CLEAN ENERGY FOR EU ISLANDS

Decarbonising maritime transport

Off-grid Scottish Islands

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CLEAN ENERGY FOR EU ISLANDS

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List of Abbreviations

CEO	Chief Executive Officer
DKK	Danish Crown (currency)
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MCA	Maritime Coastguard Agency
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MTOE	Million Tonnes of Oil Equivalent
PHEV	Plug-in Hybrid Electric Vehicle

The Clean Energy for EU Islands Secretariat

Who we are?

The launch of the Clean Energy for EU Islands Initiative in May 2017 underlines the European Union's intent to accelerate the clean energy transition on Europe's more than 1,400 inhabited islands. The initiative aims to reduce the dependency of European islands on energy imports by making better use of their own renewable energy sources and embracing modern and innovative energy systems. As a support to the launch of the initiative, the Clean Energy for EU Islands Secretariat was set up to act as a platform of exchange for island stakeholders and to provide dedicated capacity building and technical advisory services.

The Clean Energy for EU Islands Secretariat supports islands in their clean energy transition in the following ways:

• It provides technical and methodological support to islands to develop clean energy strategies and individual clean energy projects.

• It co-organises workshops and webinars to build capacity in island communities on financing, renewable technologies, community engagement, etc. to empower them in their transition process.

• It creates a network at a European level in which islands can share their stories, learn from each other, and build a European island movement.

The Clean Energy for EU Islands Secretariat provides a link between the clean energy transition stories of EU islands and the wider European community, in particular the European Commission.

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1. Introduction

Shipping in the EU emitted around 139 Mt of CO_2 in 2017 and was responsible for 2.5% of greenhouse gas (GHG) emissions. Passenger shipping, which includes cruises and ferries, accounted for a staggering 20Mt of emissions, which was more than the total national passenger car fleet of the Netherlands (1). When considering islands, transport to and from the island takes up an even disproportionally larger share of energy usage, and hence carbon emissions. This global maritime fuel usage will only increasing over time, from a value of 40 Mtoe in 2010 to a projected value of 50 Mtoe in 2030, while other sectors (e.g. public road transport, private cars and motorcycles, and trains) are reducing their fossil fuel demand (2). The shipping industry is thus under increasing pressure to act upon the Paris Agreement and reduce GHG emissions.

Two options are available to decarbonise the transport sector: to reduce the fuel required or to shift to new types of propulsion that don't require fossil fuels. Although efficiency measures for ships (e.g. design requirements, capping operational speed, or wind propulsion) have an important impact on future emissions growth, they will be insufficient to decarbonise the sector or reduce its growing energy needs (3) since there is a large performance gap between ship design standards and real-world maritime operations. Due to this, half of the EU cargo shipping emitted about 22 Mt more CO_2 than what it would have emitted if ships operated according to their design standard. This highlights the inadequacy of solely depending on ship design standards as a regulatory tool to decarbonise the sector. The solution lies thus in identifying alternative fuels and technologies that limit CO_2 emissions, while at the same time reducing the required energy input.

This report is specifically written for the off-grid Scottish Islands, who have asked the Clean Energy for EU Islands Secretariat to study their options to decarbonise transport to and from the island. The off-grid Scottish Islands are particularly interested in retrofitting their current vessels to transform them into hybrid electric-diesel boats. This report first identifies alternative fuels and propulsion technologies for ferries and small vessels and compares them from an economic, environmental and technology maturity point of view. Second, several case studies of successful implementations in the EU are presented, which can serve as a guideline for the Off-grid Scottish Islands. Lastly, the report offers concrete recommendations to two specific Scottish Islands, Foula and Fair Isle, on how to decarbonize their maritime transport.

2. Identifying and comparing energy sources

This section first identifies possible energy sources to power ferries and small vessels, both alternative fuels and new propulsion technologies. It then compares them from an environmental, economic and technology maturity point of view.

