neglect the emissions related to the fuel's production and also to the fuel 'transport' pathway (DNV, 2014) something that is not addressed by the current regimes.

Further to the above mentioned legislative issues (1) there are other challenges towards ferry electrification. In 2014, a detailed analysis of the main barriers towards ferry electrification took place in the framework of the Green Ferry Vision project. The main objective of this project was to examine the feasibility of an innovative low-weight ferry for cars and passengers - a ferry only powered by green electricity stored in batteries on board. The main barriers identified, are related to the energy efficiency (2) resulting from the current ferries ship design, the increased weight of the electric ferries due to the extra weight of the batteries and the difficulties (increased cost and lack of a favourable legal framework) on applying composite materials in the superstructure to reduce the extra weight, to the batteries characteristics (limited autonomy, charging under difficult –i.e. weather- conditions, electrical infrastructure on land etc) in combination with the operational parameters of the vessels (i.e. short port stays during the ferry's operational schedule and need for delivering large amounts of energy from the local grid during the short port stays). To the above one has to add also the human factor (4), a very critical element of maritime transportation closely related to maritime safety[4]. This particular area involves training and education issues, crew competencies as well as the overall acceptance of the full electric solution as part of the maritime transport solution. Also, the human factor is related to the key stakeholders of the maritime transportation such as the ferry operators, port authorities etc. Reluctance of those crucial to the decision making stakeholders is related to the fact that they not aware or not convinced of electric ferries as alternatives to conventional fossil fuel ferries. An overview of those barriers is presented in the next table.

[4] Around 80% of the maritime accidents are related to human errors

Table 2. Barriers towards ferry electrification.

Main Area	Current barriers
Energy Taxation (1)	• Tax regime in favour of fossil fuels and not electricity • EU's Energy directive in need of updating
Energy efficiency (2)	• Current ferry design is often not optimised in terms of energy efficiency • Reduction in new ferries' weight is often not considered • Current regulations make it difficult to apply carbon composite or other alternative materials to steel • Electrical light weight solutions instead of hydraulics for equipment • Price of building ferries using carbon composites
Battery(3)	• Short port stays during the ferry's operational schedule makes charging a challenge • Delivering enough power from the local grid to charge at very high rates during short port stays • Electrical infrastructure on land • Transferring such high powers in a safe way in all weather and operational conditions
Human factor (4)	• The maritime industry, crews and their unions are not convinced about electric ferries being part of the maritime transport solution • Crew competences needed for fully electrical operation not clarified • Educational requirement for the future ferry crews not in place • Battery packs need to prove that their redundancy and safety is as good or better than combustion engines in minds of passengers

Source: Green Ferry Vision, 2014

4. E-ferry: a new paradigm in short-medium range coastal transportation

The growth of the electrical propulsion maritime fleet led some of the major electric power companies to develop new solutions that further improve the performance of electrical propulsion. Battery technology has advanced to a level making it possible to build passenger car ferries that can sail on the high seas for longer distances, and with high trip frequency, without the need for full charging during the day. So far, the typical electric inland or coastal passenger vessels could use batteries as a main source of power for a short period and could charge the batteries whilst alongside using shore power. As H.Pestana mentions, 'the economic rational of this type of battery application is the lower cost of shore electricity when compared with the cost of generating on board. Although the equipment cost is considerably higher than of a traditional propulsion system, especially because batteries have a limited life, today's solutions allow for a payback period of less than 5 years".

As battery technology continues to develop, electric ferries will be able to replace more and more conventional car ferries, including those operating on longer connections. The battery prices are also expected to be further reduced in the near future. In a literature survey, four market studies for the automotive lithium ion battery industry have been identified (D. Bank,2010 , Dinger A., et al,2010, Hensley R., et al 2012, Alexander D., et al.,2014). All four confirm the reduction of the future price of medium to large size battery packs for electric and hybrid vehicles (varying from 6.6 to 9.1 % Compound Annual Grow Rate – CAGR reduction).

