OPPORTUNITIES FOR ELECTRIC FERRIES IN LATIN AMERICA

Infrastructure and Energy Sector

Energy Division

Transport Division

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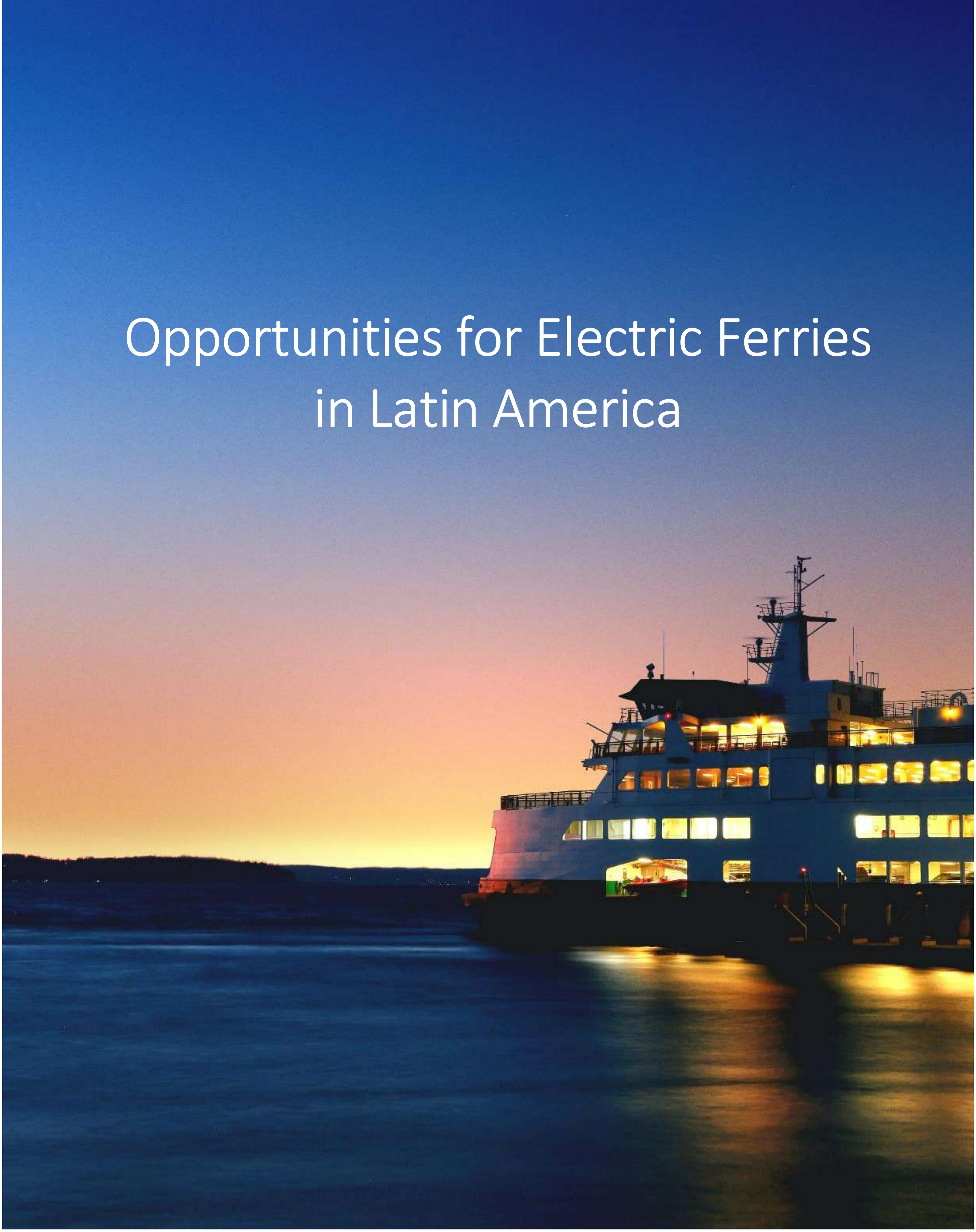
Opportunities for Electric Ferries in Latin America



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Liebreich Associates

Opportunities for Electric Ferries in Latin America

Liebreich Associates

February 2021

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1. EXECUTIVE SUMMARY

This report provides an overview of the opportunity represented by the electrification of inland and coastal ferries in Latin America.

In preparation of this report, four main pieces of research have been undertaken:

1) A review of electric ferry activity around the world and interviews with several project teams;

2) Construction of an economic model – the Latam E-Ferry Model (LEFM) – comparing the capital and operating costs of a typical mid-sized electric ferry to those of a conventional diesel-powered ferry;

3) Assembly of a data set of ferry routes in Latin America, and assessment of five initial candidate routes for electrification; and

4) Analysis of the electric ferry supply chain and identification of addressable market size in Latin America.

As a result of this work, a number of conclusions can be drawn and recommendations made.

SHORT FERRY ROUTES COULD FEASIBLY GO ELECTRIC TODAY

- Analysis of all known electric ferry projects around the world identifies three types of routes for which pure electric ferries could make sense in most countries of Latin America today:

    1. **Large ferries** (around 1,000 passengers and 150 cars) operating short routes (up to 5km one way).

    2. **Medium-sized ferries** (around 300 passengers and 50 cars) operating medium-length routes (up to 40km one way).

    3. **Fast catamaran ferries** (around 250 passengers, no cars) operating commuter or tourist routes (up to 90km one way).

- The maximum route length which can be served by each of these types of ferry will increase over time with improvements in battery energy density[1] and battery cost. We expect a doubling of energy density and an 80% reduction in cost by 2040 through scale-up and continuous improvements in current battery chemistries. Breakthrough chemistries currently in research and development, in particular solid-state batteries, could deliver energy densities three times greater than today, but most likely not for more than a decade.

- Smaller and faster electric ferries tend to be weight-constrained; larger ferries tend to be cost-constrained. As a result, we expect the Maximum Servable Route Lengths (MSRLs) to improve as shown in Table 1, assuming either a continuation of current learning rate trends or a breakthrough in battery technology.

[1] Note on units. Energy density in this report is defined as storage capacity per unit weight, measured in kWh/kg. The technical term for this would be gravimetric energy density or specific energy. In other literature, energy density may refer to storage capacity per unit volume, particularly where this is constrained, such as aviation.

	Constraint	2020 (trend)	2030 (trend)	2040 (trend)	2040 (breakthrough)
Large ferry (km)*	Cost	10	25	52	52
Mid-sized ferry (km)*	Density	45	68	92	>135
Fast catamaran (km)*	Density	90	137	185	>270

*** km figures are for one-way route lengths, including a reasonable margin of safety. Charging at one end only would halve the MSRL**

Table 1. Maximum Servable Route Lengths (MSRLs) by different target segments
Source: Liebreich Associates

OPPORTUNITIES EXIST ALONG THE ENTIRE SUPPLY CHAIN IN LATIN AMERICA

- The roll-out of electric ferries in Latin America presents opportunities along the entire marine transportation supply chain in the region. Overall, we believe it represents an estimated cumulative addressable market by 2040 of $6.8 billion.

- The largest opportunity, consisting of a cumulative addressable market by 2040 of around $4.1 billion, will accrue to the designers and builders of vessels. In order to exploit this market, however, they will need to master new skills, in particular in low-weight composites such as carbon fibre, and forge new industry partnerships.

- While Latin America has some of the world’s largest reserves of minerals used in the battery industry, it has not yet developed the local leaders in extraction, processing or battery manufacture. This is an issue that transcends the electric ferry sector.

- Electrification of ferries is also likely to present significant opportunities for large and small players in Latin America’s electrical engineering sector.

THE ECONOMICS OF ELECTRIC FERRIES ARE ATTRACTIVE

- The Latam E-Ferry Model (LEFM) developed for this report shows the following results for medium-sized ferries:

    - In the average Latin American country, electric ferries’ higher capital costs are more than offset by their lower maintenance, staff and fuel costs – even when taking into account the likely cost of periodic battery replacement during vessel life – for an average discounted net benefit of $2.7 million per vessel;

    - The economics in Latin America are generally not quite as favourable as in Europe due to lower labour costs and fossil fuel taxation, which reduce the benefits of moving away from diesel, and in some cases high electricity prices. Payback periods vary from 6 years in Trinidad and Tobago to 19 years in Jamaica.

    - Key sensitivities driving returns and pay-back periods are as follows:

    - Discount rate. Because electric ferries have higher capital costs but lower running costs than diesel ferries, their attractiveness is highly dependent on discount rates;
    - Liquid fuel versus electricity costs. Countries where fossil fuels are subsidised and electricity taxed make for worse economics; conversely, where power prices are cheap and fossil fuels are expensive, the economics look more attractive;
    - Investment required in shore-side infrastructure. Ports vary in the extent of their existing power infrastructure; also, different route and timetable profiles drive different charging requirements. The amount of investment required has a large impact on the economics of any route.
  - Looking across different countries of Latin America, for a standard 200-person, 20-car electric ferry, we see that routes in Colombia, Bolivia, Mexico, Peru, Suriname, Ecuador, Paraguay and Trinidad and Tobago are likely to see a payback period of around eight years. In the absence of policy intervention, projects in Barbados and Guyana are unlikely ever to reach payback, due to high power costs and low fuel costs.

ELECTRIC FERRIES COULD DELIVER SIGNIFICANT ENVIRONMENTAL AND SOCIAL IMPACTS

- Electrification of 100% of the ferry routes potentially electrifiable in Latin America by 2040 would deliver the following environmental benefits:
  - Saving of 471,000 tonnes of marine diesel per year, at a cost of $338 million, replaced by the consumption of 1.3 TWh of electricity – potentially renewable - at a cost of $202 million annually;
  - Emissions reductions of up to 1.3 million tonnes of CO_2 annually by 2040;
  - Significant improvements in air quality in port cities;
  - Reduction in the risk of fuel spills.
- There are also social benefits associated with the electrification of ferries, in terms of employment, gender, poverty reduction and human rights.

FOR LONGER ROUTES, A NUMBER OF OPTIONS FOR DECARBONIZATION EXIST

- A number of approaches for decarbonising routes beyond the Maximum Servable Route Lengths for pure electric ferries were identified and are worthy of further study.
- Routes that are longer than the 2020 MSRL but below the 2040 MSRL could benefit from an interim hybridisation approach, whereby the propulsion system of the ferry is electrified and battery-driven, but the vessel also carries one or more diesel or LNG generators. Further improvement in battery technology should then enable conversion to pure electric during a major planned retrofit.
- For routes that are longer than the 2040 MSRL in any foreseeable circumstances, options include biofuels, biogas, bio-LPG, hydrogen, ammonia or an e-fuel like methanol. It should be noted, however, that unlike battery-based electrification, these approaches are unlikely to be economically competitive with diesel within the coming decade.

FIVE POTENTIAL PILOTS WERE IDENTIFIED IN LATIN AMERICA

- Analysis showed that Latin America could see up to almost 90 electric ferry routes by 2040, served by more than 250 vessels;
  - 132 ferry routes under 750km were analysed, of which we estimated that 52 (39%) could feasibly switch to a mid-sized ferry using current battery technology, and up to 84 (64%) by 2040, based on expected improvements in battery performance.
- Five early candidate for pilots were identified, four of which could immediately be electrified, and one would be a candidate for interim hybridisation, as follows:
  - Florianópolis Santa Catarina, Brazil – mid-sized ferry;
  - Puntarenas to Playa Naranjo, Costa Rica – mid-sized ferry;
  - Caleta La Arena to Caleta Pulche, Chile – mid-sized ferry;
  - Cancun to Isla Mujeres, Mexico – fast catamaran;
  - Buenos Aires – Colonia del Sacramento/Montevideo – hybrid large ferry.

RECOMMENDED NEXT STEPS

The analysis contained in this report has identified a number of priority next steps if the electrification of ferries is to be pursued on an accelerated basis in Latin America.

Recommendations fall under the following six headings:

1. **Develop business plans for pilot routes**. For the five routes identified in this report as potentially attractive pilots, rapid progress is recommended. Next steps would be 1) developing a detailed operational, technical and financial model, and the associated business plan; 2) developing a business and implementation plan, with milestones; and 3) beginning discussions over finance and risk-sharing with relevant private and public stakeholders.

2. **Improve data to inform further route choices**. In order to identify further potential routes for early electrification – in addition to the pilots covered in this report – a comprehensive and more granular data set of short and medium-distance ferry routes in Latin America should be assembled. In addition to route length, frequency, and number of vessels, it would cover sufficient fields to estimate the cost and benefits of electrification.

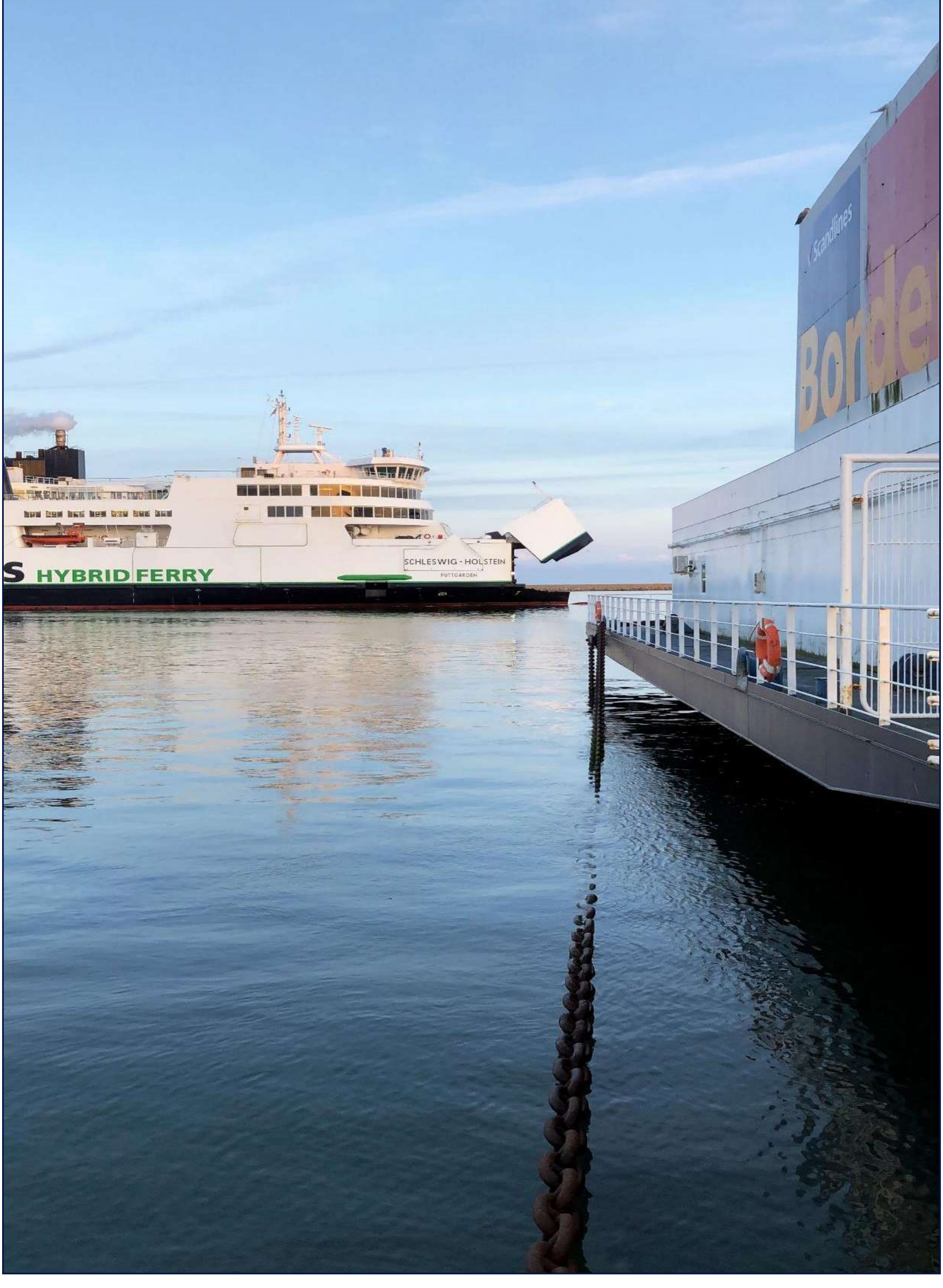
3. **Develop enabling environments.** Tax, subsidy, and tariff policy can have substantial impacts on project economics; other potential showstoppers can emerge during projects in the form of health and safety regulation, procurement processes, connection fees or port ownership structures. National and local regulations should be screened against these and other potential issues before projects are initiated.

4. **Establish funding mechanisms.** Initial projects, in particular, will need some level of grant or subsidy, or at the very least provision of concessionary finance. A dedicated facility, bringing together IDB and its private sector arm, IDB investment, as well as other multilateral development institutions – structured to encourage private capital providers – may be needed.

5. **Create a multi-stakeholder working group.** The roll-out of electric ferries across Latin America raises issues that will require industry-wide and continent-wide approaches in areas such as safety, financing, research & development and skills, which would lend themselves to the creation of a cross-sector working group. An existing body, such as the IDB Electric Mobility platform, could serve as a base. Supported by IDB and its partners, it is already providing technical advice to more than fifteen countries in the region with regard to policy, regulatory and enabling environments for electric mobility.

6. **Broaden to adjacent marine categories and other sectors**. The roll-out of electric ferries would be considerably accelerated by a continent-scale plan for a Latin American supply chain in batteries, and for the electrification of other marine and land-based transport sectors. Efforts should be undertaken to reach out and feed the results of this work into parallel efforts relating to the electrification value chain and to broaden it to other marine sectors.

Note: This report does not cover smaller community ferries or riverboats. Nor does it include leisure craft, fishing and utility vessels, tenders, tugs, or coastal freighters – all of which also offer opportunities for electrification. The need for further research covering these segments is covered in Recommendation 6.



Scandlines
HYBRID FERRY
SCHLESWIG - HOLSTEIN

2. GLOSSARY AND ACRONYMS

Table 2 Glossary

Ancillary services		Services procured by grid operators from power market participants in order to maintain a reliable and stable system
Battery Cell		Individual cell of a battery assembly
Battery Management System	BMS	Software system which manages the charging and discharging of batteries to ensure optimum performance and lifetime
Battery Module		Sub-assembly, consisting of multiple battery cells
Battery Pack		Assembly consisting of multiple battery modules, along with packaging and fire suppression systems, ready to be installed in a vehicle
Battery Electric Vehicle	BEV	Vehicle powered exclusively by electricity from battery storage
Buffer batteries		Batteries which slow-charge in port in order to reduce peak load on the electrical grid, and then rapid-charge the ferry's batteries
CAPEX		Capital expenditure
Dimethyl Ether	DME	Clean-burning, non-toxic, renewable fuel which could in theory be made as an e-fuel and act as a near drop-in replacement for diesel
Energy density		Amount of energy stored in a battery per unit weight. In other literature this is called the Gravimetric Energy Density.
Fire Suppression System	FSS	Integrated system to prevent, detect and suppress fires on board a vessel
High voltage		As per International Electrotechnical Commission, we define high voltage as above 1000V for AC and 1500V for DC
Hybrid electric ferry	HEF	Ferry with a propulsion system based on electric motors served a combination of batteries and diesel- or LNG-powered generators
Hydrogen Fuel Cell Vehicle	H2FC	Vehicle powered by hydrogen using a fuel cell – whether direct drive or driven via an intermediary battery
Latam E-Ferry Model	LEFM	A model of the economics of a 200-passenger, 20-car, 20km route ferry in Latin America, developed for this report
Levelized cost per km sailed	LCOS	The flat price that would need to be earned by a ferry operator per km over the vessels useful life to cover all costs and deliver the required return on capital to investors.
Liquified Natural Gas	LNG	Liquid form of natural gas, whose principal component is methane (CH_4), maintained as liquid at atmospheric pressure by cooling to -162°C (-260°F)

Liquified Petroleum Gas	LPG	Hydrocarbon fuel, consisting of Propane or (C_3H_8) or butane (C_4H_{10}), safely maintained as liquid at pressures below 10 atmospheres.
Lithium-ion	Li-ion	The most popular battery technology for electric vehicles, using some variant of Lithium-based chemistry
Lithium Iron Phosphate battery	LFP	Type of Li-ion battery
Lithium Nickel Cobalt Aluminium Oxide battery	NCA	Type of Li-ion battery
Lithium Nickel Manganese Cobalt Oxide battery	NMC	Type of Li-ion battery
Maximum Servable Route Length	MSRL	The longest route in km, including appropriate safety margin, which can safely be served by an electric ferry
Net Present Value	NPV	Sum of positive and negative discounted cashflows over an investment's lifetime
OPEX		Operating expenditure
Overnight cost		The initial capital cost for a vessel and its associated shore-side infrastructure, excluding costs of capital
Plug-in Hybrid Vehicle	PHEV	Vehicle with dual drive trains, capable of using either electric power or internal combustion
Power Purchase Agreement	PPA	Long-term contract under which electricity is purchased from a power project
Spodumene		Pyroxene mineral consisting of lithium aluminium inosilicate, LiAl(SiO3)2, which is a source of lithium for the battery industry
Synthetic fuel		A range of potential liquid fuel types including methanol, propanol, butanol and dimethyl ether, made either by combining electrolysed hydrogen with captured carbon or via a biomass-to-gas-to-liquids pathway


ELLEN

3. INTRODUCTION

Electrification is gaining momentum throughout the world's transportation system. Most notably, of course, in the market for cars, buses, two-wheelers, urban rail and light trucks – but the trend is set to go far beyond those sectors: delivery vehicles, municipal vehicles, commercial and industrial vehicles, even long-distance rail, general aviation and short-haul aircraft are being reimagined with electric powertrains.

The trend towards electrification will, without doubt, also transform coastal and inland water-borne transportation. While limits to energy density mean that ocean-going ships will never rely purely on batteries – hydrogen, ammonia, methanol, dimethyl ether and other energy carriers are being discussed instead – even they will switch progressively to hybrid-electric propulsion systems. Short-distance vessels of all sorts, however, will be dominated by battery-based solutions, for both cost and performance reasons.