Identifying energy sources

Many different types of fuel are used in the shipping industry nowadays, but the reference fuels are Heavy Fuel Oil (HFO) and Marine Gas Oil (MGO). HFO, also known as bunker fuel, is the remnant from the distillation process of crude oil and is therefore contaminated with compounds such as nitrogen and sulphur, which makes it more polluting than other fuels (4). The international Maritime Organization (IMO) has declared that from 2020 the sulphur content by mass in fuel can only be 0.5% (5), which will decrease the global demand for HFO (3% sulphur) or will require ships to invest in sulphur scrubbers to decrease their sulphur emissions. MGO consists of distillates, components of crude oil that evaporate during the distillation process and are then condensed back to liquid. Its sulphur content is generally lower than HFO and can even be produced below the 0.5% limit (4). In practice, HFO and MGO are often blended together and are then referred to as Marine Diesel Oil (MDO) (6).

The most promising alternative fuels today as seen by DNV GL—an international accredited registrar and classification society for several sectors including maritime, renewable energy, oil & gas and—are liquefied natural gas (LNG), liquid petroleum gas (LPG), methanol, biofuel and hydrogen (7). LNG is natural gas that has been cooled down to liquid form for easier and non-pressurized storage or transport. Additionally, LNG barely emits up to 90% less sulphur than HFO (8). LPG is a mixture of propane and butane in liquid form, which doesn't emit any sulphur. Methanol can be produced from various resources, mainly fossil sources, but also from renewable sources like liquor from paper mills and agricultural waste. In any case, methanol barely emits any sulphur and thus meets the sulphur emission cap. Biofuels come from a wide variety of biomasses that can be categorised as first generation (based on food stock), second generation (woody crops and waste), and third generation (aquatic autotrophic organisms such as algae). First generation biofuels have been criticised due to its competition with food production and due to its unwanted land use change, which can severely increase CO_2 emissions (8). Second and third generation are perceived as more sustainable as they do not have these issues. Hydrogen is an energy carrier that can be produced from various energy sources, such as renewables or natural gas. However, almost all hydrogen today is produced from natural gas.

One of the most promising propulsion technologies are battery-powered ships. Batteries provide the ability to directly store electrical energy for propulsion, opening many other opportunities to optimise the power system. Recent advancements in battery technology and falling costs thanks to the growing worldwide demand for batteries have made this technology more attractive to shipping, especially for ships running on short distances since the weight of batteries would be too high on longer distances. Ships running on batteries also make less noise and have zero emissions while sailing. However, batteries do have an environmental impact during manufacturing and the production of electricity has varying emissions depending on its source.

Environmental comparison

Of the fossil fuels currently used in maritime transport, LNG has the lowest CO_2 emissions (see Figure 1). However, the release of unburned methane (so-called methane slip) could reduce the benefit over HFO and MGO because methane (CH_4) has 25 to 30 times the greenhouse gas effect compared to CO_2 (9). In the view of the International Maritime Organization (IMO), LNG is not enough to decarbonise shipping. Even worse than HFO and MGO are the carbon footprints of methanol and hydrogen produced from natural gas. Fuels produced using renewable energy offer a smaller carbon footprint. Among these fuels is first-generation biodiesel which has a relatively low CO_2 reduction potential since this can cause detrimental land use change and can sometimes compete with food production (8). However, biogas (liquefied methane produced from biomass) has a higher CO_2 reduction potential. This type of fuel often comes landfills, livestock operations and wastewater treatment plants. Methanol from renewable sources like black liquor from a paper mill offers significant CO_2 emissions, but does require such industry to be present able to meet demand. The cleanest fuel is hydrogen produced using renewable energy. The figure illustrates that methanol from black liquor, biogas and hydrogen from water offer the highest CO_2 emission reductions.