Still today, there are limitations to the operational set-up of a fully battery driven ferry in regards to time schedules and the need for charging times at port, making the operational approach different than for a conventional fossil-fuelled ferry. The examination of the operational challenges in the framework of a viable business model allowing the commercial operation of such ferry is among the objectives of the first fully electric ferry to be built with the financial support of the European Commission. This is where the E-ferry project comes in the picture.

The E-ferry concept concerns the development of a prototype and the full-scale demonstration of a next-generation, 100% electrically powered ferry for passengers & vehicles of the following technical characteristics:

Table 3. Vessel design specifications (E-ferry project, 2015).

	Technical characteristics
Type	single ended, drive-through Ro-Ro passenger Ferry with 1 continuous main deck for trailers and cars
Capacity	31 cars or 5 trucks on open deck, 147 passengers at winter, 198 passengers at summer
Principal Dimensions	Length (oa/pp) 59,40 / 57,00 m
	Breadth mld. at vehicle deck 12,80 m, Breadth extreme 13,40 m, Depth to vehicle deck 3,70 m, Draught full loaded 2,50 m, Free height/ breadth at vehicle deck: 5,00/ 8,50m
Speed /Power	Speed at a draught of 2,30 m: Total 750/1000/1500 KW power = 13,00 knots/14 – 14,50 knots/15,50 knots
Class	Machinery, equipment, outfitting in accordance with DNV GL rules and regulations for Class notation: 1A1, Car Ferry B, R4, ICE C, EO, Battery (power)
	Rudder and propulsion system according to ICE B
Weight	Light ship weight approx: 650 Tons

The ferry is intended for coastal and inter-island operation covering distances up to approximately 13 NM. With the current state of battery technology, 100% electric solutions are not yet considered cost effective for longer distances, however this constrain is expected to be overcome in the future as battery technology develops. To validate and prove the feasibility and cost effectiveness of the concept to the industry and ferry operators the new vessel will be demonstrated in real-life conditions on the Soeby-Fynshav (a) and Soeby-Faaborg (b) connections in the Danish part of the Baltic Sea for a two-year period.

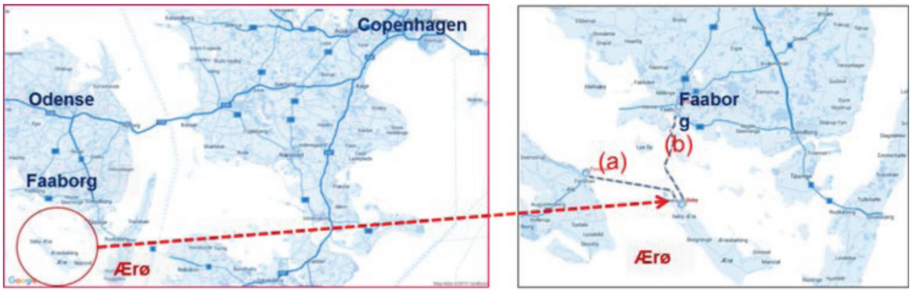

Fig. 1. The E-ferry demonstration area.

The new fully-electric ferry solution combines different innovative elements involving new technology and solutions that have not entered the market yet. Those are described in the next paragraphs.

4.1. Integrating innovative elements to a 'green' maritime transport solution

The concept introduced by the E-ferry project is new and innovative mainly for its energy efficiency dimension. It is the most efficient small to medium sized ferry hull that has been built for decades. The ferry design meets the latest and highest intact and damage stability criterion for ferries, being a two-compartment ship going well beyond the safety requirement for operation in coastal areas (category C and D normal trading areas for the typical island ferry). The number of computational fluid dynamic (CFD) calculations made for the vessel design exceeds the typical one for a vessel of this size. The provision of a 100% electric solution, powered by electricity from wind power or other renewable energy sources (RES), is also considered as one of the project's main innovations. The electric system is already installed in diesel-electric hybrid solutions with reference to more than twenty ships. However, applying it as the only drive train, is new and innovative. The ZeroCat is a similar solution that sails already in the Norwegian waters however the design and operational concept is different involving a shorter route, lower charging power and different materials (aluminium). The E-ferry is expected to have the largest worldwide battery capacity for maritime use reaching 4.3 MWh. The large battery capacity allows improved vessel autonomy.