This report focuses on electric ferries. These can already offer improved economics vis-à-vis conventional diesel ferries on short and medium-distance routes: their up-front cost and that of shoreside charging infrastructure may be higher, but their running costs are lower. It is not just that electricity is cheaper than marine diesel; crew and maintenance costs are also lower. The main propulsion diesel engine is replaced with simpler electric motors and batteries; gearboxes, vibration isolators, fuel tanks, fuel lines, engine ventilation, cooling, and exhaust systems are all eliminated, as is the need for an onboard generator to meet ancillary electrical loads; and propeller shafts and their bearings can be replaced with electrical connections.

In many ways, electric ferries are simply better vessels than their diesel equivalents: cheaper to run, and eliminating the exposure of crew and passengers to vibration and noxious exhaust gases. They also offer significant potential environmental benefits in terms of reduced CO_2 emissions, improved air quality and reduced fuel spill risk.

Figure 1. Danish electric ferry Ellen
Image: Erik Christensen/ Wikimedia Commons

A shift to electric ferries is not just about improving Latin America's transport system. It also represents an opportunity to create new value chains and industrial champions in the region. Latin America has the capacity – in raw materials, shipbuilding, manufacturing, electrical engineering and software – to be a winner in a world moving to electric marine transport.

The rest of the report is structured as follows:

- Chapter 4 – Survey of international electric ferry activity. The chapter reviews all electric ferry projects known to the authors.

- Chapter 5 – Technology and value chain. The chapter provides an overview of developments in the technology relating to maritime transport.

- Chapter 6 – Economic analysis. The chapter compares capital and operating expenditures of diesel and electric ferries.

- Chapter 7 – Environmental and social impacts. This chapter analyses the potential benefits of electric ferries in the region in terms of greenhouse gas emissions and air quality, as well as highlighting some implications for a just transition.

- Chapter 8 – Decarbonization options for longer routes. Here we take a brief look at some of the technological options for decarbonizing routes which are too long for pure electric ferries, including the concept of interim hybridisation.

- Chapter 9 – Selection of early pilot routes in Latin America. The chapter describes 6 Latin American routes and identifies which ones could progress rapidly towards electrification.

- Chapter 10 – Recommendation and next steps. The chapter presents recommendations for policy-makers and other key stakeholders.


MARIA
BOATS4U

4. SURVEY OF WORLDWIDE ELECTRIC FERRY ACTIVITY

The authors undertook a review of 35 existing and 20 planned electric ferry operations worldwide. Desk research was supplemented with phone interviews with the teams behind a number of high-profile projects. A full, detailed list of projects can be found in Appendix I

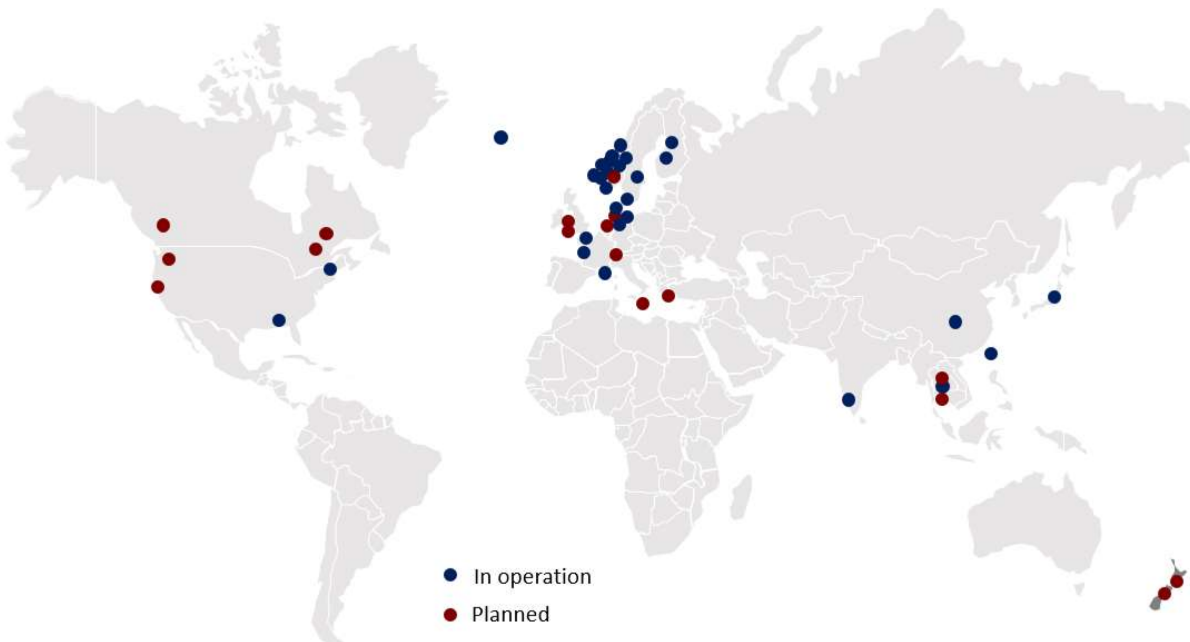


Figure 2. Map of known electric ferry projects worldwide
Image: Liebreich Associates

It is possible to synthesise from these projects the following use cases, which could already be served by pure battery-electric ferries:

1. Large ferries (around 1,000 passengers, 150 cars) operating short routes (up to 5km)

2. Medium-sized ferries (around 300 passengers, 50 cars) operating short and medium routes (up to 40km)

3. Fast catamaran ferries (250 passengers, no cars) operating commuter or tourist routes (up to 90 km)

In addition, there are examples of hybrid-electric ferries being used in two further use cases:

4. Large ferries (around 1,000 passengers, 150 cars) undertaking longer routes (over 60km)

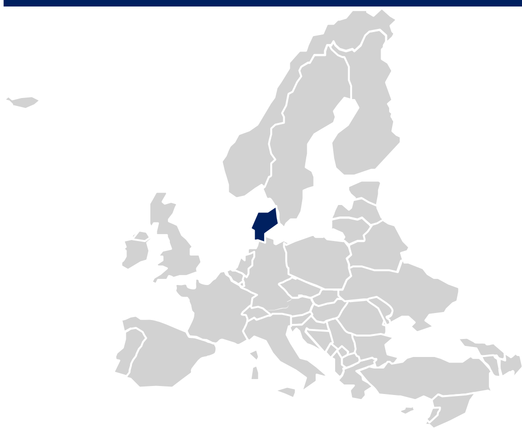
5. Commuter ferries undertaking chained routes, electric or switching to electric in city centres for air quality reasons.

In the following pages you will find examples of these use cases.

<table>
<tr><th colspan="3">MV Ampere – Norway
Medium-size electric ferry operating a short, frequent route
360 passengers, 120 cars, 5.9km, 17 round trips per day</th></tr>
<tr><th>Region</th><th colspan="2">Route map</th></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th>Specs</th><th>Route</th><th>LatAm equivalent</th></tr>
<tr><td>• Dimensions (L/B/D) 79.4 x 21.4 x3.7m
• Size: 360 passengers, 120 cars
• Gross tonnage 1598 t
• Power: 2x 450 kW motors
• Battery: 1 MWh
• Speed: 10 knots
• Charging: from batteries installed at both harbours</td><td>• 5.9 km between Lavik and Oppedal
• 17 return trips a day</td><td>• Fjords in Patagonia: routes like Primera Angostura (Magellan Strait)
• Ilhabella – São Sebastião</td></tr>
</table>

MV Ampere was the first fully electric car ferry in the world to enter operation. It was constructed after one of the biggest Norwegian operators, Norled, won the competition to operate the Sognefjord crossing between Lavik and Oppedal (northern Norway) in 2011. The Norwegian Ministry for Transport stipulated that the operator had to develop an environmentally friendly vessel – but would receive a 10-year license for the route. In 2015 MV Ampere made its maiden voyage. The vessel is a twin-hulled catamaran, capable of carrying 120 cars and 360 passengers. Costs of the projects were not disclosed; experts estimate the full cost, including charging infrastructure at around €18.7 million (20 million NOK).

Local grids in Lavik and Oppedal were fully carbon-free, as all power was sourced from local hydroelectric plants, but were unable to handle super-fast charging that would be required on this busy route. Buffer battery packs were therefore installed at both harbours. To minimise electricity costs, they are charged at reduced rates during off-peak hours. The ship has been in use since 2015 and in 2018 it made 98.7% of its trips as scheduled.

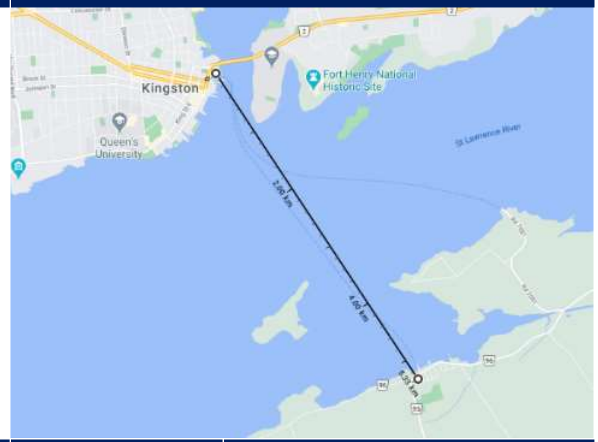
<table>
<tr><th colspan="3">Ellen – Denmark
Medium-sized electric ferry operating medium-length route
196 passengers, 31 cars, 20km, 5 return trips per day</th></tr>
<tr><th>Region</th><th colspan="2">Map</th></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th>Specs</th><th>Route</th><th>LatAm equivalent</th></tr>
<tr><td>• Dimensions (L/B/D) 59.4 x 13 x 3.7m
• Size: 196 passengers, 31 cars
• Gross tonnage: 996 t
• Power: 2x 700 kW motors
• Battery: 4.3 MWh
• Speed: 13.5 knots</td><td>• 20km between Fynshav and Søby
• 5 return trips per day
• Charging: One harbour equipped with ultra-fast charging system</td><td>• Fjords in Patagonia, Caribbean islands
• Punta Arenas - Porvenir (Tierra del Fuego)
• Ilha Grande - Angra dos Rei
• Vera Cruz - Salvador</td></tr>
</table>

Ellen is one of the most powerful e-ferries in the world. Built as a prototype, aiming to prove that electric ferries can be economically viable for medium distances, it operates on a 20km route between Danish islands of Als and Ærø. The ship, sailing at 13.5 knots per hour covers the 2-hour return trip, requiring only 40 mins of charging. To reduce costs, infrastructure was installed only in Ærø, meaning the ship makes a full return trip of 40km between charges.

Ellen has been in operation since August 2019 and has achieved positive results both in terms of reliability and passenger satisfaction, with around 20% of passengers indicating that they would consider using the service more often due to its environmentally friendly features and reduced noise levels.

The project was supported by the EU Horizon 2020 technology programme, which provided €15 million out of the total cost of €21 million (including charging infrastructure). The developer claims that the cost of a 'third of a kind' project would be significantly lower, at €16.3 million (also including charging infrastructure). For comparison, a newly built diesel ferry with similar specifications would cost around €14.1 million, while a used boat would be slightly cheaper at €12.9 million.

This is the project on which the Latam E-Ferry model was based, adapted for the Latin American costs and context.

<table>
<tr><th colspan="3">Wolfe Islander IV – Ontario, Canada
Medium-sized electric ferry operating a short route
400 passengers, 83 cars, 5km, 20 return trips per day</th></tr>
<tr><th>Region</th><th colspan="2">Map</th></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th>Specs</th><th>Route</th><th>LatAm equivalent</th></tr>
<tr><td>• Dimensions (L/B/D) 98 x 20 x 3 m
• Size: 399 passengers, 83 cars
• Gross tonnage: 1754 t
• Power: 4x 520 kW motors (and a diesel backup)
• Battery 4 MWh
• Charging: no information yet
• Speed: 11 knots</td><td>• 5km between Kingston and Wolfe Island
• 20 return trips per day</td><td>• Puntarenas – Paquera
• Puntarenas – Naranjo
• Vera Cruz - Salvador</td></tr>
</table>

Ferries are the only mean of public transport serving Wolfe Island and Amherst Island in the Canadian province of Ontario. They carry not only residents but also tourists attracted by the area's natural beauty. With almost a million passengers annually using ferries to reach Wolfe Island, it is clear how important they are for the local community and economy.

The ferries are operated by the province and are free of charge. The cost of the two electric vessels was $61 million dollars. They are to start operating in the coming year.

<table>
<tr><th colspan="3">MF Tycho Brahe/MF Aurora – Sweden/Denmark
Large electric ferry operating at high frequency on short route
1250 passengers, 250 cars, 5km, 22 return trips per day</th></tr>
<tr><th>Region</th><th colspan="2">Map</th></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th>Specs</th><th>Route</th><th>LatAm equivalent</th></tr>
<tr><td>• Dimensions (L/B/D) 111 x 28.2 x 5.5m
• Size: 1250 passengers, 240 cars
• Gross tonnage: 11,148 t
• Power: 4x 1.5 MW motors
• Battery: 4.1 MWh
• Speed: 14 knots</td><td>• 5km between Helsingør, Denmark and Helsingborg, Sweden.
• 22 return trips per day
• Charging: Both harbours equipped with ultra-fast charging system</td><td>• Chacao – Pargua
• Primera Angostura (Tierra del Fuego)</td></tr>
</table>

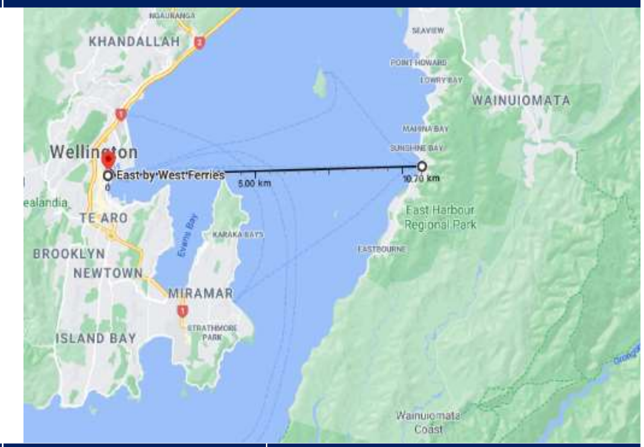
In 2017 two ships, which were both built in 1991, serving the route between Helsingør, Denmark and Helsingborg, Sweden, underwent a full retrofit including electrification.

The vessels are capable of carrying 1,250 passengers and 240 cars, with a sailing speed of 14 knots. The operator, ForSea, decided that the diesel engines would be retained as a backup, but they are not used in daily operations.

4.1 MWh of batteries were installed on each vessel, allowing for three full crossings of the 5km strait without charging. However, to extend battery life and avoid going below 30% state of charge, the vessel is charged in both ports while passengers are boarding. As the route is extremely busy (more than 40 return trips per day), high voltage lines were installed, and charging takes place at around 10 MW.

The cost of converting the two vessels was 300 million Swedish crowns (€28 million), with the EU providing 120 million SEK (€11 million). Expected payback period is 8 years, while useful life of the vessels after the retrofit is estimated to be at least 15 years.

East by West Ferries, Wellington Harbour – New Zealand
Fast electric catamaran ferry operating as a part of public transport
130 passengers, no cars, 10km, 8 return trips per day

Region	Map
	

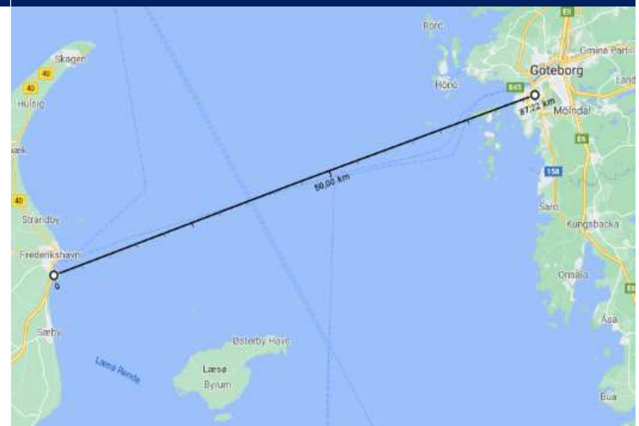
Specs	Route	LatAm equivalent
• Dimensions (L/B/D): 18.5 x 7 x 1.2m • Size: 130 passengers, no cars • Power: 2x300 kW motors • Battery: 0.525 MWh • Charging: Three crossings on batteries with quick recharges, 1h long charge. Currently charging at 300kW, plans to update to 1.1 MW • Speed: 20 knots	10km between Queens Wharf and Days Bay 8 return trips a day	• Isla Mujeres – Cancun • Chiquila – Holbox • Cozumel – Playa del Carmen

The ferry across Wellington Harbour, operated by catamaran boats with a service speed of 18 knots, is a popular option to avoid a congestion-prone 20km drive around the harbour. The route is currently served by passenger-only vessels (no cars) and is a part of the public transport system in Wellington.

Recently, the Wellington ferry has become popular amongst tourists as well as commuters because of the scenic views. This fact, alongside a broader push towards energy transition in New Zealand, led to a decision to electrify the route. When it begins operation at the beginning of 2021 it will be the first electric ferry in the Southern Hemisphere, and one of the fastest in the world.

The provision of charging infrastructure turned out to be a challenge as the Wellington Harbour area is an upscale neighbourhood, so it was impossible to undertake the heavy engineering works required to install high voltage cables: chargers with lower power rating were used instead. The ship is built out of carbon fibre to conserve weight and enable the high speeds required.

Stena Jutlandica – Denmark
Large hybrid ferry operating longer distances at lower frequency
1500 passengers, 550 cars, 90km, 2 return trips per day

Region	Map
	

Specs	Route	LatAm equivalent
• Dimensions (L/B/D) 184 x 28 x 6 m • Size: 1500 passengers, 550 cars • Gross tonnage: 29,691 t • Power: 25 MW engine • Battery: 1 MWh/20 MWh*/50 MWh* • Charging: details of future stages not presented yet • Speed: 21.5 knots *planned	90km between Frederikshavn-Gøteborg, 2 return trips a day	•Buenos Aires – Montevideo •Scarborough – Port of Spain •Roatan – La Ceiba

Stena Lines, one of the biggest ferry operators in Northern Europe, embarked on a step-by-step process of electrification of one of its biggest vessels in 2018.

Stena Jutlandica's bow thrusters are now almost fully battery-powered, which dramatically reduces the use of diesel fuel in port. This was achieved with a 1 MWh battery pack. In phase two, up to 20 MWh of batteries are to be installed, powering two of the four engines, allowing the vessel to sail an 18.52km section of the route within the Gøteborg archipelago using batteries alone. In the third phase, with a 50 MWh battery pack installed, the vessel would be fully electric and able to cover the whole route between Frederikshavn-Gøteborg using just battery power.

The first stage of electrification was co-funded by the Swedish Transport Agency and the European Union, which together covered 50% of the cost.

MS Gaarden - Germany
Mid-sized hybrid ferry operating within a city public transport system
300 passengers, no cars, shuttle operation

Region	Map
	

Specs	Route	LatAm equivalent
• Dimensions (L/B/D) 32 x 9 x 2.4m • Size: 300 passengers, 40 bicycles • Power: 2x 255 kw electric + 2x305 kw diesel motors • Battery: 349 kWh • Speed: 11 knots • Charging: Overnight	• F1 route between Bahnhofbrucke and Laboe	• Sao Paulo ferry system • Rio de Janeiro ferry system • Florianópolis ferry system

The commissioning of hybrid ferry “MS Gaarden” was undertaken by the municipal authorities in Kiel, a port city in northern Germany, mainly in order to limit air pollution.

The vessel operates on the F1 route between the central railway station and outer parts of the city located closer to the sea. It is a hybrid ferry: while batteries are used to power engines when sailing through the central part of the city, clean-burning gas-to-liquid fuel is used in the outer part of the fjord. Sailing speed is 11 knots, and batteries are charged overnight.

The MS Gaarden cost €4.5 million, of which federal subsidy met a total of €0.6 million.

The municipal transport company is planning in the near future to order three more hybrid ferries and one solar-powered battery electric ferry for €4 million each, with the federal government contributing a total of €3.2 million.

Stakeholders view on completed projects

Stakeholders involved in the projects assessed generally consider them to be successful, in particular, those in the Nordic countries, which typically have more years of operating experience behind them.

Norled, the operator behind the first electric ferry, MV Ampere placed several new orders for electric ferries after the success of the pilot. Chairman of Norled, Ingvald Løyning, said in a press release from November 2018: "It is worth investing in green technology - both for the environment and for the wallet. Of course, there are some starting costs that need to be taken into consideration, but over time, we see that green technology is good business".

Electric vessels have also been recognised by industry experts, with battery-powered ferries winning Skipsrevyen's "Ship of the year" award in 2018 and 2016. Both were delivered Brødrene Aa, producer of lightweight catamarans and ordered by the same operator – yet another proof that pilot projects are successful.

Although the body of research into passengers' opinions on electric ferries is limited, the existing surveys (conducted as a part of the Ellen E-Ferry project) suggest that passengers value the increased comfort of operations and appreciate the environmental benefits.