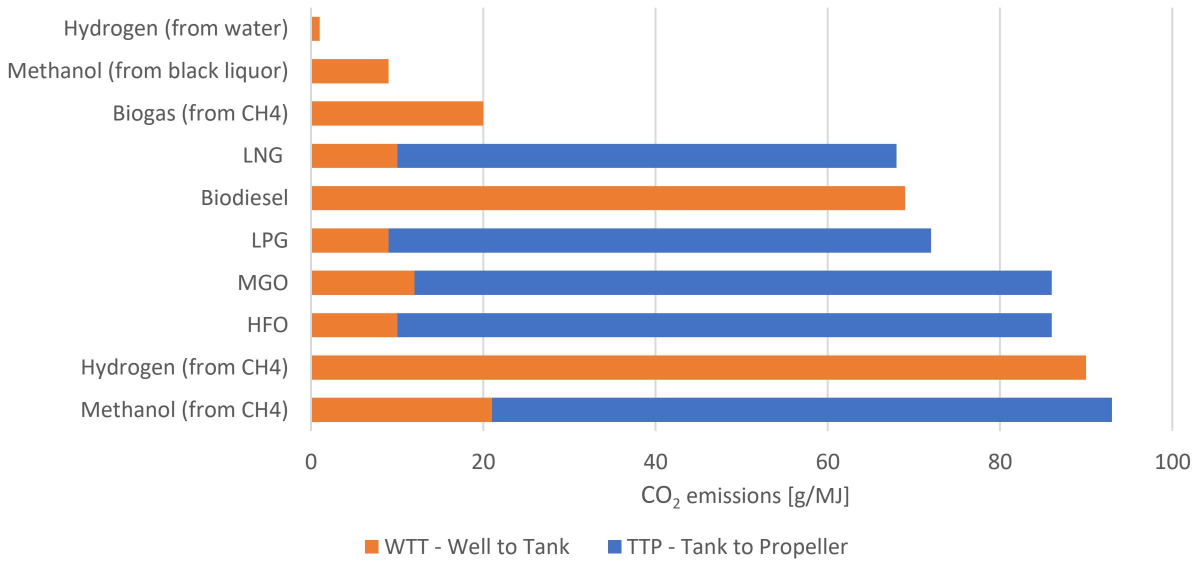

Figure 1: Renewable hydrogen, methanol and biogas offer the most CO_2 reductions of all alternative fuels considered. Graph adapted from (10)

While battery-powered ships have zero emissions during sailing, they do have emissions because of the manufacturing of the batteries and because of the production of electricity, which has a varying impact depending on its source. Figure 2 shows the Well-to-Tank CO_2 emissions of the three least emitting alternative fuels and various methods of electricity production. Electricity production fares far better than all fossil fuels from an environmental point of view, and renewable electricity production fares better than non-fossil fuels apart from hydrogen from water. Wind has the lowest emissions at only 0.6 g CO_2e/MJ. Hydrogen from renewable sources comes in second place because the electricity first has to be converted to hydrogen through electrolysis at an efficiency of 75%, and then liquefied or compressed and transported (11). Solar comes in third place, followed by biogas and methanol based on biomass. Natural gas and coal emit more GHG than the alternative fuels and hence are not a suitable source of electricity to decarbonise the maritime transport sector.