In practice, the charging process is improved compared to what is already available at the market; in this case charging is needed at only one end of the route. The sailing range between needed charging periods is also improved (2x13NM). The overall concept includes an innovative charging system with a fully automated shore connection. For the very high peak power and current needed of the specific vessel, a pantograph solution is being designed with the pantograph stretching out from the berth side and fixed conductors on board the vessel.

Another innovative element concerns the lightweight approach adopted with lightweight equipment and materials including composites for the superstructure. The ambition to eliminate oil for the machinery is taken also to hydraulics where the electrical drive train will deliver the power to all moving parts via electrical actuators (e.g. linear actuators for the bow door will be designed as part of this development). Composites are used for shipbuilding, but mainly for smaller size vessels. After extensive applications and research in the naval field, composites and other lightweight materials increasingly have entered the shipbuilding market. Applying composites for all or part of the superstructure for larger vessels such as conventional SOLAS ferries is new and innovative. The application of composites is related to reductions ιn weight (lighter&better superstructures), reduced building time, more cost efficient operation, increased comfort and decreased environmental impacts (Wenström, J.,2005). The only relevant project in this field is the Danish COMPAS project (COMposite super-structures for large PASsenger Ships) which aims at making the path easier for design and retrofit of composite superstructures for large passenger ships. While the COMPAS project will apply composites as a retrofit solution to the Scandlines ferries, the E-ferry project applies composites in building of new ferries.

Finally the introduction of modern and higher safety standards in the design criteria , the simple drive train design that also indicates that maintenance and repair cost will be lower and the ability to operate in ice conditions (up to 15-20 cm) are also considered innovative elements.

4.2. Competitive advantage and market potential

The market analysis of the new solution was based on an assessment of its competitive advantage in relation to five operational performance objectives (cost, quality, speed, dependability and flexibility) introduced by Slack et al. (2004). These were translated into the ferry operational environment and were further broken down into seven performance objectives as shown in the following table.

The E-ferry concept was also examined in terms of its potential in the EU ferry market. This potential is dependent of five main parameters: the average route length of the ferry market in question (1), the electricity grid in the geographical area (2), the national taxation regime on energy (3), the average age of the existing ferry fleet (4) and the environmental incentives built into tenders or national regulations (5). The analysis focused on the Scandinavian area and in particular on Denmark, Norway and Sweden. For those countries the market potential of the E-ferry concept was found to be in the range of 65 to 80 percent of the current domestic ferry market. The share was smaller in Denmark with a relatively new ferry fleet and higher in Sweden with a very old but also standardised ferry fleet. The Norwegian market is by far the largest but again national regulations and infrastructural challenges have to be met to penetrate the two latter country markets.

The analysis will cover at a second phase other important ferry market segments with particular focus on Greece, - the largest EU ferry market- and the North Sea coast of The Netherlands and Germany. For the particular case of Greece, the coastal passenger shipping system consists of passenger (pax) and freight-passenger (ro-pax) vessels, mainland and island ports, and coastal (multilink) and ferry (single/short-link) lines. The system employs ships of all types, such as mono-hull conventional open-deck and closed-deck vessels for passenger and passenger-vehicle transport, passenger and passenger-vehicle catamarans, passenger vehicle high speed mono-hulls (HSVs) and passenger carrying hydrofoils. The ferry transport network comprises main and secondary coastal lines distributed in nine basic island regions, as well as through straits crossings, which in total provide 1,500 connections between 40 mainland and 100 and island ports. The preliminary examination of the Greek case concluded with 3 major barriers towards E-ferry uptake: (1) the average route length of the routes is much longer than in Scandinavia, (2) the electrical grid requires investments from the government or other public and (3) the competition is fiercer making it difficult to guarantee the return on higher investment cost although running costs would be significantly lower in the long term.

Table 4. Performance Objectives assessment.