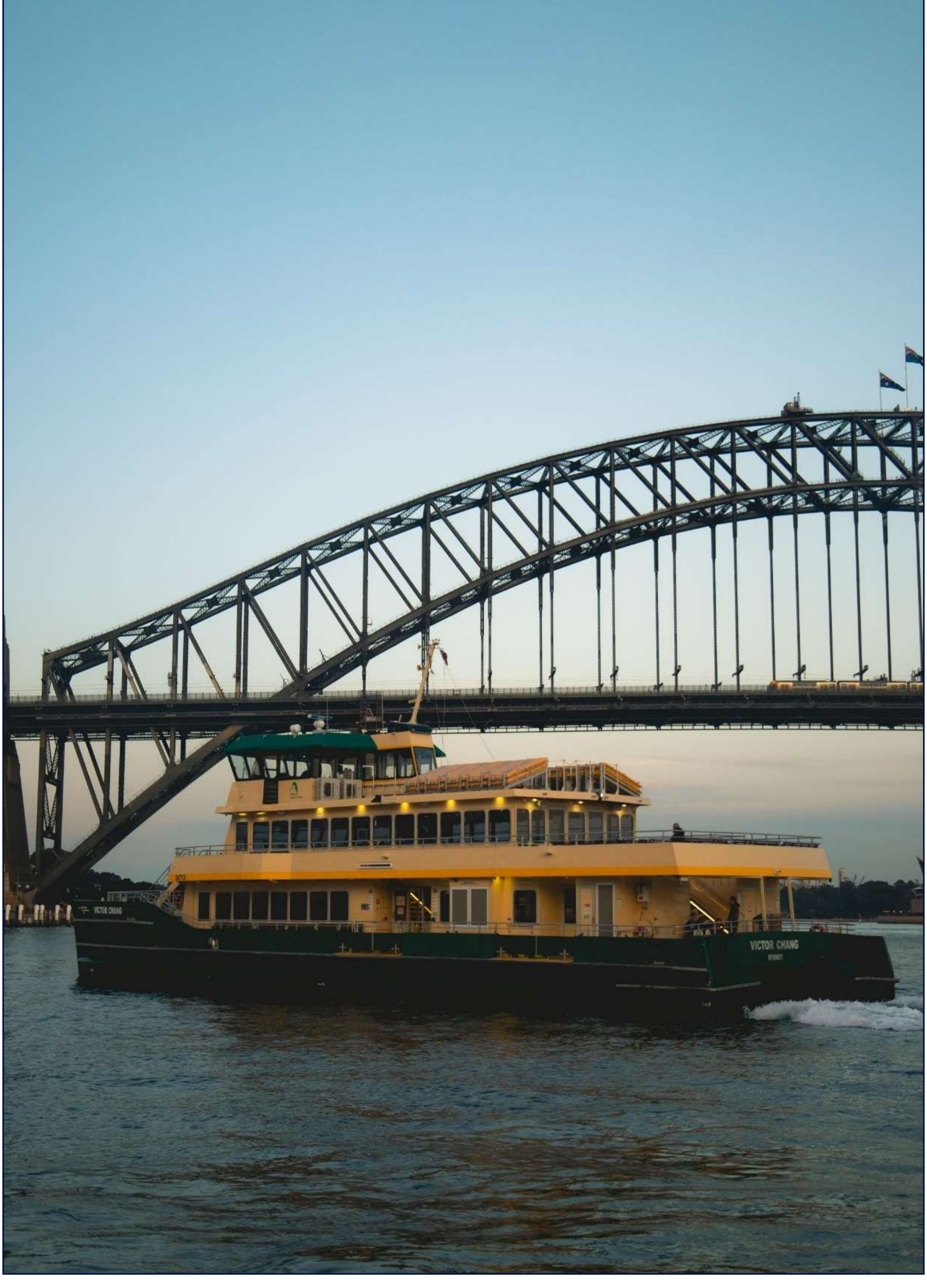
Accident protocols and safety issues

Presence of batteries onboard adds a new risk for operators of electric ferries to manage – in case thermal runway of batteries might lead to a fire.

On 10th October 2019, the Ytterøyningen hybrid ferry [1] in Norway, constructred by Corvus Energy, experienced a battery fire while running on its diesel engines. The vessel was able to moor, and all passengers, crew and vehicles were able to disembark without injury. Investigators concluded that the cause of the fire was a leakage in the battery coolant circuit.

As a result of this incident, there is a concern that electric ferries might be less safe than their diesel equivalents. However, according to a study[2] conducted by Maritime Safety Research Centre at University of Strathclyde together with representatives of Fjellstrand AS and Kolumbus AS, battery powered fast ferries are as safe as their diesel-powered counterparts, with similar accident frequencies for both type of ships. The authors of the report found further room for improvement, suggesting moving the battery room to the main deck is the most cost-effective way of increasing safety levels.

The investigation into the Ytterøyningen accident stressed the need for the battery to be connected to the ship systems at all times, in order to enable their condition to be continuously monitored.


VICTOR CHANG
SYDNEY

5. SUPPLY CHAIN OPPORTUNITIES

In this chapter, we look at the implications of electric ferries along three main segments of the value chain: battery supply; system and vessel design and build; and onshore infrastructure and power procurement.

Despite its strength in raw materials, Latin America has no significant presence in battery manufacturing, something that will need to be addressed as electrification spreads through all transportation sectors. By contrast, the region does have well-developed shipbuilding and electrical industries; electrification of ferries will require these to be brought together in an unprecedented way.

Overall, we estimate that the roll-out of electric ferries in Latin America represents a cumulative addressable market of $6.8 billion by 2040.

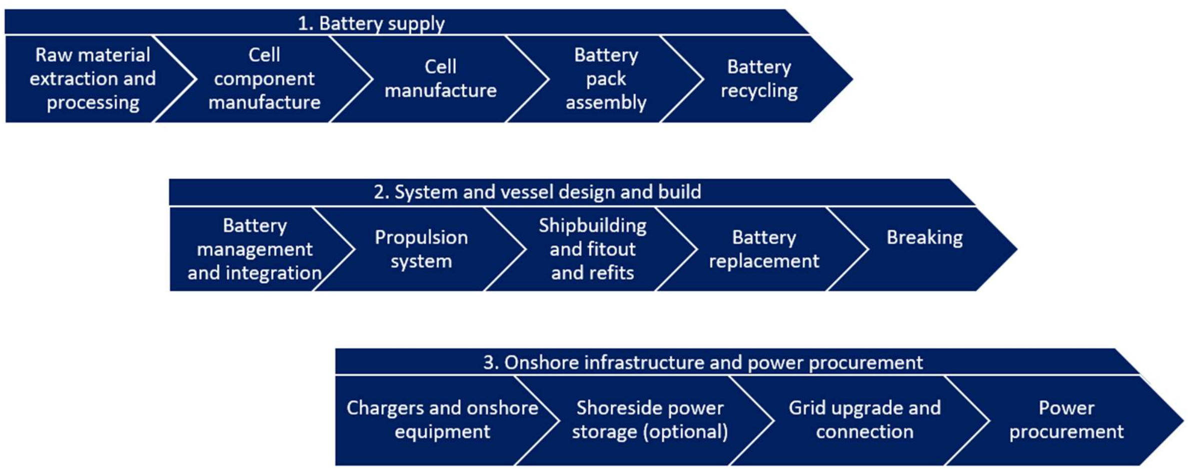


Figure 3. The electric ferry value chain – on a full life-cycle basis – divided into its three main segments
Image: Liebreich Associates

5.1. Addressable market size

We estimate the cumulative addressable market for new-build electric ferries and associated shoreside infrastructure to be $6.8 billion by 2040. This is based on identification of 90 routes for medium and larger ferries which could be electrified, and a similar number of smaller ferries and new routes, each operated by an average of three vessels.

It is worth noting that this does not include very small community ferries and riverboats, nor does it include leisure craft, fishing and utility vessels, tenders, tugs or coastal freighters. Since these too offer opportunities for electrification, it is likely that the annual market for battery-powered marine craft of all sorts in Latin America will grow to several billion dollars per year by the end of the decade.

The $6.8 billion cumulative total addressable market by 2040 would be divided as follows between the different parts of the value chain:

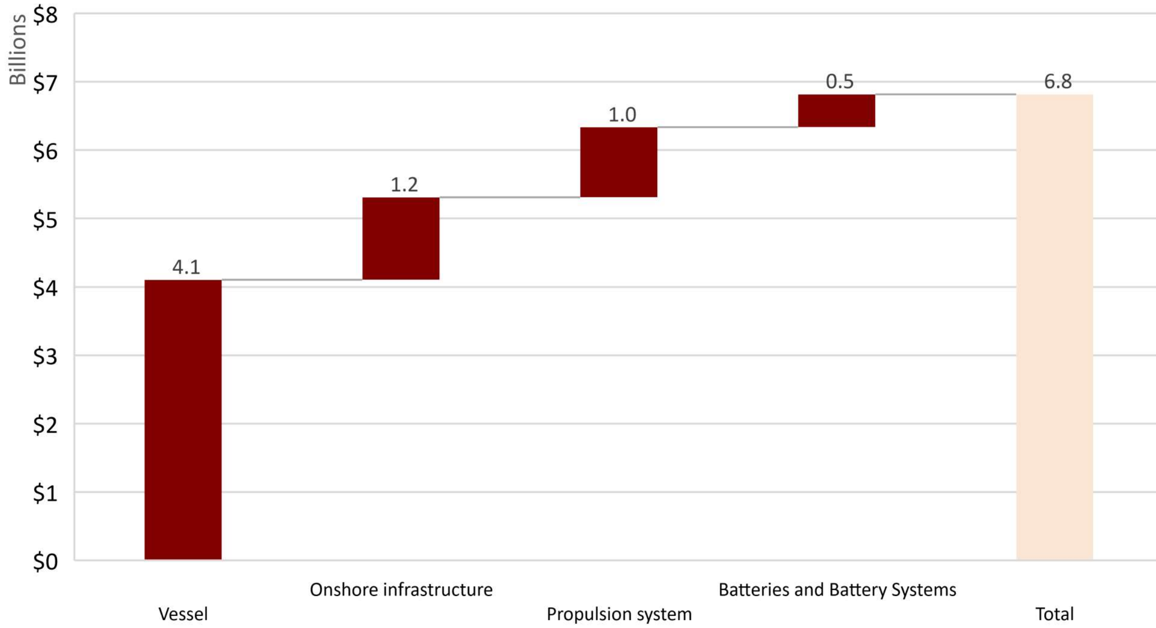


Figure 4. Cumulative addressable market for electric ferries in Latin America by 2040 (new build only)
Source: Liebreich Associates

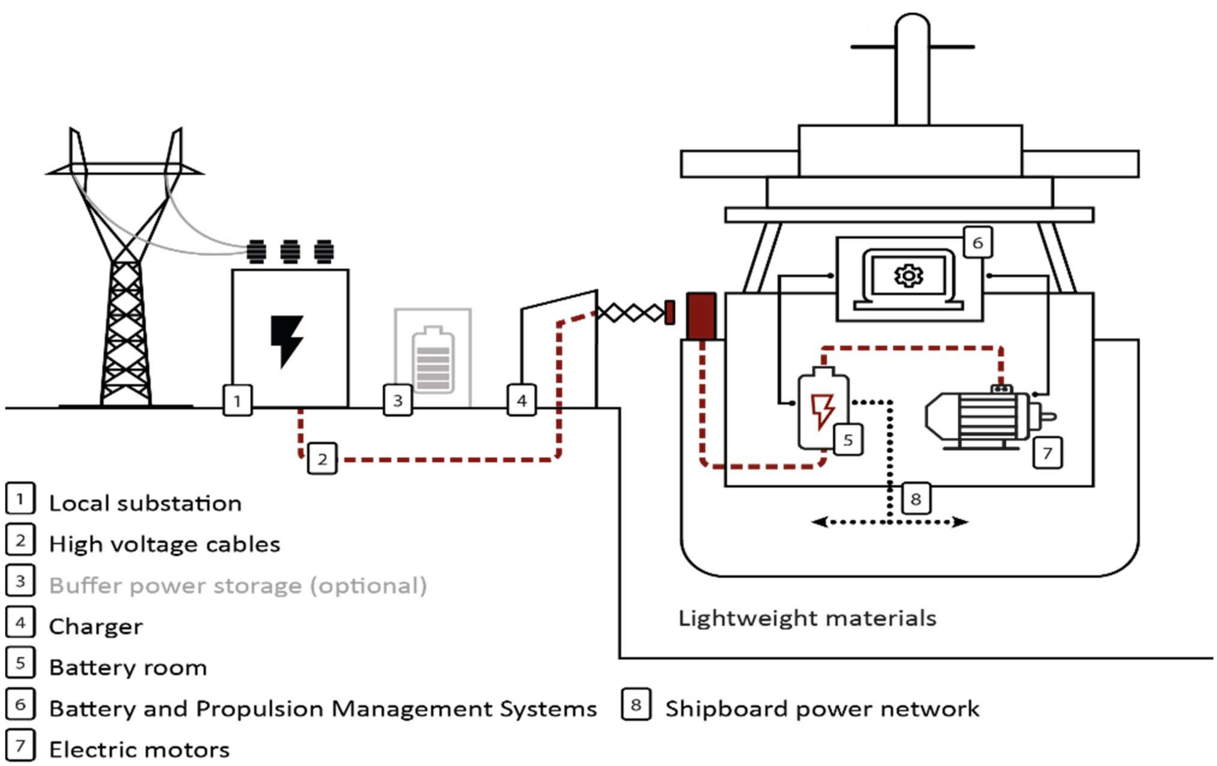


Figure 5. Schematic of an electric ferry and associated onshore infrastructure
Source: Liebreich Associates

5.2. Batteries and battery systems

The reason that so many short-distance ferry routes could today be switched to electric vessels lies with the dramatic improvements in cost and performance of batteries in recent years. This is part of a larger trend: a 2018 report by Cantor Fitzgerald, an investment firm, estimated that the global market for maritime energy storage equipment might be as much as $6.5 bn a year[3].

Despite having the world's largest reserves of lithium, there is no large-scale battery manufacturing industry in Latin America[4], something which may change in the near future. The development of a robust market for electric ferries would reinforce the logic of developing a regional battery supply chain as well as depending on such development for its economic competitiveness.

Chile and Argentina have the world's lowest variable lithium extraction costs, but after accounting for royalties and transport to Asia, where most producers are located, they are currently undercut by Australia. This could be about to change. Both countries are undertaking efforts to improve their competitiveness, as reflected in BloombergNEF's 2020 Global Lithium-Ion Battery Supply Chain Ranking, which shows their current rankings of 17th and 20th improving by 3 and 4 places respectively by 2025.

Moving up the value chain, Posco-Samsung have a 3,200 tonnes cathode production capacity in Chile, and in May 2020, Oxis Energy announced it would build a Lithium-Sulphur battery factory with a 70MWh of capacity in Brazil, in partnership with Minas Gerais Development Company CODEMGE.

According to our addressable market model, we estimate that the electric ferry market represents a cumulative addressable market for batteries and battery systems of $0.5 billion.

MANUFACTURING

The first stage of battery production is the mining and processing of lithium, cobalt, nickel, aluminium, manganese and graphite. Latin America has the world's biggest deposits of lithium, but the biggest single producer is Australia, due to the low cost of extracting its spodumene and exporting it to Asia, where the bulk of batteries are currently made. Chile and Argentina together accounted for 32% of the global lithium market in 2019.

The Democratic Republic of Congo (DRC) is the biggest cobalt producer in the world, providing around 70% of the global supply in 2019. Its extraction has been subject to significant concerns about human rights and child labour, in particular in the artisanal mining sector, which produces around 20% of the DRC's cobalt. The battery industry is responding by acting on three fronts: improved transparency of sourcing; upscaling of non-artisanal mining; and engineering cobalt out of its products.

Indonesia is the biggest producer of nickel, providing 30% of the global production in 2019. Other notable producers include the Philippines and Russia. The metal is widely recycled, with only half of US consumption being from newly mined nickel.

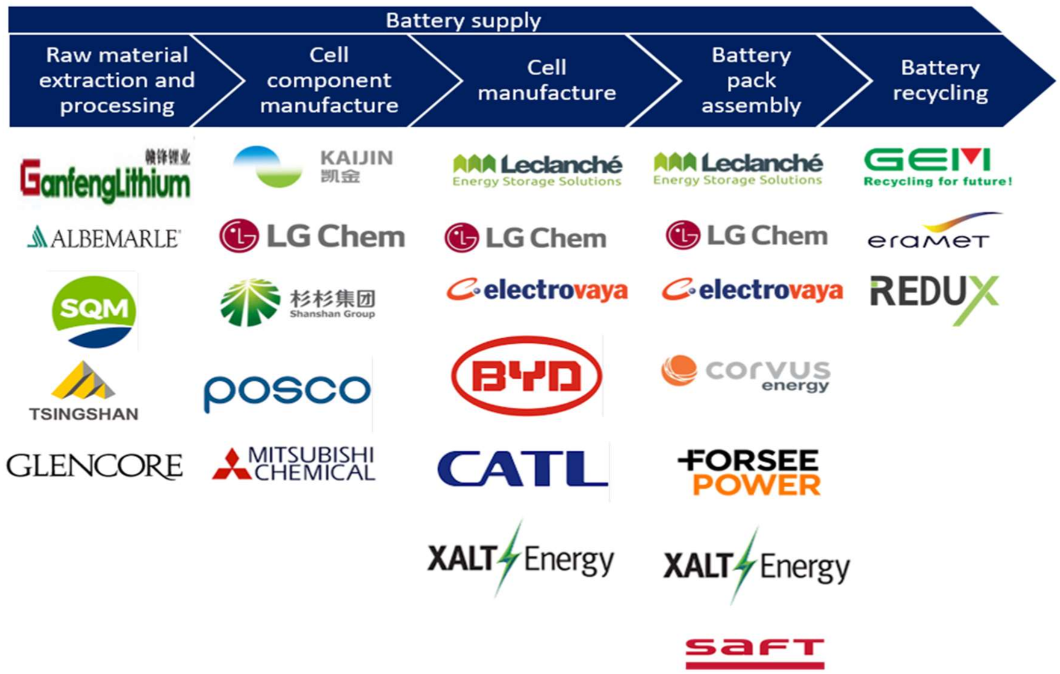


Figure 6. Battery manufacturing value chain and selected leading global players
Image: Liebreich Associates, logos of respective companies

Once processed, raw materials are fabricated into cathodes, anodes, electrolytes, and separators by specialist manufacturers.

These battery components are then assembled into cells. BloombergNEF notes that while cell manufacturing is currently highly concentrated in Asia, an ever-growing demand for EV and grid-connected batteries around the world – as well as fears over job losses in the automotive industry – is leading to a concerted push by policy-makers, particularly in Europe, to establish local factories.

CURRENTLY COMMON CHEMISTRIES

Since their market premiere in the early 1990s, lithium-ion (Li-Ion) batteries have been powering ever larger devices – from phones through laptops all the way, beginning just over a decade ago, to cars, and now buses and trucks. Electrifying ships is another step up in terms of scale: while it takes a 75 kWh battery to travel 500km in a Tesla Model 3, it takes 50 times that battery capacity to power a 240-car, 1250-passenger ferry on a busy 5 km route.

The most common battery chemistry for maritime solutions is currently lithium nickel manganese cobalt oxide (NMC). It combines a long cycle life with acceptable energy density. Other popular chemistries include lithium nickel cobalt aluminium oxide (NCA), which is similar to the NMC in terms of energy density but is currently more costly – it is used in EVs, most notably by Tesla.

A third notable chemistry is lithium iron phosphate (LFP), which has better thermal stability, meaning reduced fire risk. It is more capable of handling prolonged charging, but has lower energy density, making it less suitable for applications where weight is critical.

COST AND PERFORMANCE TRENDS

Experience curves for batteries are steep, with learning rates of around 18% – in other words, for every doubling of cumulative installed capacity, there is a 18% decrease in unit costs[5]. Since this learning effect can be expected to continue, over time longer and faster routes will become economically viable.

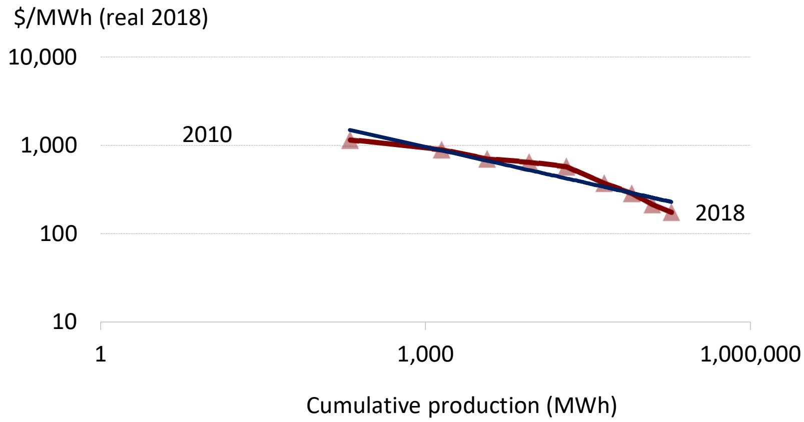


Figure 7. Experience curve for batteries, 2010 to 2018
Source: BloombergNEF

Technological progress is also visible in terms of energy density, meaning more energy can be stored within the same weight of battery. This is of crucial importance for electric ferries, as battery weight affects the overall tonnage of the ship. In many cases, it is the physical size and weight of the battery that acts as a limit to the length or speed of routes that can be operated, rather than the economics – so, as battery energy density increases, so does the addressable market.

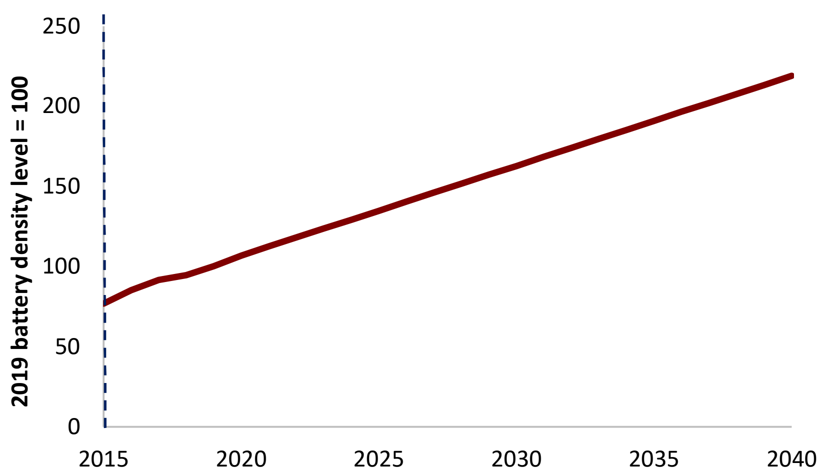


Figure 8. Battery energy density index (2020 = 100)
Source: BloombergNEF

MARINE BATTERIES

Marine vessel batteries will be bigger than those used in the automotive industry and must be designed for the very different operation conditions on board a ship. Certification requires the most rigorous insulation and fire safety standards to be met, so production is specialised, and unit costs are higher than for EVs.[6]

Since the use of electric propulsion in the maritime environment is much newer than in the automotive sector, costs are expected to drop more rapidly for around a decade before falling into line with the sector's overall decline rates.