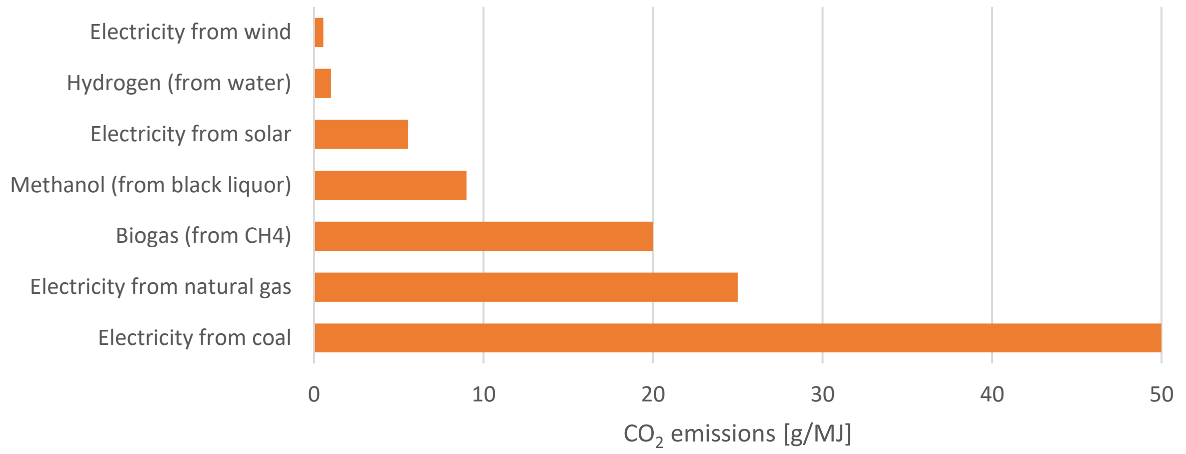

Figure 2 Electricity from renewable sources offers more WTT C02 reductions than the least emitting alternative fuels. Data source: (10) and (12)

Economic comparison

The price of shifting to alternatives fuels will ultimately determine whether the shift is feasible as it is usually the most crucial parameter of the business case. This price includes the investment in the new technology engine and the fuel price over the lifetime of the ship.

Figure 3 shows the minimum and maximum price of various fuels normalised with the Brent crude oil price, which serves as the baseline over a period from 2005 to 2016 (13). Hydrogen is not included in the graph since green hydrogen produced from renewables is generally not yet price competitive with low-cost LNG available in industry. This might change in the future as the costs of producing hydrogen from renewables are falling rapidly (14). Almost all hydrogen today is produced from natural gas and coal, referred to as grey hydrogen, which is more expensive than natural gas and has even more CO_2 emissions than the reference shipping oils.

Similar to hydrogen, most methanol nowadays is produced from natural gas (15), which does not significantly reduce CO_2 emissions. The price of this type of methanol (the lower value in Figure 3) is therefore still above the natural gas price The upper methanol price in Figure 3 corresponds to methanol from biomass, such as black liquor during paper production.

Biofuels are produced from biomass and refer to both biodiesel and biogas in Figure 3. The prices vary depending on the type of biofuel but is typically still above the baseline of Brent crude oil. The rest of the fuels don't offer any CO_2 reduction and only serve as a benchmark. Environmentally friendly alternative fuels are thus generally more expensive than reference marine diesel oil.

In terms of the 'fuel' price of battery-powered ships and how it relates to the reference fuels: battery-powered ships operate on electricity, of which prices vary from region to region. In the first half of 2019, residential EU electricity prices ranged from 0.10 €/kWh in Bulgaria to 0.31 €/kWh in Denmark (16). The electricity prices on the Off-grid Scottish islands also differ from island to island, from 0.21 €/kWh on Rum to 0.32 €/kWh on Fair Isle, with an overall average electricity price of around 0.29 €/kWh. In contrast, marine diesel—with an energy density of 10.3 kWh/l (17) and an average price of 0.69 l/€ on the Off-grid Scottish islands—costs only about 0.07 €/kWh.