Performance Objective	Competitive advantages
Cost	Lower operation cost due to (1) the vessel's low energy consumption in combination with its lower energy price per energy unit (2) lower manning requirements (3) less need for maintenance
Speed	The innovative design & hull form allows for higher speed at restricted depths and in confined waters. At the same time higher oil prices and the requirement to reduce emissions has forced fares up or slow steam practices impacting travelling time and departure frequency negatively. Due to its independence of fossil fuels, the E-ferry will not have to slow steam as the prices for electricity was found to be both stable and predictable over time (GreenFerry Vision, 2015)
(Departure)Frequency	The frequency of departures is closely interlinked to speed of the ferry and the time spent at port. The second parameter is clearly a disadvantage compared to fossil fuel where bunker processes can be done fast or with long intervals of several days in some cases. The new concept proposes more and smaller ferries. This operational set up will
Dependability	The very simple design of ferry and its unrivaled redundancy of the complete drive train, with separated controlling units, no combustion engines or bunker oil involved, battery packs separated in several independent enclosed spaces and the very simple cargo deck layout, will most likely be experienced as a more dependable ferry operation. The improved wind stability criteria ensure that the E-ferry design is less exposed to weather problems and can continue sailing safely in higher winds than the existing island ferries on most Scandinavian routes. The E-ferry's power-to-weight ratio is very high making it extremely maneuverable. The higher departure frequency, if using a strategy of smaller but more ferries, will also mitigate the effect of delays to total travel time if passengers arrive late due to road congestion or delays in connecting public traffic modes.
Safety	Improved safety of the E-ferry compared to other small island ferries in Denmark and most other countries. Apart from the higher inherent redundancy in fully electrical operation, the design meets relevant national and international legislation and requirements including EU-directive 2009/45/EU and SOLAS. This design also meets the latest and highest intact stability criterion for ferries, being a two-compartment ship going well beyond the safety requirement for operation in coastal areas (category C & D normal trading areas for the typical island ferry). These very high safety standards means that the E-ferry could be operated in open seas, e.g. in the Mediterranean. The evacuation system is, like the rest of the E-ferry design, extremely simple and allows efficient crowd management and easy evacuation directly from the passenger accommodation on main deck without passing any staircases or similar
Comfort	The E-ferry design will meet higher wind stability criterions and at the same time a narrower hull form is expected to give the ship better sea keeping capabilities as known from elegant ferries in the past. At the same time passengers will be located closer to centre of gravity and therefore less exposed to accelerations from rolling in the sea. Noise levels will also be limited.
Environmental Quality	The zero-emission propulsion (given that electricity is charged from RES) will outperform any conventional competitor. For the life cycle assessment it is also found that battery packs can be recycled up to 99.7 % and therefore are not considered to result in significant environmental impacts.

5. Conclusions

The E-ferry concept that is presented in this paper is directly addressing the urgent need of reducing the increasing European CO_2 emissions from waterborne transportation.

Ferries are very popular in Europe, where more than one third of the world fleet operates. However, the EU ferry fleet is old and in need of newer, more energy efficient and less CO_2 emitting and polluting types. By far the majority of European ferries are older than 20 years. The situation is even more critical in the inland waterways sector, where the majority of the fleet is more than 30 years old.

The new fully electric concept aims to become a game changing approach to short and medium range ferry connections. The E-ferry concept goes beyond a sustainable transport solution targeting also cost effectiveness. Changing to the E-ferry concept is a typical case of higher investment cost against lower operational cost. However, the operational cost should also be seen in a broader sense including external cost and taking into account derived improvements in transport quality (expressed through cost, speed, frequency, dependability, safety, comfort and environmental quality). The E-ferry concept considers the cost balance in this broader perspective taking into account impacts to economic, environmental and social balances. Fortunately, despite of obsolete maritime and energy regulations, in many cases the e-ferry concept will be the most economically attractive choice. This means that, not only does the E-ferry eliminate CO_2 emissions and pollutants, it can present a cost-effective alternative.

The cost-effectiveness of the innovative shift towards electrically driven Short Sea ferries would benefit from changes of current regulations (e.g. if CO_2 quotas were to be imposed on shipping as for businesses on land). It could change the balance between up front finance cost and future running cost thus shortening the payback time and increasing the incentive for ship-owners to expedite investment in new E-ferry tonnage.

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