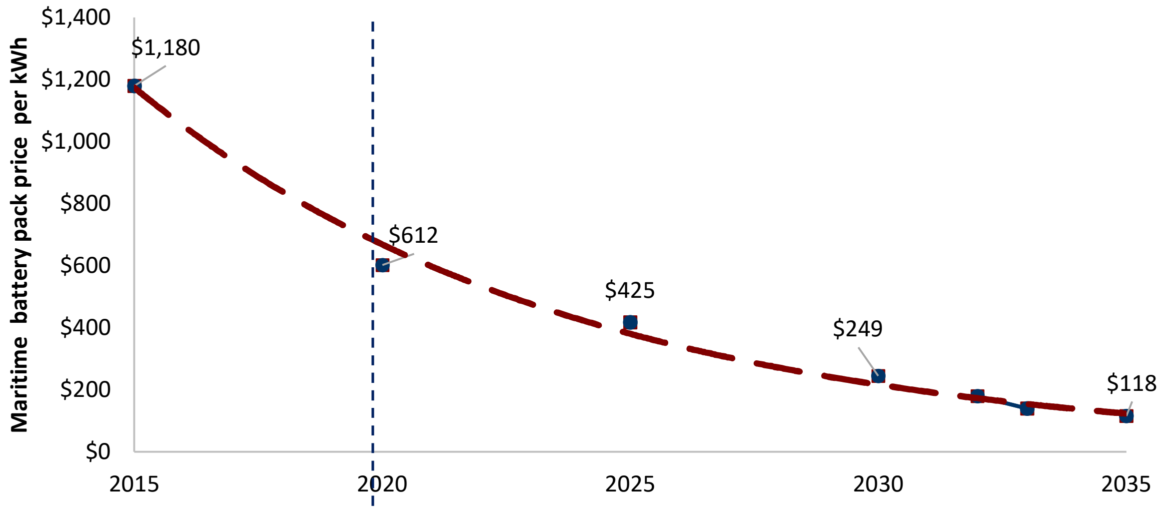


Figure 9. Expected marine electric vessel battery pack price forecast to 2035
Source: E-Ferry project, Leclanché; Liebreich Associates

FUTURE BATTERY CHEMISTRIES

While Li-Ion batteries dominate the electric transportation space today and continue to deliver performance improvements, a number of new chemistries currently in early development stages could potentially replace them, potentially driving a breakthrough in the Maximum Servable Route Length for electric ferries.

One way of improving the performance of next-generation batteries would be to use silicon anodes. Silicon has very high capacity, but it deteriorates rapidly with every charge cycle. A number of research projects are devoted to increasing its stability.

Another potential breakthrough would be solid-state batteries, using ceramic or glassy electrolytes instead of liquid ones. This would increase energy density by up to three times, as well as delivering improved safety – because of much lower risk of liquid leakage and flammability – and would allow the use of lithium-metal anodes, which react with liquid electrolysers and so cannot be used with them. Research suggests solid state batteries might also be charged faster and have longer life cycles. There are a number of companies producing solid-state batteries at a small scale (most notably a Toyota-Panasonic JV and VW-backed QuantumScape), but due to high costs, mass rollout looks to be a few years away.

Were one or more of these breakthroughs to be delivered, it would extend the length of routes that could be physically and economically served by electric ferries – possibly up to 270km one-way for a fast carbon-fibre catamaran.

Potential future Maximum Servable Route Lengths

Taking these trends together, we expect to see an increase in Maximum Servable Route Lengths (MSRLs) for the three sectors identified for electrification of at least two times, in the case of mid-sized ferries and fast catamarans, which are weight-constrained, and five times in the case of larger ferries, where the constraint is economic. Were there to be a breakthrough in battery chemistry, as promised by solid-state batteries, then even weight-constrained routes could be extended by a factor of three or more.

	Constraint	2020 (trend)	2030 trend	2040 trend	2040 (breakthrough)
Battery energy density improvement (index relative to 2020)	-	100%	152%	205%	300%+
Battery price ($/kWh)	-	612	249	118	118
Large ferry (km*)	Cost	10	25	52	52
Mid-sized ferry (km*)	Density	45	68	92	> 135
Fast catamaran (km*)	Density	90	137	185	> 270

*** km figures are for one-way route lengths, including a reasonable margin of safety. Charging at one end only would halve the MSRL**

Table 3. Maximum Servable Route Lengths (MSRLs) by different target segment
Source: Liebreich Associates

REPLACEMENT CYCLES

Despite recent improvements in battery lifetimes, it is expected that the first generation of electric ferries will need replacement batteries after around 10 years. Given that vessels typically have a useful lifetime of thirty years, there will generally need to be two battery replacement cycles. In the future, it may be possible to reduce this to just one battery replacement cycle after 15 years.

Expected improvements in battery energy density also mean that certain routes which cannot currently be served by a pure electric ferry, could operate until the first battery replacement as a hybrid, as described in Chapter 8 on options for decarbonizing longer routes.

Figure 10. Ellen's battery room
Image: Erik Christensen/ Wikimedia Commons

Figure 11. System and vessel design and build - value chain and leading global players
Image: Liebreich Associates, logos of respective companies

BATTERY PACKS AND BATTERY MANAGEMENT SYSTEMS

Battery cells are assembled into modules and battery packs that are ready to be installed in electric vehicles or vessels.

The safe operation and design lifetime of batteries is heavily dependent on sophisticated Battery Management System (BMS) to keep them between 30% and 80% charged. A modern BMS monitors each cell's state of charge, voltage, current, temperature (to ensure thermal stability) and so on, using the data to optimise charging and discharging, and increasingly uses machine learning to do so.

Battery management systems are then integrated with the Power Management Systems (PMS) that control the ship's propulsion system.

RECYCLING

In any ferry electrification project, it is important to take into account battery end-of-life issues up front.

The current generation of batteries will need replacement after around a decade, although leading battery providers expect packs produced in future to have a longer life. Once batteries reach the end of their service life, there are several things that can be done with them.

- The vessel, with its degraded battery can be moved to a shorter or slower route;
- The battery might be retained and re-purposed for shoreside power storage, to allow for more rapid charging of ferries without overloading the grid; this is the approach currently being analysed by Stena Group subsidiary Batteryloop[7];
- Batteries can be disassembled, and individual modules or cells that still perform well re-assembled into reconditioned battery packs;
- Cells that have genuinely reached the end of their life can be recycled to recover their mineral content. This is currently a nascent industry, due to the low volume of larger Li-ion batteries currently reaching the end of their lives, and 70% of all current Li-ion battery recycling takes place in China. Given the value of the raw materials, battery recycling can be expected to become a profitable industry, leaving no EV or ferry batteries to end up in landfill.

5.3. Shoreside infrastructure

A wide array of electrical works is required to enable seamless operations for an electric ferry: laying kilometres of high voltage lines, building local substations, installing charge-points and – in some cases – buffer batteries to smooth the demand for power from the local grid and avoid excessive peak charges.

All this should provide a strong source of business for the region's major electrical engineering players – such as Ingesat in Chile, Focus and SEP in Brazil or OBINAL in Uruguay – as well as for smaller providers.

The opportunities are substantial – according to the addressable market estimate presented above, the cumulative addressable market for onshore infrastructure for electric ferries in Latin America is around $1.2 billion by 2040.

CHARGERS

The connection of charging cables for electric ferries can be undertaken manually – for instance in the case of the early catamaran ferry project, *Future of the Fjords,* in Norway. Crew members connect two charging cables, each delivering 1.2 MW, to the vessel at the ferry station. Charging voltage is 1000V DC.

In most cases, however, charging connection is automated, for reasons of safety as well as time constraints. The high power and voltage used in the system make it hazardous to operate and for frequent connections with short turn-around times, as much time as possible has to be spent on charging itself, rather than connection. Combined with an auto-mooring system, automated charging also allows for a reduced number of crew members.

Karimi et al[8] present three types of automated charging solutions. *MF Aurora* and *MF Tycho Brahe* are charged using an autonomous robot arm that utilises a 3D laser positioning system. Another solution, used by MV Ampere, is Cavotec's Automated Plug-in System, using a tower from which a plug is released. E-ferry Ellen uses a Mobimar system that utilises the existing infrastructure (a car ramp) to connect the charger. With such a variety of systems and solutions used, there is as yet no common charging plug standard. The aforementioned vessels are all described in more detail in Chapter 4.

Figure 12. Ellen's battery charger, visible to the side of the ferry ramp
Image: Mobimar

The first projects to use induction charging have already been implemented on a short river crossing in Norway. These reduce time at each ferry stop and limit the cost of installing chargers.[9]

Figure 13. System and vessel design and build - value chain and leading global players
Image: Liebreich Associates, logos of respective companies

GRID UPGRADES AND CONNECTION CHARGES

With MWh-scale batteries and limited turn-around time on busy routes, many e-ferries require ultra-fast charging. This may require upgrading the grid connection to high-voltage supply – the costs of which must be figured into the business case for any route electrification project. It can also cause planning resistance, especially in big cities where ports may lie alongside prime real estate.

Alternatives include using existing low- to medium-voltage electrical connections, which reduces the cost of grid upgrades and connection fees but results in longer charging times. This makes it suitable only for routes with lower frequency. Other options include installing battery storage systems – known as buffer batteries – on-shore or on floating pontoons. These are themselves charged more slowly while the ferry is on route and then used to rapid charge the ferry without overloading the grid. This solution was successfully implemented on the Larvik-Oppedal route in Norway, where the MV Ampere operates.

Overnight slow charging is an economically viable option for short, less frequent routes. Batteries are fully charged when the vessel is not in operation, usually without the need to upgrade the local infrastructure. Electricity prices are often lower at night.

ELECTRICITY PROCUREMENT

For any electric ferry project, a significant volume of electrical power needs to be procured at low cost. This is quite separate from the purchasing of a grid connection and payment of connection charges – those cover only the hardware required to deliver the power to the quayside, but not the power itself.

At the simplest, the operator of an electric ferry can simply plug the vessel in when it is in the harbour and pay the resulting bill to the relevant utility. This naïve approach, however, has two important drawbacks. First, it is likely to result in a higher electricity bill than necessary. And second, it misses the opportunity to use the development of an electric ferry to increase the volume of renewable electricity generated locally.

The following strategies can be employed to reduce costs and increase the provision of clean energy:

- Forward purchasing. Because a ferry timetable is generally known a long time in advance, it should be possible to purchase power more cheaply in the forward markets than in the spot markets.

- Credit enhancement. Wholesale forward prices are normally expected to be lower for a municipality, as it would be perceived as lower risk than a private company. If the ferry operator is a private company, power prices might be reduced by offering the route under a PPP model (see section 6.4 on business models) or by securing payment guarantees from local or national authorities.

- Power purchase agreements. In cases where an operator expects to run the same route for an extended period, a decade or more, power might be bought under a power purchase agreement directly from a project developer, enabling them to build new renewable energy capacity. The power developer should offer a lower price since its risk is reduced by signing up a reliable long-term client. This is likely to be particularly attractive where the intention is for an electric ferry to operate specifically on wind or solar power, though attention must be paid to the total cost of power – including that needed to meet needs when there is no sun or wind.

- Ancillary revenues. In an increasingly large number of countries, power market participants can earn revenues by providing a range of ancillary services to the grid, such as frequency or voltage support, dynamic back-up or demand response. Because an electric ferry has a large battery, there may be opportunities to earn money by selling services into these markets, depending on route length, timetable and battery size.

Ultimately, the opportunity for an operator to manage the cost of power procurement will depend on utility regulation in the country and region in question. It is beyond the scope of this report to analyse where any of these approaches might be possible. For the modelling in Chapter 6, it was assumed that the power price was the average wholesale price paid in the relevant national market.

A good starting point for research on individual countries is the 2020 Climatescope report[10], originally developed in 2012 by BloombergNEF in partnership with the Multilateral Investment Fund of the Inter-American Development Bank Group, as well as the websites of national utility regulatory commissions.

5.4. Vessels

We estimate that electrification of short-haul ferries represents a cumulative $4.1 billion opportunity to the sector by 2040. Detailed analysis of the shipbuilding industry in Latin America is beyond the remit of this work, but this section looks at some of the main implications on it of electrification of ferries.

The skills required to play a leading role in ferry electrification as a shipbuilder differ in significant ways from traditional ones. Leadership will also require new partnerships – with battery and electric propulsion system providers, electrical engineering contractors, charger manufacturers, providers of finance and so on. Those shipyards nimble enough to navigate this landscape should reap the benefit of a new generation of high-value vessel procurements and earn the chance of becoming a regional leader.

Experience from Europe demonstrates that smaller shipbuilders have the agility required to create first-of-a-kind, tailor-made solutions. Fjellstrand AS, responsible for MV Ampere in Norway, has just one hundred

employees; in New Zealand, SSC Marine, designer of the electric catamaran due to start operating in Wellington Harbour, as well as the Wellington Electric Boat Building Company which is building it, are no larger. As the market grows, smaller players are expected either to scale up or to license their designs and other intellectual property to larger shipyards.

There could also be export opportunities: the two ships ordered by the government of Ontario (Wolfe Islander and Amherst Islander, described in Chapter 4) were built in a Romanian shipyard operated by a Dutch company, Damen.

Shipyards like Vard Niteroi in Brazil, which has experience in hybrid propulsion vessels, or Astillero Occidental in Paraguay, which recently completed a catamaran ferry of a size perfect for electrification, would appear to be well positioned for export throughout South and Central America, and possibly beyond.

VESSEL DESIGN

Electrification of ferries requires shipyards to adopt new design and construction approaches: it is not just a matter of swapping propulsion technology within an existing vessel design. Electrification involves more than just replacement of combustion with electric motors and fuel tanks with batteries: it also involves the removal of gearboxes, fuel lines, propellor shafts, exhaust systems, secondary generators and vibration management – to be replaced by fireproof battery compartments and much more sophisticated battery and propulsion management systems.

The emphasis on weight may necessitate the use of new construction materials. Other than battery energy density, vessel weight is the main factor driving Maximum Servable Route Length. For mid-sized ferries, the weight constraint is likely to require construction in aluminium, rather than steel, which is up to 70% heavier. Fast catamaran ferries will require composite construction – in glass or even carbon fibre, which is up to 45% lighter even than aluminium.

Figure 14. Carbon fibre hull of the Wellington fast catamaran during construction
Image: Wellington Electric Boat Building Company

Carbon fibre may even make economic sense for some larger ferries, despite higher capital costs, due to the reduced size of propulsion systems and batteries and lower maintenance costs. The cost of carbon fibre – both raw material and fabrication – is dropping precipitously, due to its steep learning effect. As a result,

over time the economics will tilt further towards the use of carbon fibre for electric ferries, particularly on any route where high speed is valued.

It should be seen as a strategic priority for Latin America to grow its carbon fibre design, supply and recycling capabilities – not just to serve the electric ferry sector – given the material's increasingly important role in sectors like aerospace, automotive supply, sports equipment and pressure vessels.

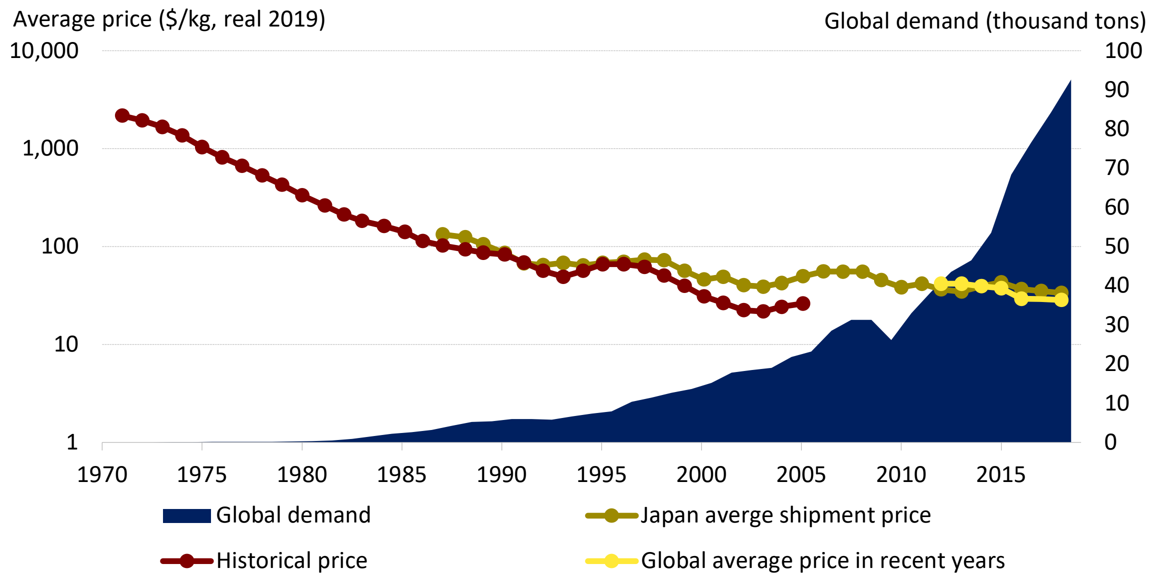


Figure 15. Global carbon fibre market size and average price
Source: BloombergNEF based on METI, Academic papers, AVK report


NORLED
AMPERE

6. ECONOMIC ANALYSIS

In this section we compare the economics of a mid-size electric ferry – 200 passengers and 20 cars – operating 5 times a day over a 41km route (return), with charging at one end, with the equivalent diesel vessel.

The starting point was data published by the Danish "Ellen" E-ferry project[11], for the estimated costs of a third-of-a-kind project – in other words excluding one-off pilot project costs, and assuming some modest scale in manufacturing has already been achieved – and the equivalent diesel. This data was localised to represent an average Latin American country, creating a base case Latam E-Ferry Model (LEFM).This model can also be used to examine the sensitivity to changes in input variables like interest rates, fuel and electricity costs, and to compare the potential returns available in different Latin American countries.

The first comparison, as described below in section 6.1., was the total ownership cost for vessels and associated shoreside infrastructure. This includes costs of periodic engine refits and battery replacements, but excludes financing costs. In section 6.2., we look at the discounted net present value of costs difference between a diesel and electric ferry, which includes the cost of capital.

Revenues, e.g. from ticket sales, were not taken into consideration. This reflects an implicit assumption that the choice of propulsion system makes no difference to route revenue, even though there is some anecdotal evidence that passengers, in particular tourists, prefer electric ferries. A detailed description of the assumptions behind the model can be found in Appendix II: Economic Model Methodology.

6.1. Base case

We used the LEFM to look first at overall differences in costs between electric and diesel ferries. As can be seen in Figure 16, total undiscounted costs over a 30-year lifetime are around 25% higher for a diesel ferry compared to an electric ferry. If divided over the total undiscounted number of km assumed in the base case model, the total cost per km for a diesel ferry equals to around $33.1/km and for the equivalent electric ferry around $26.6/km.

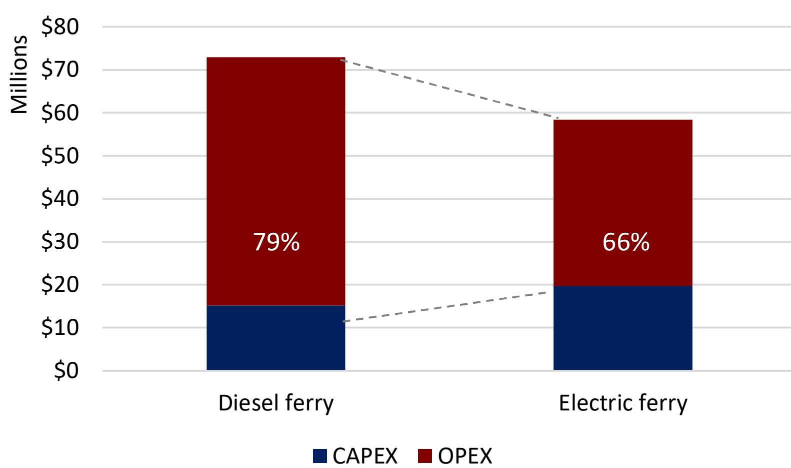


Figure 16. Total CAPEX and OPEX of an electric and a diesel ferry (undiscounted)
Source: Liebreich Associates LEFM

The initial "overnight cost" for the electric ferry, including shoreside equipment, are approximately one third higher than those of an equivalent existing diesel ferry. The vessel and propulsion system are simpler, resulting in some savings. However, the battery system, shoreside infrastructure and typical electrical connection fee more than absorb any savings.