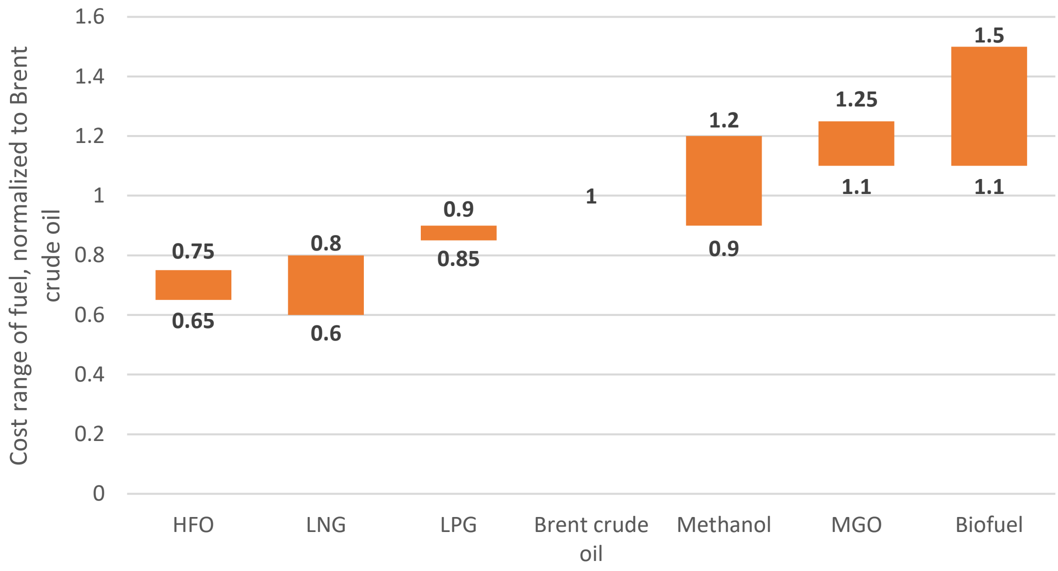

Figure 3 Alternative fuels are among the most expensive on the market. Graph adapted from (13)

From a tank to propeller point of view, electrical propulsion systems are more efficient than conventional propelled ships running on fuel. The efficiency of the electrical power system is around 90% of the electricity provided from shore while a typical diesel ship engine has an efficiency of 35% to convert chemical energy to motion (18), which is less than half of the electrical system. Hence, the cost per kWh of electricity can be more than twice for the same energy output as marine diesel. Additionally, the maintenance costs of battery-powered ships are lower since a diesel engine has thousands of moving parts while a battery-powered ship only has bearings that need maintenance. The case studies in Section 3 show that battery-powered ships can in fact operate at a lower price in certain conditions.

Additionally, a mixture of electric and diesel power, a hybrid system, also offers interesting and economic possibilities. The latest hybrid systems have a full electric propulsion with the diesel engine acting solely as a generator. This allows the diesel engine to operate continuously at its maximum efficiency, substantially reducing the required fuel input. These hybrid systems can operate in different modes, running purely electric for limited periods, running on a combination of electric and diesel power with the engine supplying power directly to the motors, or running with the diesel engine supplying power to recharge the batteries and supplying the motors (19).

Technology maturity comparison

No ship running on biogas currently exists, but the Norway-based cruise operator Hurtigruten is planning to power its ships with liquified biogas fuel (LBG) from 2021 (20), see Figure 4. Methanol is used on a total of 16 ships, mainly in chemical tankers but can also be used in ferries, as showcased by the Stena Germanica (21). This ferry operates in the Baltic Sea since 2014 and uses methanol as its main fuel.

Hydrogen ships are still at an early design phase with applications in smaller passenger ships, ferries or recreational crafts. An example is the HySeas III, the world's first hydrogen-powered sea-going ferry which will sail between two islands in the North of Scotland, Shapinsary and Kirkwall, in 2021 (22).

Ships operating on batteries are more prevalent and are commonly used in the ferry sector, compared to other sectors (see Figure 4). This is because the energy density of batteries is still too low, which makes it impossible for large oceanic ships that must travel large distances with one charge. Ferries, however, travel shorter distances, dock more frequently and can thus charge more often (23). Norway's Ampere is an example of a battery electric car ferry (24). It sails the Lavik-Oppedal crossing in Norway in 30 minutes, after which the batteries are recharged at the docks in 10 minutes. Additionally, the four ferries of the "Bird Flight Line" between Germany and Denmark sail with hybrid technology, a combination of an internal combustion engine and an electric drive system that reduces the CO_2 emissions by up to 15% (23).