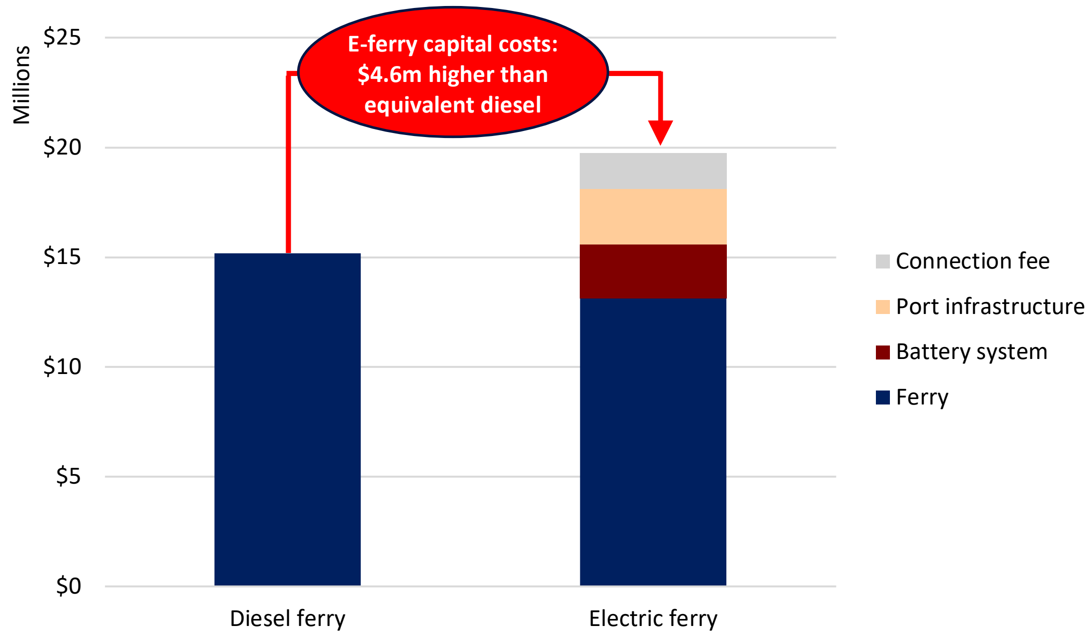


Figure 17. Capital costs breakdown of an electric and a diesel ferry (undiscounted)
Source: Liebreich Associates LEFM

When it comes to the operating costs, however, the advantage of the diesel ferry reverses, with operating costs for an electric ferry around 35% lower. The biggest avoided cost is the diesel itself, with the cost of electricity ferry in the base case 'average Latin American country' being only 53% of the bunker fuel cost.

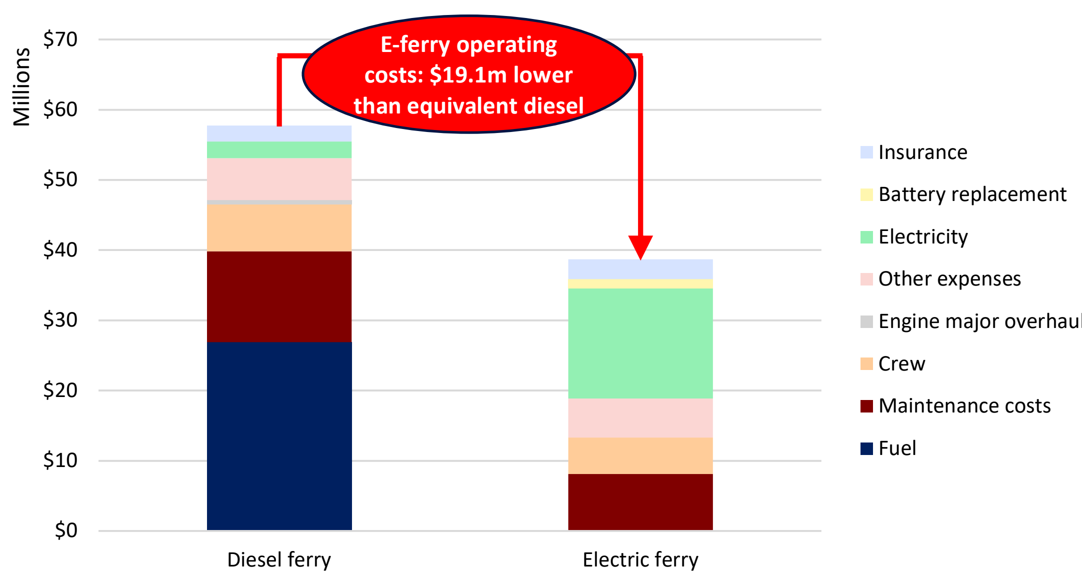


Figure 18. Operating costs breakdown of an electric and a diesel ferry (undiscounted)
Source: Liebreich Associates LEFM

There are further savings from maintenance, with the e-ferry requiring less attention, and lower crew costs due the simplicity of its control and operating systems. A significant additional cost, however, is the need to replace the batteries after around a decade of operation.

Given that electric ferries cost more up-front, but then are cheaper to operate over a 30-year lifetime, it is also useful to look at the comparison of operating costs on a discounted basis. As shown in Figure 19, the discounted net present value of the operating costs is around $7.8M lower for an electric ferry than for its diesel equivalent. The base case scenario assumes 7% discount rate.

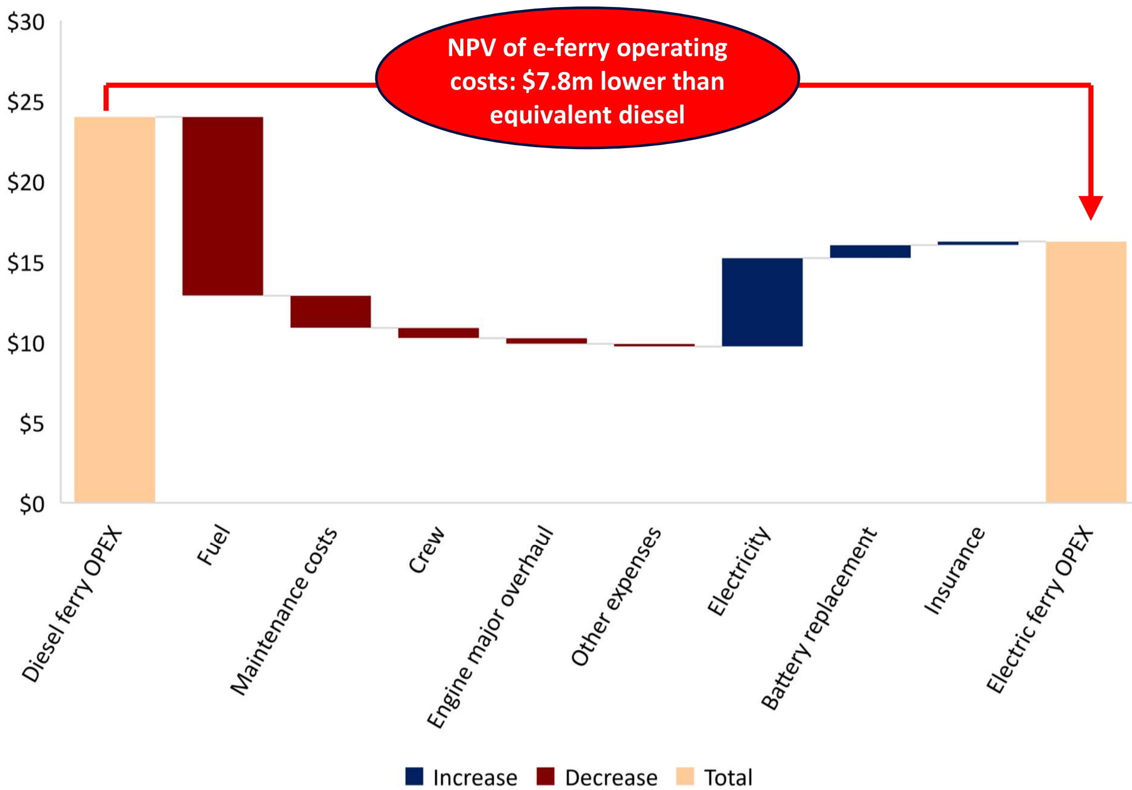


Figure 19. Net Present Value waterfall, showing positive and negative impacts of operating cost differences, electric versus diesel ferry

Overall, what we learn from the base case 'average Latin American country' is that, as long as electric ferries are technically feasible from a range and speed perspective, they are likely to make economic sense. While electric ferries are considerably more expensive to purchase, they are so much cheaper to operate that their overall economics are generally attractive.

One implication of the higher capital cost and lower operating cost, however, as we shall see in the sensitivity analysis, is that the availability of affordable finance will be key to the rollout of electric ferries in the region.

6.2. Sensitivity analysis

LEFM was used to examine the sensitivity of savings achieved by deploying an e-ferry to different variables on an NPV basis. From this it can be seen that the greatest sensitivities are to the cost of capital and to fuel prices. Minor changes to battery costs are relatively unimportant – suggesting that a strategy of waiting one or two years for cost reductions is not warranted – although the expected 60% drop over the coming decade will have a significant impact.

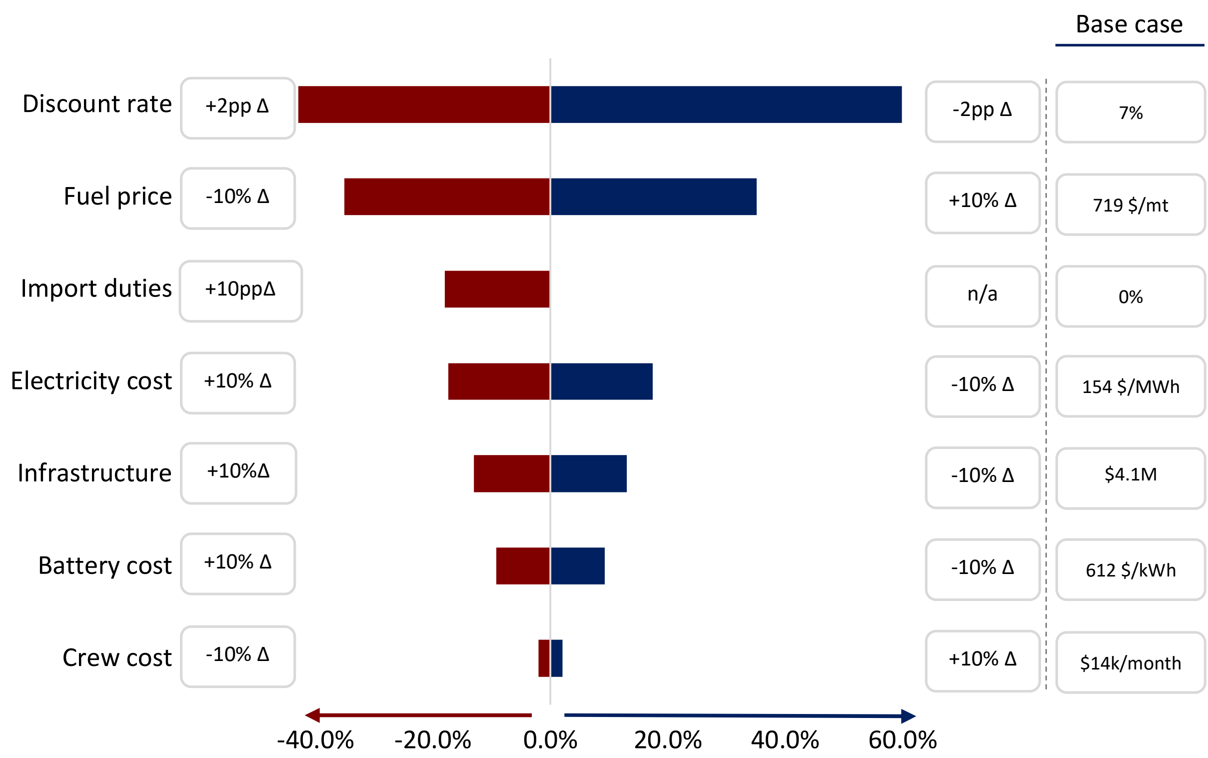


Figure 20. Sensitivity of NPV of relative savings (e-ferry vs diesel ferry) to changes in various input costs
Note: pp – percentage points; import duties assumed to apply to propulsion system (e-ferry), batteries, port infrastructure.
Source: Liebreich Associates LEFM

DISCOUNT RATE (COST OF CAPITAL)

The sensitivity analysis demonstrates that cost of capital is likely to be the single most important factor influencing profitability of ferry electrification. According to the baseline scenario for electrification to have a positive NPV, the blended average discount rate must not exceed 13%.

While this looks easily achievable, it should be noted that this analysis relates to a third-of-a-kind project. Pilot and very early projects will have higher capital and connection costs, and so the breakeven project returns are likely to be considerably lower, requiring support from local, state and/or regional development institutions.

It should be noted that most of the projects discussed in Chapter 4 received either direct funding or preferential financing terms from their respective regional or national bodies.

FUEL PRICE

The second driver of the difference in operating cost between traditional and electric ferries is the higher cost of diesel versus electricity.

In any planned project, data must be obtained on a local basis, since marine gasoil (MGO) prices can differ widely between ports: in 2020, for instance they ranged from $698 per metric ton in Trinidad & Tobago to $830 per metric ton in Uruguay (see Appendix II).

Detailed analysis must also account for any subsidy schemes, local or national, which might apply to fuel provided to public transport providers. Where such subsidies exist, policy intervention would need to ensure that it applied equally to electricity.

A quick rebound in the oil price after the pandemic would accelerate the electrification trend. Were low oil prices to persist, electrification of maritime transport might not be as fast.

ELECTRICITY COST

According to BloombergNEF and the IADNB Hub de Energia, industrial electricity prices in Latin America have averaged $154/MWh in recent years – but there is substantial variability between countries – from $50/MWh in Paraguay and Trinidad & Tobago to over $200/MWh in Jamaica (see tables in Appendix II).

Preferential power pricing for e-ferry operators, especially in countries with high electricity prices, would allow them to be more competitive; where there are fuel subsidies for public transport providers, these should be applied to electricity purchases to level the playing field[12]. Preferential power pricing is not a new concept, with many state entities in Latin America already enjoying non-market prices.

IMPORT TARIFFS

Given the well-developed ship-building industry in Latin America, it seems safe to assume that construction and fit-out of e-ferry vessels will be undertaken locally, using locally-sourced materials, and as such would not be affected by tariffs (see Chapter 5 for more on local supply chain opportunities and challenges). Two crucial e-ferry components, however, battery packs and electric motors, may need to be imported and are subject to tariffs in many Latin American countries.

While "Primary cells and batteries" (HS code 8506) are almost exempt from tariffs in Colombia (0.2%), they are subject to a 6% tariff in Chile and 10% in Argentina and Brazil. "Electric motors and generators, excluding generating sets" (HS code 8501) are generally subject to fairly high tariffs, with an exception of Colombia, where they are exempted from any import duties. The tariffs in Chile, Argentina and Brazil are 6%, 13.6% and 14.4% respectively.

SHORESIDE INFRASTRUCTURE REQUIREMENT

The most important driver of differences between the capital cost of traditional and electric ferries relate to charging points and other onshore infrastructure.

Constructing high-voltage cables to the quay-side, which can be required to ensure that the local grid is able to handle surges in power demand from ultra-rapid charging, can be a costly endeavour. Even if the operator of the e-ferry is willing to cover the expenses, it generally requires infrastructure works which can be disturbing for local residents (i.e. burying of high-voltage cables underground).

There may be creative ways to reduce infrastructure costs. One which has been trialled in Norway is the use of floating power storage pontoons, which serve to reduce peak power. Authorities thinking about electrifying a number of ferry routes over a longer timeframe should consider installing sufficient grid capacity upfront, in order to reduce cost and disruption later. Similarly, providing power infrastructure that can be shared between operators might also reduce costs.

BATTERY PRICES

The economic modelling showed that modest differences in battery costs will be of limited importance for the NPV of savings achieved by electric ferries, since they constitute only a modest proportion of the capital cost of a vessel, even taking into account replacement cycles. However, while a 10% reduction in battery costs only results in 7.9% reduction in the discounted value of capital spending, this is deceptive. Battery costs are projected to reduce by 60% over the coming decade.

The substantial reduction in future battery costs will meaningfully improve economics of electric ferries, which are already positive. This will be of a particular importance in the large ferry segment, where the limitation on electrification is related to cost, rather than to weight.

6.3. Illustrative economics for Latin American countries

In addition to using LEFM to examine sensitivity to different cost drivers, it was also used to compare economics in different countries. A caveat is required. The authors of this report do not have access to granular data on fuel and power costs, interest rates of infrastructure constraints for specific cities and routes, so national data points or regional averages were applied. This analysis must therefore be understood to be illustrative.

As can be seen below, cash cost breakeven between an electric and diesel ferry for the median Latin American country occurs around Year 11. Projects in the top quartile countries could see breakeven in six to eight years, while projects in the bottom quartile countries might take 13 or more years. In the case of a small number of outliers where there is very expensive electricity, the average project may never break even.

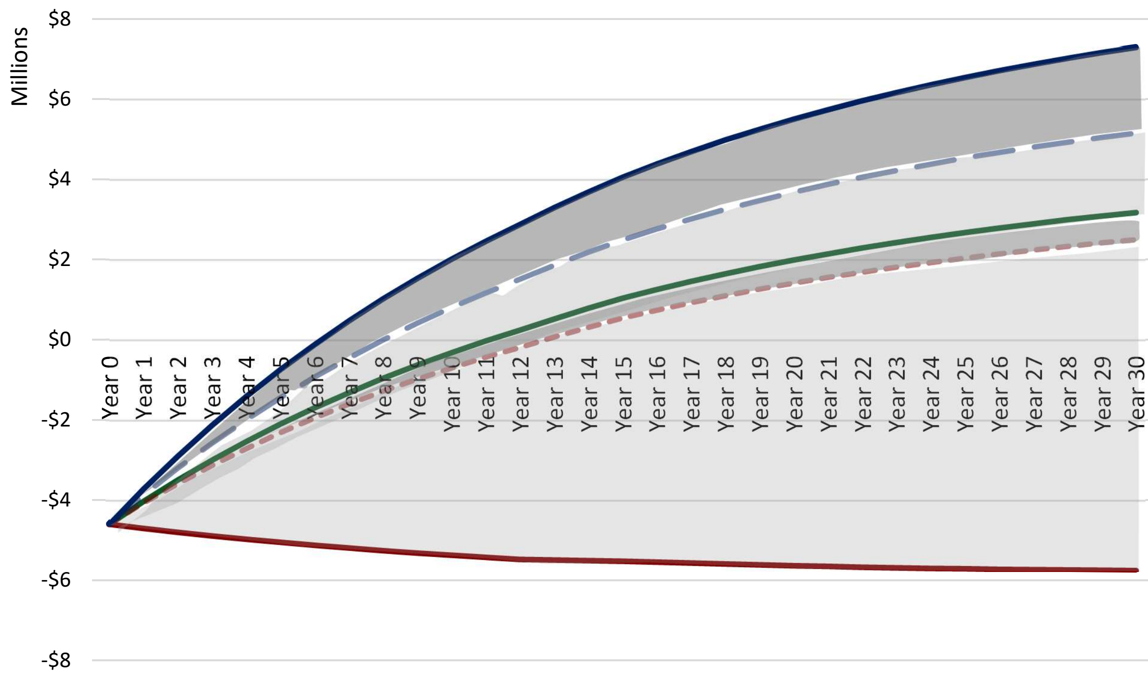


Figure 21. Discounted cumulative savings from ferry electrification in Latin America by country quartile (illustrative)
Source: Liebreich Associates LEFM

Note that, for the purpose of these calculations, it is assumed that a sinking fund was used to accrue for periodic battery replacements (in the case of the electric ferry) and engine overhauls (in the case of the diesel equivalent). Otherwise, there may be an early breakeven, followed by an immediate requirement for fresh capital.

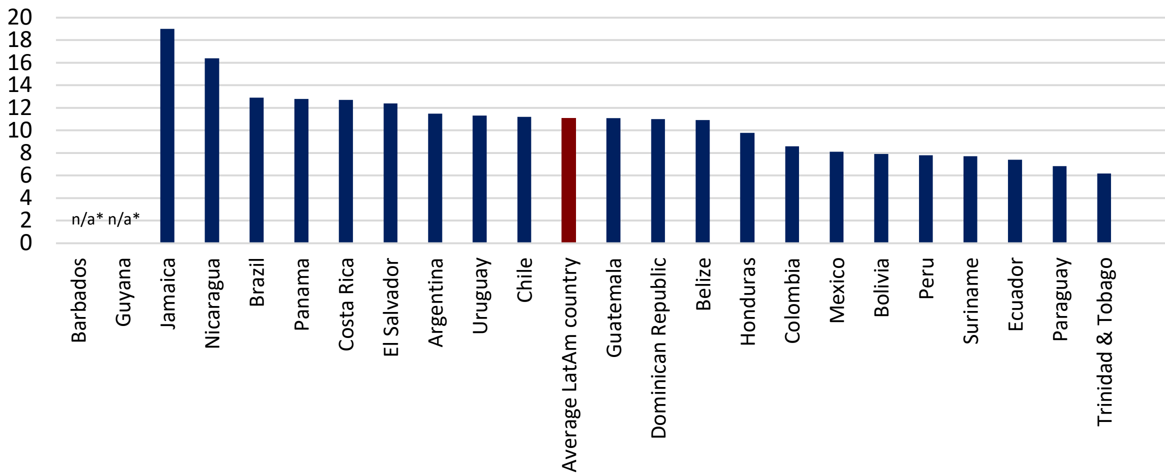


Figure 22. Cost parity incl. financing costs between electric and diesel ferry by country (illustrative)
*** Barbados and Guyana do not break even for the assumed ferry lifetime**
Source: Liebreich Associates LEFM

Looking across different countries of Latin America in terms of likely payback periods for a standard 200-person, 20-car electric ferry, we see that Colombia, Bolivia, Mexico, Peru, Suriname, Ecuador, Paraguay and Trinidad and Tobago all come in at around eight years. In the absence of policy intervention, projects in Barbados and Guyana are unlikely ever to reach payback due to high power costs and low fuel costs. As with other analysis presented in this section, this requires two caveats: first, it does not reflect the economics of a particular project, which may differ from the mean; and second, it is only applicable to third-of-a-kind, not to a pilot project.

The net present value of converting the base case ferry to electric can also be calculated for each Latin American country using LEFM – at least on an illustrative basis. Returns vary from negative for Barbados and Guyana, to over $5m for a number of countries.

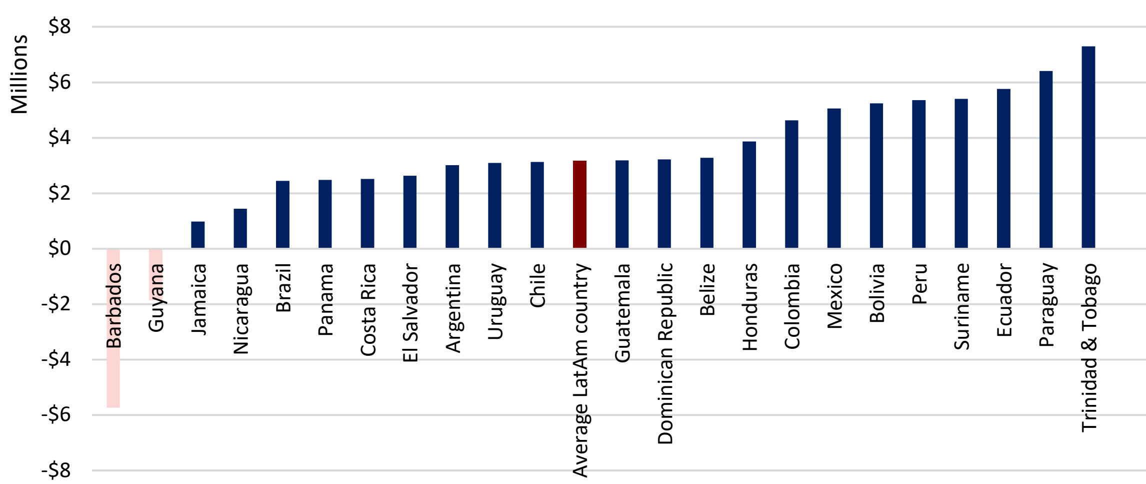


Figure 23. Net Present Value of relative savings by country
Source: Liebreich Associates LEFM

6.4. Business models

Business models for the ownership and operation of ferries in Latin America range from fully municipally owned at one end of the spectrum, through to fully private at the other, via a number of hybrid models:

- **Municipal ownership**. Many ferry operations are owned and run by local municipalities. This is particularly prevalent where routes are unprofitable or where they form part of public transport systems;

- **Outsourced operation**. This is one step away from public ownership of ferry operators: as far as the passenger is concerned, the ferry is still part of a public transport system, but operation is contracted out to a private operator for a fixed period of years. vessels can remain in public ownership or be owned by a third-party leasing company or by the operator.

- **Route concessions.** In this approach, the local municipality awards licenses to operate routes for a fixed period to one or more private ferry operators. Passengers are aware that the ferries are privately operated, prices may be regulated or unregulated, and there may be competition between operators. Here the vessels are almost always owned by leasing companies or operators.

- **Fully deregulated.** Where there is sufficient traffic to ensure that two or more operators can compete profitably, routes may be fully deregulated and served by any private ferry company willing to take the risk of setting up in business. Vessels are always owned either by leasing companies or operators.

When it comes to electric ferries, the main difference from conventional ferries which might impact the choice of business model is the fact that they cost more up-front, and have lower operating costs.

Higher capital costs make it more likely that financial investors will be needed to cover up-front costs of the vessel and shore-side infrastructure. This in turn means that some form of enhanced risk management is likely to be required in order to ensure a sufficiently long period of profitable operation to pay back the upfront costs.

Risk management tools will be of particular importance for the first few electric ferry projects in the region. The economic analysis in this report is based on "third-of-a-kind" costs, in other words not including one-off costs of initial projects and assuming some modest scale in the supply chain has been achieved.

Support mechanisms that have been used in some of the early electric ferry projects around the world include the following:

- **Grant.** Many of the projects described in this report were innovative, first-of-the-kind undertakings – such as new ferries covering longer distances (Ellen) or retrofits of large vessels (MF Tycho Brahe and MF Aurora). These two projects received grants from the European Union's innovation-supporting programme Horizon 2020.

- **Concessional finance**. As electric ferries are becoming more popular they are also being deployed in developing countries. To make it possible, concessionary finance is sometimes used – loans are given on preferential terms, with development institutions covering the difference between the preferential and market rate or extended grace periods. Development funding for the first electric ferry in the Maldives (as a part of a wider electrification programme) was secured with the assistance of the Asian Development Bank in this way.

- **Subsidised shore-side infrastructure**. The cost of installing chargers and conducting necessary grid upgrades is significant and the infrastructure might be used by other operators in the future, so public bodies sometimes may decide to provide direct funding for shore-side infrastructure. This was the case in Taiwan, where the local Environmental Protection Agency provided funding for, inter alia, developing fast charging stations in Kaohsiung.

Other approaches that could be tried include the following:

- **Extended route concessions**. With higher upfront investments required for electric ferries compared to diesel ones, providing operators with a longer, stable and steady stream of revenues may help to unlock a project. This could be achieved by extending the length of the route concession offered during tenders, so that increased CAPEX can be remunerated by lower OPEX over a longer period.

- **Minimum revenue guarantees.** Similar to extended route concessions, projects might be unlocked by guaranteeing a stream of revenues for a given initial period. Such a measure might allow the operator to secure lower interest terms on their loan, since revenues would be to an extent guaranteed by the state/municipality, often viewed as a low credit risk.

- **Credit guarantees.** To unlock private sector financing for first-of-the-kind projects like electrification of a ferry route, local or federal governments – or multilateral finance agencies - could agree to act as a guarantor on the loan to the operator.

- **Subsidised or tax-free electrical power.** To further reduce operating cost and shorten the payback period, national or regional administrations could subsidise electricity prices for the ferry operator or exempt them from taxation.


ANEK LINES
HELLENIC SPIRIT

7. ENVIRONMENTAL AND SOCIAL IMPACTS

7.1. Carbon emissions

Unlike almost any other available option, the electrification of ferries offers a path all the way to zero emissions for those routes where they can be implemented from a route length perspective. In order to get there, the supply chain would need to transition to zero-emissions, as well as the electricity on which they are run. As the proportion of renewable energy in the Latin American electricity mix increases over time, this becomes an increasingly feasible proposition.

Shipping is currently responsible for around 2.9% of global CO_2 emissions. However, according to a study undertaken by Öko-Institut in 2015 on behalf of the European Parliament[13], this could rise to 17% by 2050 were it to lag behind while the world decarbonises. The International Maritime Organisation (IMO) has set a 50% GHG emission reduction goal by 2050 compared to 2008 levels. Shipping to and from Latin America alone accounts for at least 30 million tonnes of CO_2 equivalent a year, according to an estimate[14] by the United Nations Conference on Trade and Development (UNCTAD).

Ferries and cruise ships are responsible for a modest 2% of global emissions from the shipping industry, or less than 0.1% of global emissions from all sources, so the potential emissions reductions by electrifying ferries will be almost imperceptible. However, diesel ferries have a disproportionate impact on air quality in the port cities from which they operate.

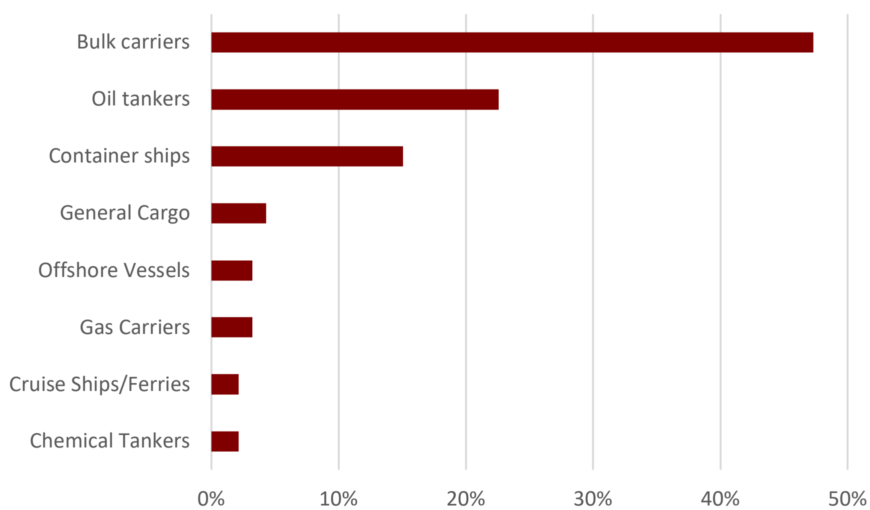


Figure 24. Share of shipping industry CO2 emissions, by vessel
Source: Shell based on UNCTAD; IMO; IEA; Deloitte

Compared with an existing diesel ferry, the Danish e-ferry Ellen emits 3,327 tonnes less CO_2 per year[15]. That is equivalent to the annual emissions from around 700 typical internal combustion passenger vehicles. During production of a 4.3 MWh battery pack between 215 and 430 tonnes of CO_2 are emitted.

The addressable emissions reduction in Latin America – assuming 100% of ferry routes that could be electrified undergo the process and assuming an average grid intensity of 166 g/kWh until 2040 – could be as much as 1.3 MT of CO_2 annually by 2040. That would be equivalent to removing over 280,000 typical internal combustion passenger vehicles from the roads.

7.2. Air quality

according to the Health Effects Institute[16] in 2019 alone over 200 thousand deaths in Latin America could be attributed to air pollution exposure. In many major coastal cities like Puerto Montt, São Paulo, Valparaiso, and Buenos Aires air particulate matter (PM2.5) concentration regularly exceeds WHO limits.

Despite the recent tightening of standards for sulphur content of marine fuel, pollution limits for vessels are still much less strict than those for land vehicles. Fuel-sulphur concentration in bunkers for vessels operating in the Emission Control Areas (i.e. coastal areas) cannot exceed 0.1% for ferries – for petrol in the EU the limit is 0.001% - 100 times more stringent.

A study by Transport & Environment[17] concluded that in Europe cruise ships emit 19 times more sulphur oxides than the 260 million cars on the continent, and the cruise ships emitted a similar amount of nitrous oxide as 40 million cars. In countries with long coastlines the ratio is higher – cruise ships sailing in the Norwegian exclusive economic zone emit 1.4 more NO_x than all the cars in the country. The ratio is 0.38 for Portugal and 0.26 for Spain. Latin America most likely shows a similar tendency.

The team behind the Ellen ferry in Denmark indicates that as much as 70.8 metric tons of NO_x, 2.4 tons of SO_2 and 1.4 tons of PM_{10} would be emitted annually by an equivalent diesel ferry operating a daily 40km return trip. E-ferries, of course, do not emit any NO_x, SO_x or PM_{10} during their operation.

Air quality is often a more immediate driver of action at the local level than climate change: municipalities are answerable to their local constituents, and action can be taken on a local level – as can be seen in the case of Kiel, described in Chapter 4.

7.3. Spill contamination risk

A little-discussed environmental risk posed by diesel ferries lies in the risk of contamination from fuel leakages or accidents. The risk is far from theoretical, as a quick google search reveals a steady stream of incidents, for instance:

- 17th August 2019, 8,000 litres of diesel spilled into the Costa del Sol harbour while a ferry was being refuelled.
- 3rd July 2020, a ferry bunkering at the Hamilton Ferry Depot spilled approximately 1 gallon of diesel into the water – a tiny amount that could nevertheless contaminate a million gallons of water.
- 11th June 2020, the old Stockton ferry sank on Lake Macquarie, New South Wales, Australia, losing 100 litres of fuel and causing a 400m oil slick.

The risk comes not only from the diesel or other liquid fuel on board (including potential biofuels or synthetic fuels), but also from the lubrication oil, required in considerable volume for vessels powered by combustion engines and their associated drive trains. In addition, there are risks all along the fuel distribution chain – from the refinery to dockside bunkering – risks which all climate models suggest will worsen due to increases in flooding and extreme weather events.

Electric ferries pose a far lower spill risk. The avoidance of liquid hydrocarbon fuels and the significantly reduced requirement for lubrication oil renders these vessels inherently safer from a contamination perspective, making them particularly attractive for operation in fragile ecosystems.

7.4. Social impacts

As Latin America shifts to a low-carbon economy, as in the rest of the world, it is vital to ensure a just transition – one that takes into account the impacts on employment, poverty reduction, gender and minority inclusion.

It is beyond the scope of this report to model the social impacts of electric ferries in detail. However, it is possible to note a number of potential advantages and caveats:

- **Employment.** The overall impact of electric ferries on jobs is likely to be mixed. Since they are simpler to operate and require less maintenance in operation, there are likely to be net reductions in the among onboard crew and at maintenance yards in the longer term. However, there will be additional jobs – requiring higher skill levels and paying better salaries – in design, construction and refitting of electric ferries in shipyards, as well as new jobs in shore-side construction, electrical installation and maintenance.

- **Gender.** The construction of electric ferries will require more graduate-level skills than equivalent diesel vessels: the value-add involves more electrical engineering and use of high-end composites, and less conventional marine and diesel engineering. Electric ferries will be physically easier to operate and maintain than old diesel ferries, removing any excuse for gender bias in crewing. Electrification of ferries could therefore contribute to a step-change improvement in gender balance among both construction and operating staff in what have traditionally been a heavily male-dominated sectors.

- **Poverty.** As seen from the economic modelling, on the right routes electric ferries will be cheaper on a total cost of ownership basis than diesel ferries. This suggests that they can be a useful tool in opening up affordable transportation options to the less well-off.

- **Human rights.** The shift to electric ferries per se should have no impacts in terms of human rights. However, the shift to electrification in the broader economy, and particular the rapid development of a battery supply chain does raise cause for concern - in terms of child labour, health and safety, and modern slavery. These are all areas where a joint approach with other sectors will be required (see recommendation 6 below).

8. DECARBONIZATION OPTIONS FOR LONGER ROUTES

As we have seen in Chapter 5, the length of routes which can be served by a pure electric ferry is limited by either battery energy density or economics, depending on vessel size, which raises the question of how to decarbonise longer routes. There are a number of options which could work from a technological perspective to reduce or eliminate emissions from ferries.

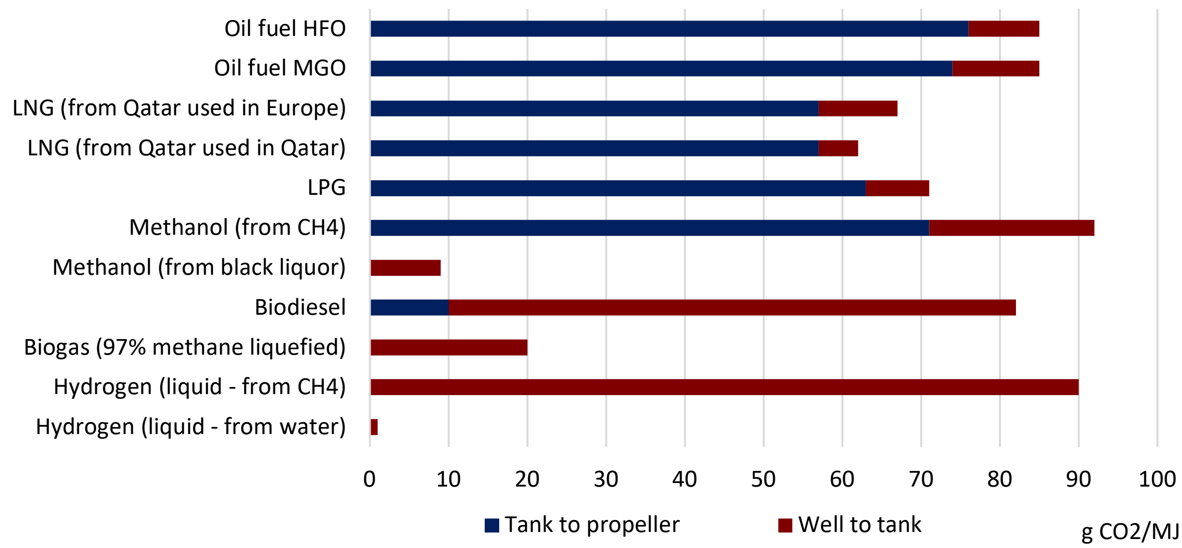


Figure 25. CO2 emissions of alternative fuels under consideration for long-distance shipping
Source: DNV GL

Unlike electrification, few of these offer the operation of true zero-emissions operation, and all are likely to suffer from higher total cost of operation than diesel for the foreseeable future. Despite expected future cost reductions, the risk is that there may be no point at which these technologies make economic sense in the absence of a carbon price.

It is beyond the scope of this work to examine the current and future cost trajectories of these technologies, or the carbon price at which they will make economic sense over time. For the sake of completeness, however, we will list some of the main technological contenders.

INTERIM HYBRIDISATION

As we have seen, increases in battery energy density and reductions in costs mean that over time, longer routes could be served by electric ferries than is now possible. This opens up the first strategy for the decarbonization of routes too long to be served today by a purely battery-powered vessel: interim hybridisation.

Under this strategy, a route which cannot currently be fully electrified but could be by 2030 or 2040, would be served for some interim period by a hybrid vessel - in other words one with an electric propulsion system served by both batteries and a diesel- or LNG-powered generator.

The goal would be to convert the vessel to full electric at one of its periodic major overhauls. This could involve not just upgrading the batteries, but also removing generators, fuel tanks and related equipment in order to free up space and weight for additional battery capacity.

It is beyond the scope of this study to model the economics of an interim hybrid strategy. The vessel is certain to cost more up-front than an equivalent diesel, but there should be some operating savings immediately due to the use of electricity for part of the routes served. There should then be increased operating savings after the eventual conversion to pure electric. Careful planning the eventual conversion at the point of vessel design should reduce cost and risk when the time comes for the pure-electric refit.

LIQUID BIOFUELS

Biofuels is the name for a whole range of fuels that are derived from biomass. Currently the cost of biofuels is almost always higher than that of equivalent mineral-based fuels.

The main driver behind their potential usage in transport is their high potential for GHG reductions – this ranges between 19% to 88% based on life-cycle assessments, according to DNV GL. This high variation is a result of different types of primary biomass and production processes.

Another major advantage of biofuels is their compatibility with existing infrastructure and engine systems, avoiding the need for costly upgrades, retrofits or redesigns.

BIO-LNG

Liquefied natural gas (LNG) is natural gas (main component – methane) that has been cooled down to liquid state. It has relatively low carbon content, which means that its potential for reducing CO_2 emissions vis-à-vis diesel is significant. LNG's calorific value is around 20% higher than that of marine diesel but its energy density is significantly lower, which means that around 1.8 times more tank volume is required compared to marine diesel to cover the same sailing distance.

LNG delivers an 85% reduction in nitrogen oxides (NOx) and negligible sulphur oxides (SOx) or particular matter (PM). In terms of GHG emissions, LNG promises up to a 21% reduction on a well-to-wake basis (i.e. GHG emissions traced from source to ship-board combustion), but this is highly dependent on levels of 'fugitive methane'. Methane, the main component of LNG, has a 28 times higher global warming potential compared to CO_2 over a 100-year period, and even a small leakage of unburnt methane during the process of extraction, processing, transport, bunkering and combustion of LNG can substantially diminish or even negate any GHG reductions.

There are currently over 160 LNG-fuelled ships in operation (excluding 600 LNG carriers, of which the majority are also LNG fuelled) and a further 200 on order. "MF Glutra", the first ever LNG-fuelled ferry, came into service in 2000 and operates in the Norwegian fjords.

According to SEA-LNG, an industry coalition established to demonstrate LNG'S benefits as a marine fuel, prior to the recent crash in oil prices, LNG offered ship-owners an economic payback period of 2-5 years, depending on the route and type of vessel. However, achieving deep emission reductions would require the use of liquified biogas, rather than natural gas, which currently trades at prices 2-5 times as high, pushing back the payback period considerably.

BIO-LPG

Liquefied petroleum gas (LPG), is a mixture of propane and butane in liquid state. It has a wide range of applications including heating appliances and vehicles. There has been little or no uptake in the marine industry.

LPG has a 12-15% higher calorific value compared to marine diesel, but its energy density is lower, so greater storage volume is required to deliver the same energy as marine fuel oils.

Compared to traditional oil, LPG could reduce GHG emissions by around 13-18%, practically eliminate sulphur oxides (~97% decrease) and decrease NOx emissions by around 10-20%. Based on DNV GL analysis, LPG also has the potential to compete financially with LNG, but its current role in the shipping industry is minimal.

Globally, there is some production of bio-LPG, which would enable up to an 80% reduction in lifetime CO2 emissions compared to diesel, but only at a significantly higher cost.

HYDROGEN FUEL CELLS

Hydrogen is currently primarily used as a feedstock for the manufacture of fertilisers and in oil refineries. Around 98% of current production is from fossil fuels, with the majority produced by the thermal processing of natural gas. A small amount is produced via electrolysis, where electricity is used to split water into hydrogen and oxygen, though this proportion is likely to increase due to the attention and funding now being lavished on the sector.

For years, hydrogen has been presented as the perfect fuel with which to decarbonise transportation, but so far with very low levels of uptake, especially in comparison with battery-powered vehicles. There are good reasons for this:

- If produced with the use of renewable energy or nuclear power, hydrogen would be a CO_2-free fuel. However, it would always be at least twice as efficient to use that renewable energy directly, rather than convert it into hydrogen and back to electricity for use in an electric vehicle of any sort.

- Although hydrogen boasts approximately 2.7 times the energy density of diesel by weight, it takes up much more room - seven times as much at 700 atmospheres. It can be stored as a liquid, but only at -253 degrees Celsius.

- For marine purposes, hydrogen can be burned in modified versions of the combustion engines currently in use – whether turbines or reciprocating - or else used in fuel cells to generate electricity. Either way, the resulting drive trains will be significantly more complex than a pure battery-electric drive train and hence require more frequent and costly maintenance.

As a result, therefore, for any route that can be served directly by a battery-electric ferry, hydrogen will not be competitive, either now or in the future. To decarbonize longer routes, however, which cannot and will not be served by pure battery vessels, hydrogen may become the fuel of choice.

Currently, hydrogen-powered ships would be far from economically viable, and it is unlikely their costs can be brought down below diesel at any point. Nevertheless, since they do offer one potential route to true zero-emissions shipping for longer routes, a few retrofits are underway. For instance, a Norwegian ship is planned to be retrofitted with a 3.2MW hydrogen fuel cell by 2023.