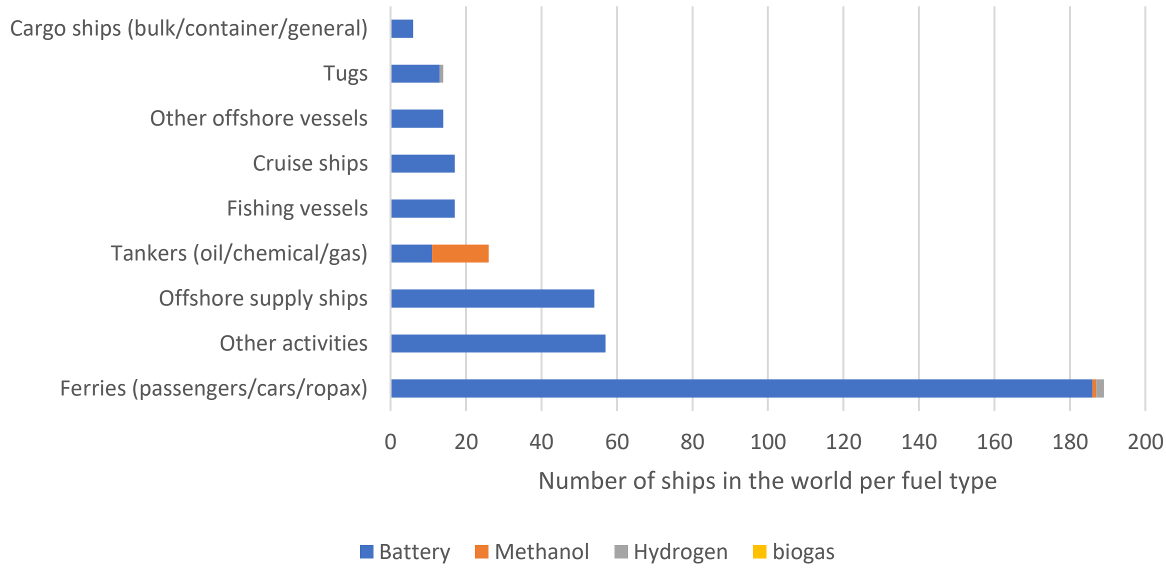

Figure 4 Battery-powered ships are the most mature technology and mostly used on ferries. Graph adapted from (25)

Due to the environmental merit of battery-powered ships charged by renewable energy, its economic feasibility and the fact that the technology is proven and mature, this report will continue by solely discussing battery-powered ships (pure electric as well as hybrid) in more detail as this is the most feasible option to decarbonise maritime transport on the Off-grid Scottish Islands in the near future. The report will discuss electric ferries as well the option to retrofit smaller vessels.

In depth-analysis of battery-powered ships

"Battery power has come a long way and their range has significantly improved over the past years; in addition, battery solutions are becoming cheaper and last much longer than they did just a few years ago" (Remi Eriksen, CEO and President of DNV GL). This has resulted in ships running on electricity becoming more common, as illustrated in Figure 5 s. In 2020, 191 battery-powered ships were in operation and an additional 159 were under construction, almost doubling the market. Most of these battery-powered ships are ferries, as shown in Figure 4 . As pointed out before, ferries travel small distances at a time with the possibility to recharge in between trips, which is ideal for battery operation. Still, the shipping industry has historically been a conservative sector and this shift to battery-powered ships is mainly driven by innovations in the car industry. To stay competitive, the car industry must come up with solutions that meet much stricter environmental requirements as well as satisfying increasing consumer requirements.