In late November 2020 DFDS, a major European ferry operator announced an ambitious plan to develop a hydrogen fuel cell ferry capable of carrying 1,800 passengers and 380 cars to ply the 500 km route between Oslo and Copenhagen – well beyond the range of a pure electric ferry. According to the plan, the fuel cell system would produce as much as 23 MW and hydrogen for the ferry would be produced using offshore wind. Provided the project receives the EU financing for which it has applied, the vessel could enter operation in 2027.

AMMONIA

Another promising long-term alternative for zero-emissions shipping is ammonia, but it is very unlikely to find a use in passenger ferries.

Ammonia is a compound of nitrogen and hydrogen, whose current main application as an industrial fertiliser. There has been growing interest in recent years in its potential as a clean fuel for long-haul transport. It can

be stored as a liquid at -33 degrees Celsius, or as a compressed gas, and used either in combustion engines or in fuel cells. If produced from hydrogen electrolysed using renewable energy it can be entirely CO_2 free.

As is the case with other alternative fuels, however, ammonia has a lower energy density, requiring around 2.4 times more storage space for the same amount of energy content, compared to standard fuel oils. If produced from renewable electricity, its wind-to-wake efficiency would be even lower than hydrogen, since its production requires first electrolysis and then, additionally, the Haber-Bosch process.

There is currently no ship that uses ammonia as a maritime fuel but the first is under development. The Viking, a supply ship, owned by Norwegian shipping company Eidesvik and on contract to Equinor, will operate on a 2 MW direct ammonia fuel cell. Interestingly, in 2003, the same ship was also the first supply vessel powered by LNG, and in 2016 after a battery retrofit, it became the first hybrid supply vessel[18].

The reason ammonia is highly unlikely to be approved for use as a fuel for ferries is that it is highly toxic. The safety challenges of large volumes of ammonia sharing a vessel with passengers are likely to be insuperable.

SYNTHETIC FUELS AND E-FUELS

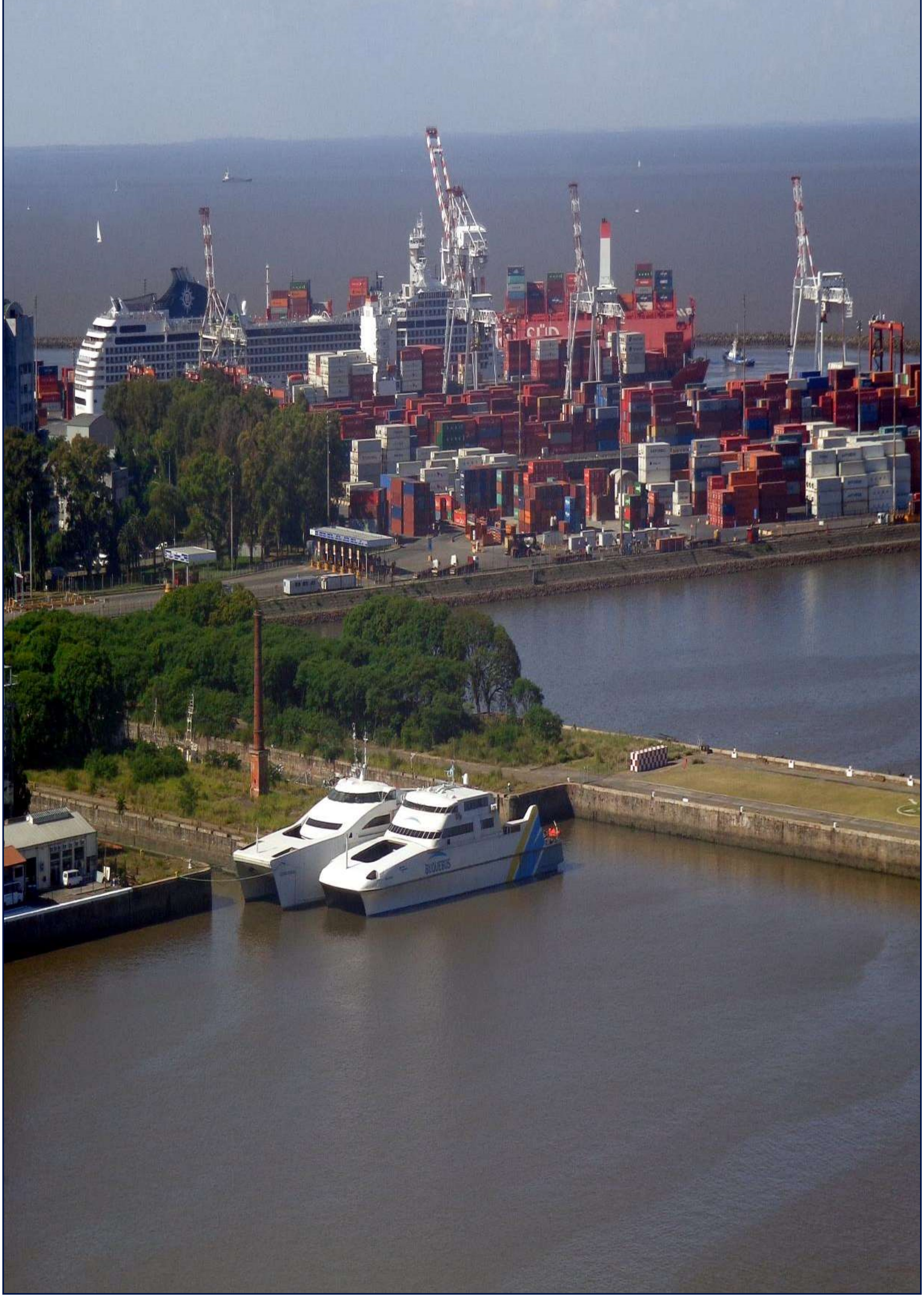
In theory, ferries could be run on a range of zero-carbon synthetic fuels or "e-fuels". In practice these are likely to cost up to an order of magnitude more than marine diesel, and at present there is practically no element of the supply chain in place for their production or distribution.

Methanol, also known as wood alcohol and methyl alcohol (CH_3OH), is widely used across multiple industries e.g. in building materials and plastic packaging. Due to its high hydrogen-to-carbon ratio compared to traditional oils, its potential to reduce GHG emissions is high, but depends on the feedstock and source of energy used for production. Apart from GHG reductions, methanol could also enable reductions in SOx of up to 99% and NOx reductions of up to 60%.

One of the big challenges is methanol's low energy density – it requires 2.4 more storage volume for the same energy content as oils. The biggest challenges facing the use of zero-carbon methanol as a way of decarbonising the maritime sector are its cost, which is likely to remain two to eight times that of fossil-based bunker fuel, and methanol's toxicity.

There are a few examples of methanol-fuelled ships already operating on commercial routes. The first marine vessel retrofitted to run on methanol was Stena Germanica, a large cruise ferry operated by Stena Line between Gothenburg and Kiel. The ferry uses a mix of fuels – 95% methanol and 5% diesel[19]. Another interesting example is MS Innogy, an excursion vessel operating on Lake Baldeney in Essen, Germany. It is powered by a fuel cell that uses methanol to produce electricity on board the vessel to supply a battery-backed electric motor[20].

Other synthetic "E-Fuels" that have been suggested include dimethyl ether (DME), which would have the great advantage of being almost a drop-in replacement for diesel – other than requiring storage at a pressure of 8 atmospheres – but which, like methanol, would be considerably more expensive to produce than fossil diesel.



9. SELECTION OF EARLY PILOT ROUTES IN LATIN AMERICA

Latin America boasts a great diversity of ferry routes: fast urban ferries allowing people of Rio de Janeiro to reach the island parts of their city; gigantic ferries crossing the Gulf of California in Mexico; island connections offering the only link to the mainland, river ferries plying routes that are hundreds of kilometres long.

In this section, we identify the types of routes that could economically be electrified over the coming two decades and take a deeper look at some initial candidate routes.

It should be noted that small community ferries and riverboats such as those described in the 2017 CEPAL report Energy Efficiency and Electric-Powered Mobility by River: Sustainable Solutions for Amazonia[21], were not included in the scope of this report or of the routes analysed.

9.1. Overview

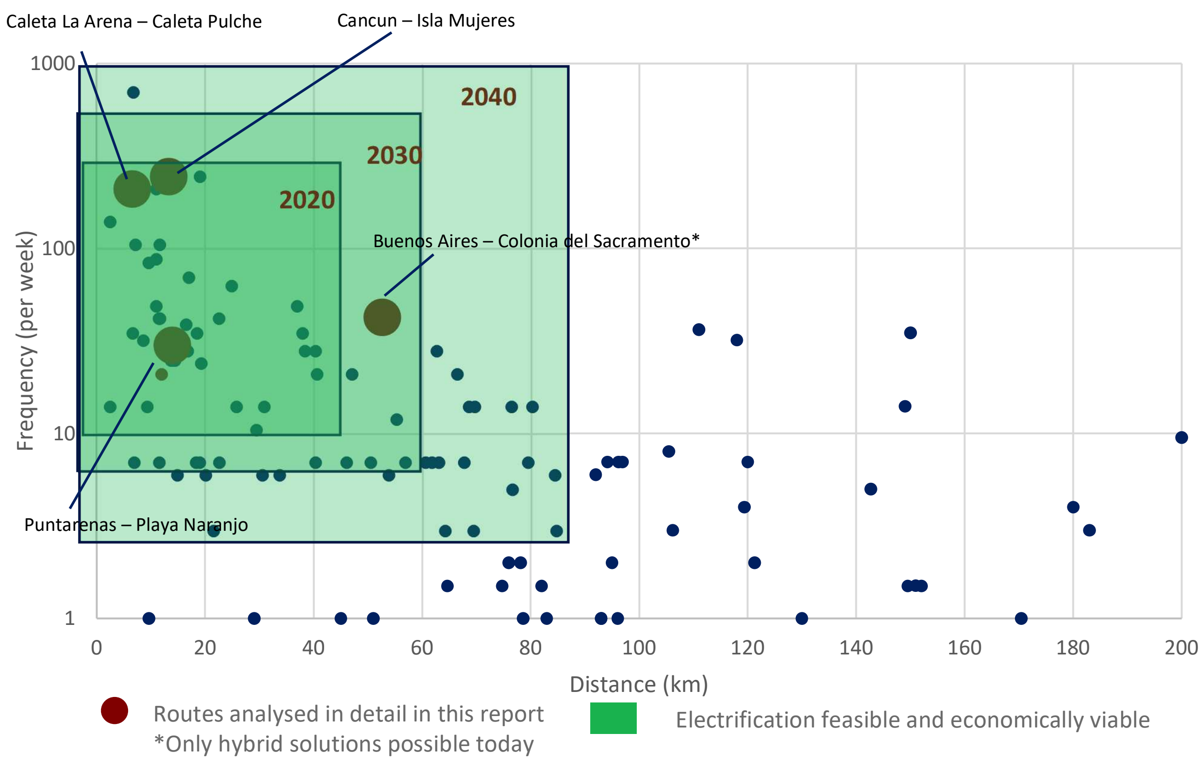


Figure 26. Latin American ferry routes by distance and frequency, showing which ones can be profitably electrified now, in 2030 and 2040 (illustrative).
Source: Liebreich Associates

When identifying ferry routes to electrify, there are a number of constraints that must be borne in mind:

- Battery energy densities create a hard upper limit for ferry route lengths for smaller and faster ferries;
- Battery costs create a hard upper limit for route lengths for large ferries, where weight is less of an issue, but the economics are generally more competitive;

- The high capital costs of ferries and shoreside infrastructure mean that infrequent routes don't work economically: you need to amortise those costs over large numbers of journeys;

- Very high-frequency routes are challenging to electrify as they require a very fast turn-around time in port, which drives a need for rapid charging and hence very high-voltage power supplies.

Figure 27. Stena Jutlandica, which is being electrified step-by-step, starting with its bow thrusters Image: Arild Vågen/ Wikimedia Commons

A total of 132 Latin American ferry routes with regular operations were analysed.

- Of these, 51 (39%) are shorter than 45 kilometres, meaning the route could be covered by a medium-sized electric vessel using current technology.

- 69 (52%) are shorter than 65km meaning they could be electrified by 2030, assuming weight of battery pack is a constraint. Under the same assumption

- 84 (64%) of the identified ferry routes could be electrified by 2040 assuming current battery technology develops according to current learning curves, as described in Chapter 5.

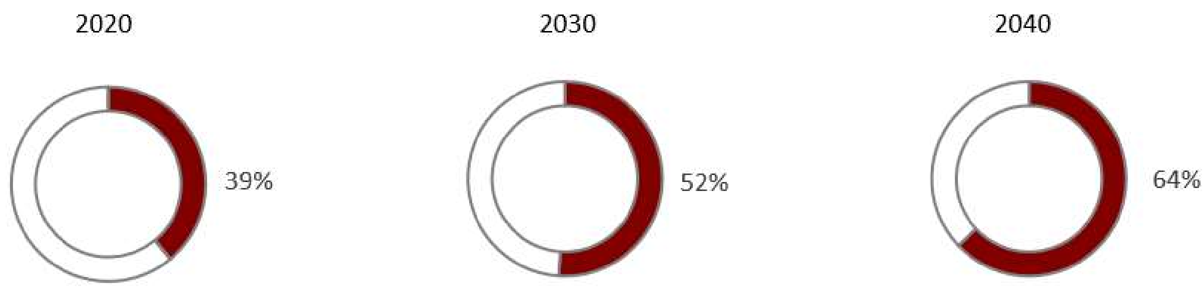


Figure 28. Share of routes in Latin America that could be electrified by year - with mid-sized vessels
Source: Liebreich Associates

If the routes were to be operated by bigger vessels, capable of taking more than a thousand passengers on board only 10% of the routes could be electrified today, rising to 30% in 2030 and 43% in 2040.

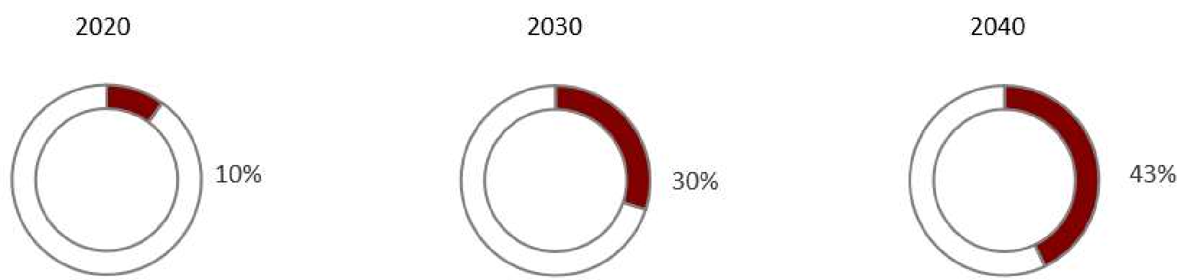


Figure 29. Share of routes in Latin America that could be electrified by year - with large vessels
Source: Liebreich Associates

9.2. Potential early pilot route evaluation

After discussions with stakeholders, five pilot routes were chosen for evaluation:

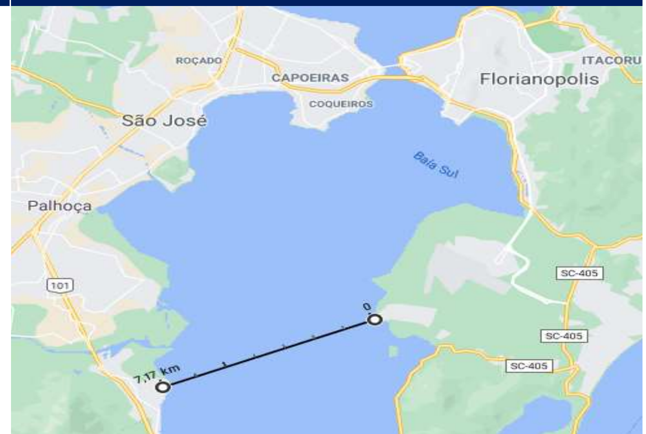
- Florianópolis ferry system (Brazil)
- Buenos Aires – Colonia del Sacramento/Montevideo (Uruguay)
- Puntarenas to Playa Naranjo (Costa Rica)
- Cancún to Isla Mujeres (Mexico)
- Caleta La Arena to Caleta Pulche (Chile)

Figure 30. Potential Latin America electric ferry pilot routes evaluated
Image: Liebreich Associates

In the following sections, a description of the route will be provided – including length, frequency, type of vessel used as well as operator. We also look at the operators because, due to high upfront investment, electrification might be easier for larger companies or state operators with access to funding.

9.3. Florianópolis (mainland to Santa Catarina Island)

Medium-size ferry operating a short, frequent route

Region	Route map
	

Current Specs	Route	Economics
• Not applicable – planning stage of the ferry system	• 7km between Pontal na Palhoça and Tapera • Frequency depending on traffic analysis	• Cost parity with diesel ferry: 9.1 years • NPV on relative savings: \$2.2M (based on mid-size electric ferry) • 70 crossings a week assumed

Description

Most of Florianópolis, the capital of the state of Santa Catarina lies on an island. Over 400,000 people living on the Santa Catarina island rely on three bridges providing a connection to the mainland. They are all located in the middle of the isle, leaving those living in the northern and southern parts without a convenient, direct connection to the mainland. Additionally, with renovation works on the iconic Hercílio Luz bridge finished only recently, the crossings were oftentimes clogged.

Next steps

With the state government planning to create ferry connections to ease traffic congestion, it is a great opportunity to introduce the first electric ferry to Latin America. First of the planned routes, Linha Sul (the Southern line) between Pontal na Palhoça and Tapera has a perfect distance (7 km) and a number of international projects would provide useful experience: for instance, including electric ferries in municipal transport has been done in cities like Kiel (see Chapter 4 for details). Similar solutions are also present in Copenhagen, Stockholm and soon in Amsterdam.

The pro-forma economics shown here relate only to a single route. However, detailed analysis of the whole planned network should be conducted – electrification of multiple routes might help limit the costs of the shoreside infrastructure, for instance if chargers can be be shared.

9.4. Buenos Aires – Colonia del Sacramento/Montevideo

<table>
<tr><th colspan="3">Large ferry operating longer distances at lower frequency</th></tr>
<tr><th>Region</th><th colspan="2">Route map</th></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th>Current Specs</th><th>Route</th><th>Economics</th></tr>
<tr><td>• Operated by large vessels capable of taking at least 450 passengers and 55 cars
• Operated by large companies – Buquebus and Colonia Express</td><td>• 52km between Buenos Aires and Colonia del Sacramento
• ~50 crossings a week to Colonia directly</td><td>• Electrification not feasible as of today: hybrid solutions to be considered</td></tr>
</table>

Description

Some of the busiest ferry routes in Latin America run from the estuary of the Rio de La Plata, connecting Buenos Aires (one of the most active passenger ports in Latin America – in 2019 it served almost 2.4 million passengers) to the Uruguayan ports of Colonia del Sacramento, Montevideo and Piriapolis, a holiday resort.

Next steps

The popularity of the Colonia del Sacramento and Piriapolis routes would make them excellent candidates for electrification, with high frequency and occupancy translating into significant OPEX savings for operators.

Full electrification could not quite be achieved with using today's battery technology but, assuming the projections described in Chapter 5 materialise, the route between Buenos Aires and Colonia del Sacramento could be served by mid-sized electric ferries by around 2023 – as long as ferries can be charged at both ends of the route. The vessels would need to be somewhat smaller than those currently used by local operators like Buquebus and Colonia Express. Economically viable electrification of large-sized vessels able to cover such distance should be possible around 2040.

The Buenos Aires-Montevideo route is too long to be electrified, assuming no technological breakthrough in battery technology. Vessels serving on them will have to use different technology – a number of possible solutions are discussed in Chapter 8. Interim solutions include hybrid ferries that would be operating on batteries in proximity to the harbours to limit air pollution in the cities. However, it would be worth exploring potential for electrification, likely costs of onshore infrastructure (looking into state of the grid in harbour areas, etc) and potential business models in more detail.

9.5. Puntarenas to Playa Naranjo

<table>
<tr><th colspan="3">Medium-sized electric ferry operating medium-length route</th></tr>
<tr><th>Region</th><th colspan="2">Route map</th></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th>Current Specs</th><th>Route</th><th>Economics</th></tr>
<tr><td>• Operated by medium-sized ferries taking 350 and 650 passengers on board
• Operated by a small company Coonatramar
• Cruising speed of ca 10 knots, journey time of 75 mins</td><td>• 14km between Puntarenas and Playa Naranjo
• ~30 crossings a week</td><td>• Cost parity with diesel ferry: 16.4 years
• NPV on relative savings: $1M (based on mid-size electric ferry)</td></tr>
</table>

Description

The Gulf of Nicoya in Costa Rica, a popular tourist destination can only be crossed via ferry. Travellers can go from Puntarenas on the east side of the gulf to Naranjo and Paquera on the west side.

The very low CO_2 intensity of the local grid (ca 30 g/kWh) means that electrification of maritime transport in Costa Rica would be very beneficial for the environment.

Next steps

As the route is relatively short and crossings are frequent enough to economically justify the switch, this is a perfect candidate for electrification. Given the length of the crossing and frequency, grid investment should be limited because high-voltage installations would not be required to fully recharge the ferry between crossings.

Since the route is served by vessels of different sizes, the electrification could start with smaller ones, requiring less upfront investment.

9.6. Cancun to Isla Mujeres

<table>
<tr><th colspan="3">Fast catamaran ferry operating as a part of public transport</th></tr>
<tr><th>Region</th><th colspan="2">Route map</th></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><th>Current Specs</th><th>Route</th><th>Economics</th></tr>
<tr><td>• Operated by fast catamaran ferries of all sizes
• Operated by a large company Ultramar
• Cruising speed of ca 25 knots, journey time of 20 mins</td><td>• 9km between Cancun and Isla Mujeres
• 35 crossings a day</td><td>• Provisional: model based on mid-sized ferries adapted by assuming 30% higher estimated e-ferry cost, assuming three ferries cover the route
• Cost parity with diesel ferry: 8.0 years
• NPV on relative savings: $5.9M</td></tr>
</table>

Description

The Mexican state of Quintana Roo, with its long coastline and numerous islands is a popular tourist destination. Thousands of passengers take ferries to reach Cozumel, Isla Mujeres or Holbox from the mainland each month. As the three islands have almost no cars, the routes are operated by high-speed catamaran boats (average speed of 25 knots) that take only foot passengers. The connections are frequent (ferries to Isla Mujeres depart from Cancun every half an hour during peak) and distances do not exceed 18 kilometres.

Next steps

With high frequency, short distances, established operators and an incentive to introduce clean transport options for tourists, the three routes are perfectly suitable for electrification. Furthermore, high-speed catamarans of the size used by e.g. Ultramar made of carbon fibre have already been deployed, meaning regulatory approval would be easier to obtain.

9.7. Caleta La Arena to Caleta Pulche

<table>
<tr><th colspan="3">Medium-sized electric ferry operating on a short route</th></tr>
<tr><th>Region</th><th colspan="2">Route map</th></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><th>Current Specs</th><th>Route</th><th>Economics</th></tr>
<tr>
<td>• Operated by mid-sized vessels
• Large operators: Naviera Puelche and Naviera Paredes
• Service subsidized by the Chilean government
• Journey time of 30 minutes</td>
<td>• 6km between Caleta La Arena and Caleta Pulche
• 30 crossings a day</td>
<td>• Cost parity with diesel ferry: 5 years
• NPV on relative savings: $4.5M (based on mid-size electric ferry)
• Assuming three ferries cover the route</td>
</tr>
</table>

Description

The Carretera Austral is a 1,200 km long intermodal highway connecting the Chilean regions of Los Lagos and Aysén. As the road goes through several fjords, parts of the highway can be crossed only by ferry. The connection between Caleta La Arena and Caleta Pulche is particularly busy, with over 200 crossings a week. The southern, coastal part of Chile is a global biodiversity hotspot and an attractive tourist destination.

Next steps

As a part of a busy route, with hundreds of passengers and cars a day, as well as a short distance – the route is well-positioned for electrification. The unique and precious fauna and flora, as well as popularity of the region among tourists are further arguments for electrification that would help limit pollution and preserve biodiversity.

ferry
100% electric
ELLEN
SØBY
IMO No. 9805374

10. RECOMMENDATIONS AND NEXT STEPS

The analysis contained in this report has identified a number of priority next steps for electrification of ferries to be pursued on an accelerated basis in Latin America.

10.1. Develop business plans for pilot routes

For the five potential early pilot routes identified in this report, the following next steps are recommended:

1. Undertake detailed modelling of the operational, technical and financial aspects of implementing electric ferries on these routes;

2. Create a business and implementation plan for each case, complete with milestones and go/no-go decision points, taking into account the potential bottlenecks in terms of grid connections, health and safety regulations, etc.

3. Begin discussions between local, national and regional public and private stakeholders over finance and risk-sharing.

10.2. Improve data to inform further route choices

In this report, we took a first look at 132 regional ferry routes, of which we found 39% (were medium-size ferries to be used) or 10% (were large ferries to be used) are potentially suitable for immediate development based on the state of battery technology today.

To be sure that these or other routes can be electrified would require more granular information than could be gathered for all these routes in the time-frame available. A comprehensive data set of short and medium-distance ferry routes in Latin America should be assembled, containing the following data fields:

- Route length, frequency and number of vessels;

- Turn-around times, since these drive the requirement for high-voltage charging with expensive civil works and connection fees;

- Vessel size and nature (number of passengers, number of cars, cargo weights, etc);

- Shoreside infrastructure, in particular regard to the availability of power;

- Cost of marine diesel and cost of electricity;

- Environmental data on carbon-intensity of power supplies, including data on options for entering power purchase agreements (PPAs) with dedicated renewable energy provision;

- Data on local air quality;

- Remaining lifetime of existing ferries and route concessions.

The resulting information will also give supply chain players greater confidence in the scale of the opportunity, supporting any potential decision to invest in manufacturing capacity.

10.3. Develop enabling environments

As we learned from the sensitivity analysis, tax, subsidy and import tariff policy can have substantial impacts on project economics. The scan of experience from around the world also showed that other regulatory issues may emerge and block projects or unexpectedly increase their costs.

The following areas should therefore be reviewed on a national basis for any country hoping to host an early electric ferry project.

- **Fiscal policy.** Is it possible to waive tax on electricity?
- **Connection fees.** Could these be waived, either for a pilot project or permanently for e-ferries?
- **Subsidies.** If fuel subsidies for exist for diesel, can they be extended to electricity?
- **Import tariffs on batteries and electrical equipment.** Could they be waived for a pilot project?
- **Health and safety regulations.** Are they appropriate for e-ferries and e-ferry charging, and if not, how must they be reformed?

At the city or municipality level too, there might be hurdles that should be identified early and cleared, such as the following:

- **Concession length.** Because of the high up-front cost of e-ferries, private ferry companies may require extended concessions in order to amortise the cost of shore-side investment – are these feasible?
- **Procurement processes.** Can a single procurement cover the building of a ferry, its shoreside infrastructure and its operation, or must they be separated? What are the implications?
- **Port ownership.** Does the municipality or ferry operator have the right to mandate the upgrading of shoreside facilities to provide sufficient power for charging? How to ensure this does not cause delays?

10.4. Establish funding mechanisms

The Latam E-Ferry Model developed for this report is based on third-of-a-kind economics – i.e. expected costs and cash flows for projects after initial pilots have been done and some scale and experience has been achieved in the supply chain. The economics of a first-of-a-kind project are likely to be considerably worse, with costs 25% to 40% higher.

Therefore, for the initial projects there will inevitably be a need for some level of grant or subsidy, or at the very least significant provision of concessionary finance. A dedicated facility, bringing together IDB and other national development institutions – structured to encourage private capital providers – would help accelerate the first few projects.

There is an important discussion to be had about how to share the risks and costs of the early projects between a) public and private players; and b) local, national and regional sources of public funding. Experience from Europe shows a heavy involvement of the EU's Horizon 2020 technology mechanism, providing grants for first-of-a-kind projects (E-ferry Ellen, conversion of MF Tycho Brahe and MF Aurora to electric) and of the national states and their agencies (as it was in the case of Kiel). An appropriate solution for Latin America will have to be found.

10.5. Create a multi-stakeholder working group

The roll-out of electric ferries across Latin America will be dramatically accelerated by the development of industry-wide approaches across a range of areas including operational protocols, safety systems and finance. Many of the most promising routes cross borders; and supply chain players will need to work together to address issues arising in the battery, ship-building and electrical engineering sectors.

The creation of a multi-stakeholder sectoral body would provide a useful forum for the following:

- Coherent messaging vis-à-vis governments and other stakeholders;
- Standardisation of vessel design;
- Identification of industry-wide technology and market research priorities;
- Development of technical and safety standards, for vessels as well as charging equipment;
- Development of training and skills-building programmes.

10.6. Broaden to adjacent marine categories and other sectors

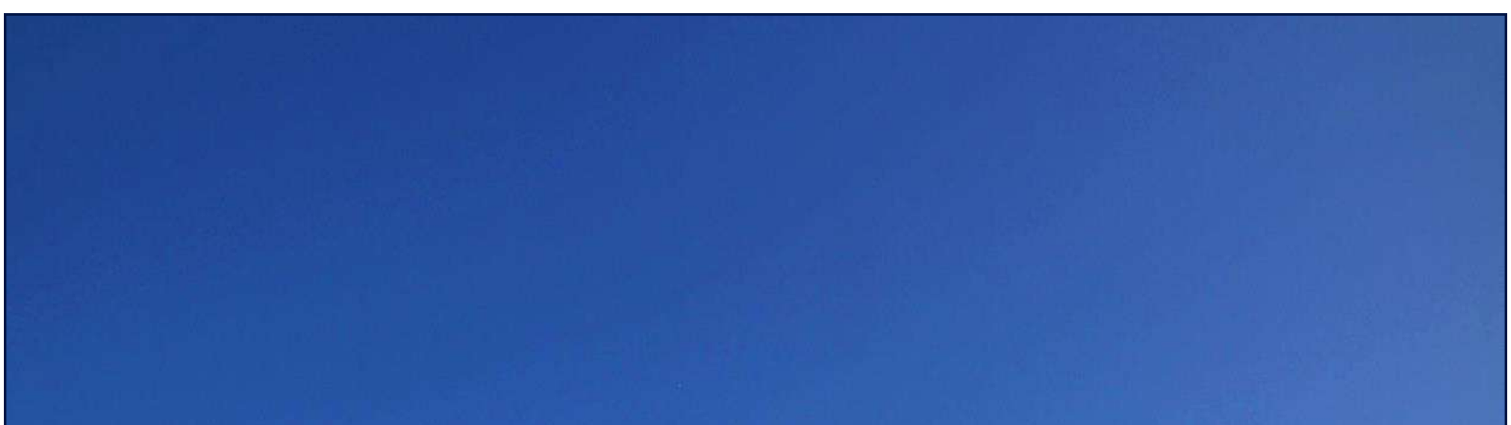
A roll-out of electric ferries in Latin America will not be conducted in a vacuum. It will interact with developments in other marine categories and adjacent sectors.

The following initiatives are therefore recommended:

1. Undertaking similar research for other potentially electrifiable marine sectors – such as smaller community ferries and riverboats, leisure craft, fishing and utility vessels, tenders, tugs or coastal freighters – in order to demonstrate to supply chain players of all sorts the full scale of the addressable opportunity in marine electrification.

2. Reaching out to key supply chain players and those developing national and regional strategies in the following adjacent sectors, in order to share knowledge, to identify and exploit synergies and to deal jointly with issues (such as potential environmental and social harms caused by the battery supply chain):

    - Battery supply chain;
    - Ship-building;
    - Electrical engineering industry;
    - Automotive and train technology suppliers;



APPENDIX I: GLOBAL ELECTRIC FERRY ACTIVITY

Table 4. List of operational and announced electric ferries around the world

Route	Type	Country	Year	Size
		Operational		
Marseille municipal	Electric (solar powered)	France	2010	35 passengers
Lorient municipal	Electric	France	2013	100 passengers
Puttgarden-Rødby	Hybrid	Germany	2013	11140 passengers 364 cars
Lavik - Oppedal	Electric	Norway	2015	360 passengers 120 cars
Flam - Gundvagen	Electric	Norway	2016	400 passengers
Anda - Lote	Electric (diesel backup)	Norway	2017	349 passengers 120 cars
Helsingør - Helsingborg	Electric (converted)	Sweden Denmark	2017	1250 passengers 240 cars
Vaikkom - Thavanakkadavu	Electric (solar powered)	India	2017	75 passengers
Krokeide – Hufthammar	Electric (diesel backup)	Norway	2018	395 passengers 130 cars
Husavik - Sandvikvåg	Electric	Norway	2018	146 passengers 45 cars
Turku Archipelago	Electric (converted)	Finland	2018	375 passengers 90 cars
Bangkok municipal	Electric (converted)	Thailand	2018	40 passengers
Isle of Wight	Hybrid	UK	2018	1208 passengers 178 cars
Sandefjord - Strömstad	Hybrid	Norway	2018	2000 passengers 500 cars
Kaohsiung	Electric	Taiwan	2018	150 passengers 46 scooters
Brekstad - Valset	Electric (diesel backup)	Norway	2019	195 passengers 50 cars
Capbreton	Electric	France	2019	35 passengers
Alabama River	Electric	US	2019	132 passengers 15 cars
Wuhan	Electric	China	2019	300 passengers
Fynshav - Ærø	Electric	Denmark	2019	196 passengers 31 cars
Stockholm municipal	Electric	Sweden	2019	98 passengers
Fredrikstad municipal	Electric	Norway	2019	550 passengers
Sasebo – Oshima	Electric	Japan	2019	50 passengers 4 cars
Stavanger -Lysefjorden	Electric	Norway	2020	297 passengers
Hareid - Sulesund	Electric (diesel backup)	Norway	2020	339 passengers 120 cars
Langevåg – Buavåg	Electric (diesel backup)	Norway	2020	200 passengers 50 cars

Magerhorm – Sykkelven	Electric (diesel backup)	Norway	2020	349 passengers 120 cars
Våge to Halhjem	Electric	Norway	2020	292 passengers 120 cars
Edøya – Sandvika	Electric (diesel backup)	Norway	2020	149 passengers 50 cars
Kvanne - Røkkum	Electric (diesel backup)	Norway	2020	149 passengers 50 cars
Copenhagen municipal	Electric	Denmark	2020	50 passengers
Niagara Falls	Electric	US	2020	600 passengers
Kiel municipal	Hybrid	Germany	2020	300 passengers
Westmand Island	Electric	Iceland	2020	550 passengers 75 cars
Vartiosaari - Laajasalo	Electric	Finland	2020	6 passengers
		Announced		
Festøya - Solavågen	Hybrid	Norway	2020	
Phuket	Electric	Thailand	2020	
Malta – Comino	Hybrid	Malta	2020	
Wellington Harbour	Electric	New Zealand	2021	
Amsterdam	Electric	Netherlands	2021	
Kingston - Amherst Island	Electric	Canada	2021	
Mannheller - Fodnes	Hybrid	Norway	2021	
Esbjerg - Fanø	Electric	Denmark	2021	
Plymouth	Electric	UK	2021	
Oslo municipal	Electric	Norway	2021	
Halsa-Kanestraum	Electric	Norway	2021	
Kootenay Lake	Hybrid	Canada	2023	
Lake Geneva	Hybrid	Switzerland	2023	
Seattle (parts of the whole ferry system)	Electric/Hybrid	US	2028	
North to South Island	Hybrid	New Zealand		
Gulf of Corinth	Electric (converted)	Greece		
Kingston - Wolfe Island	Electric	Canada		
Bangkok	Electric	Thailand		
Isle of Man	Hybrid	UK		
Oakland – San Francisco	FCEV	US		

APPENDIX II: ECONOMIC MODEL METHODOLOGY

Methodology and assumptions

The model presented in Chapter 6 is based on data from the E-ferry project in Denmark (comparison between 3rd of a kind electric ferry project and an existing diesel ferry – based on the MF Marstal).

In the base case of the model in Chapter 6, we analyse a route that is 22 nautical miles (41 km) long, with 5 crossings a day, 360 days a year. We assume 4 crew members for Ellen and 6 for MF Marstal (the difference being due to electric drivetrain being easier to maintain and the electric ferry's auto-mooring feature, reducing crew needed in port operations). The E-ferry is charged at only one harbour.

Table 5. Comparison vessels in Ellen e-ferry project
Source: E-Ferry Project D7.5 Final validation and evaluation report available at: shorturl.at/kquDH

Vessel	Propulsion	Cost of ferry (incl. all systems)	Port infrastructure (incl. connection fee)	Total cost
E-ferry series no. 3	Pure electric	$15,635,509	$4,120,027	$19,755,537
MF Marstal	Diesel	$15,169,675	n/a	$15,169,675

Table 6. Ellen e-ferry and MF Marstal specification
Source: E-Ferry Project D7.5 Final validation and evaluation report available at: shorturl.at/kquDH

	E-ferry	M/F Marstal
Length, oa	59,4 m.	49,9 m.
Breadth, moulded	12,8 m.	13,1 m.
Depth, moulded	3,70 m.	3,7 m.
Gross tonnage	996 t.	1617 t.
Service speed	13,5 kn.	11 kn.
Max speed	14,2 kn.	12 kn.
Number of cars	31	42
Number of passengers	147/196	250/395
Number of crew	4	6
Fuel consumption per day	0	3.3 mt
Electricity consumption per day	9443 kWh	1430 kWh

The model was adjusted to fit the Latin American context by:

- Adjusting electricity prices;
- Adjusting marine fuel prices;
- Adjusting crew cost (discounting by factor equal to the quotient of Danish and a particular country's average salary);

The base case model in Chapter 6.1 and 6.2 assumes the average electricity price, fuel price, average net salary for Latin America; in Chapter 6.3, adjustments were made for each of the 23 countries. Data tables can be found in the following sections.

The LEFM model is based on a number of assumptions.

- The assumed time horizon is 30 years – regular lifetime of this type of vessel;
- Revenues were not taken into the consideration as the main purpose of the model was to compare costs of electric and diesel ferries. It is important to highlight that electrification of a route could attract new passengers, as the operation would be quieter and more eco-friendly; however, it could also discourage some who might fear lack of reliability of the new technology;
- As both diesel and electric ferry need to undergo a refit (refurbishment of power train and batteries respectively), a sinking fund was added as an expenditure for both. Annual cost was calculated as the total cost of refit divided over the number of years in service before the planned refit year;
- Price of $212.40 /kWh was assumed for battery replacement cost in year 12 and $118/kWh in year 24 (as per Leclanché's forecast);
- Total of $590,000 was assumed for diesel engine refurbishments;
- 5% was added to bunker fuel costs to account for distribution costs;
- The discount rate of 7% was assumed for all Latin American countries;
- Assumed EUR/USD exchange rate of 1.18.

It is important to note that the economics of the early pilot routes in Latin America described in Chapter 9, were based on the same assumptions as those for the base case model, with the exception of five location-specific variables: route length, frequency, electricity prices, marine fuel prices and labour prices.

For instance, in the case of the Florianópolis route (please see chapter 9.3), the model used the following data:

- Route length: 7km
- Frequency: 70 crossings per week
- Electricity price: $168.21/MWh
- Marine fuel price: $708/mt
- Crew cost based on the average monthly salary of $354

The rest of the assumptions described above remained the same.

Electricity prices:

Table 7. Electricity prices in Latin American countries

Country	Year	Unit	Source	Cost
Argentina	2018	USD/MWh	BNEF	$155.67
Barbados	2015	USD/MWh	IDB Energy Hub	$430
Belize	2015	USD/MWh	IDB Energy Hub	$144.56
Bolivia	2018	USD/MWh	BNEF	$95.55
Brazil	2018	USD/MWh	BNEF	$168.21
Chile	2018	USD/MWh	BNEF	$158.76
Colombia	2018	USD/MWh	BNEF	$105.49
Costa Rica	2018	USD/MWh	BNEF	$179.68
Dominican Republic	2018	USD/MWh	BNEF	$145.8
Ecuador	2018	USD/MWh	BNEF	$80.1
El Salvador	2018	USD/MWh	BNEF	$163.4
Guatemala	2018	USD/MWh	BNEF	$153.64
Guyana	2015	USD/MWh	IDB Energy Hub	$290
Honduras	2018	USD/MWh	BNEF	$132.63
Jamaica	2018	USD/MWh	BNEF	$218.73
Mexico	2018	USD/MWh	BNEF	$99.31
Nicaragua	2018	USD/MWh	BNEF	$194.17
Panama	2018	USD/MWh	BNEF	$181.2
Paraguay	2018	USD/MWh	BNEF	$56.81
Peru	2018	USD/MWh	BNEF	$89.68
Suriname	2015	USD/MWh	IDB Energy Hub	$83.1
Trinidad & Tobago	2015	USD/MWh	IDB Energy Hub	$50.97
Uruguay	2018	USD/MWh	BNEF	$158.08
Average LatAm country	n/a	USD/MWh	*Average of the above*	$153.72

Source: IDB Energy Hub (https://hubenergia.org/en), BloombergNEF

Fuel prices:

Table 8. Maritime fuel prices in Latin American countries

Country	Metric	Period	Unit	Note	Price per mt
Argentina	MGO fuel	VIII 2019 - III 2020	USD/mt	National	$760
Barbados	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Belize	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Bolivia	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Brazil	MGO fuel	VIII 2019 - III 2020	USD/mt	National	$708
Chile	LSMGO fuel	VIII 2019 - III 2020	USD/mt	National	$807
Colombia	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Costa Rica	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Dominican Republic	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Ecuador	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
El Salvador	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Guatemala	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Guyana	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Honduras	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Jamaica	MGO fuel	VIII 2019 - III 2020	USD/mt	National	$723
Mexico	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Nicaragua	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Panama	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Paraguay	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Peru	MGO fuel	VIII 2019 - III 2020	USD/mt	National	$747
Suriname	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Trinidad & Tobago	MGO fuel	VIII 2019 - III 2020	USD/mt	National	$698
Uruguay	MGO fuel	VIII 2019 - III 2020	USD/mt	National	$830
Argentina	MGO fuel	VIII 2019 - III 2020	USD/mt	National	$760
Barbados	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719
Belize	MGO fuel	VIII 2019 - III 2020	USD/mt	LatAm average	$719

Source: Shipandbunker.com South America Atlantic Bunker Prices

Average salary

Table 9. Average monthly net salary

Country	Unit	Source	Value
Argentina	USD	Numbeo	$451
Barbados	USD	Estimate	$1340
Belize	USD	Estimate	$350
Bolivia	USD	Numbeo	$525
Brazil	USD	Numbeo	$354
Chile	USD	Numbeo	$646
Colombia	USD	Numbeo	$308
Costa Rica	USD	Numbeo	$762
Dominican Republic	USD	Numbeo	$331
Ecuador	USD	Numbeo	$501
El Salvador	USD	Numbeo	$372
Guatemala	USD	Numbeo	$540
Guyana	USD	Estimate	$402
Honduras	USD	Numbeo	$485
Jamaica	USD	Numbeo	$639
Mexico	USD	Numbeo	$486
Nicaragua	USD	Numbeo	$297
Panama	USD	Numbeo	$772
Paraguay	USD	Numbeo	$340
Peru	USD	Numbeo	$440
Suriname	USD	Estimate	$295
Trinidad & Tobago	USD	Numbeo	$903
Uruguay	USD	Numbeo	$594
Average LatAm country	USD	*Average of the above*	$527

APPENDIX III: LIST OF TABLES

APPENDIX IV: LIST OF FIGURES

APPENDIX V: IMAGE SOURCES

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