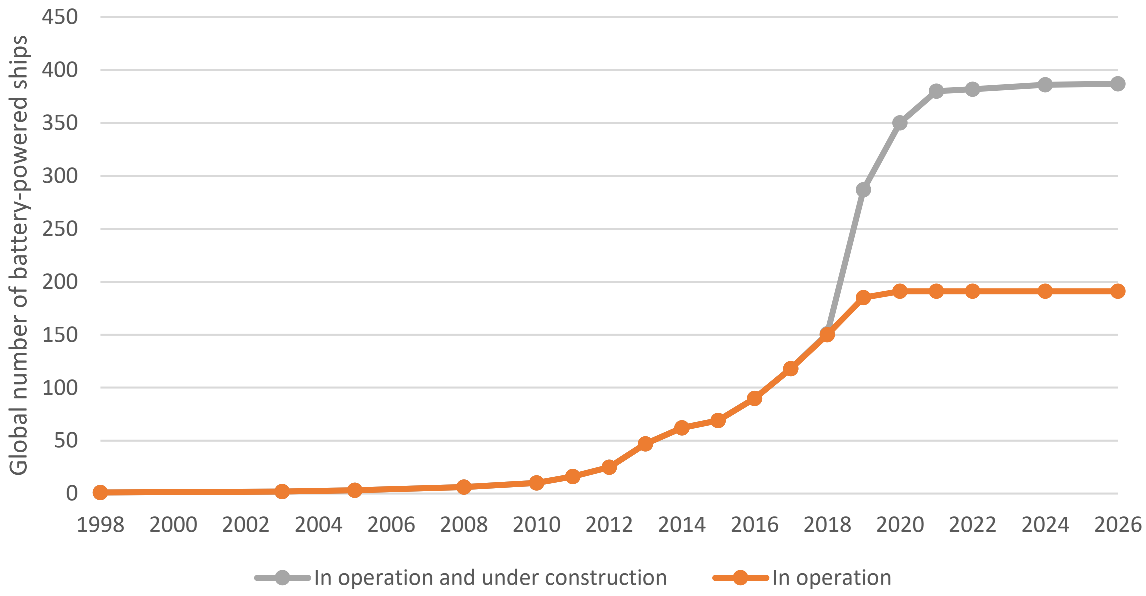

Figure 5 Battery-powered ships have increased in numbers and many more are under construction. Graph adapted from (25)

Not all battery-powered ships are fully electric though, the majority (53%) are a mild hybrid, while 22% and 18% are plugin-hybrid and pure electric ships respectively (see Figure 6). On a full-electric ship, all the power—for both propulsion and auxiliaries—comes from batteries. A plug-in hybrid ship, similar to a plug-in hybrid car (PHEV), is able to charge its batteries using shore power and has a conventional engine in addition. The ship can operate on batteries alone on specific parts of the route, when manoeuvring in port, during stand-by operations. A hybrid ship uses batteries to increase its engine performance and does not use shore power to charge its batteries (26).

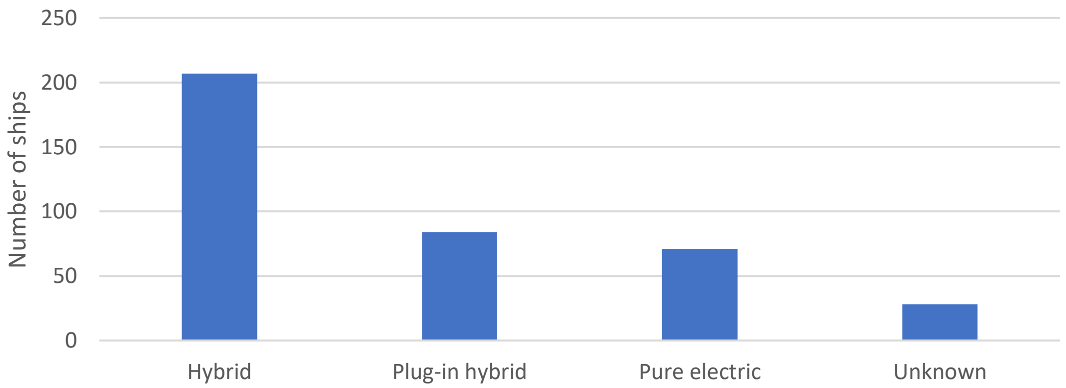

Figure 6 Half of the battery-powered ships are hybrids; the other share is divided between plug-in hybrid and pure electric. Graph adapted from (25)

Hybrid solutions are especially interesting for ships that experience large load variations during operation, since the introduction of a battery system allows the engines to optimally operate with respect to fuel oil consumption and/or emissions. This can be achieved by selecting engine sizes that operate at optimal loads for most of the time, with additional power obtained from the batteries when required. When power requirements are low, the batteries can be charged using the excess energy generated by running the engine at the optimal load. Alternatively, in operating conditions requiring very low loads, the ship may be able to operate on battery power alone (26).

Furthermore, a staggering 259 battery-powered ships operate or are under construction in the EU and Norway (see Figure 7). This is 71% of all battery-powered ships worldwide. Most of these EU ships operate in Norway, which has 161 battery-powered ships. This corresponds to 44% and 62% of global and EU battery-powered ships respectively.

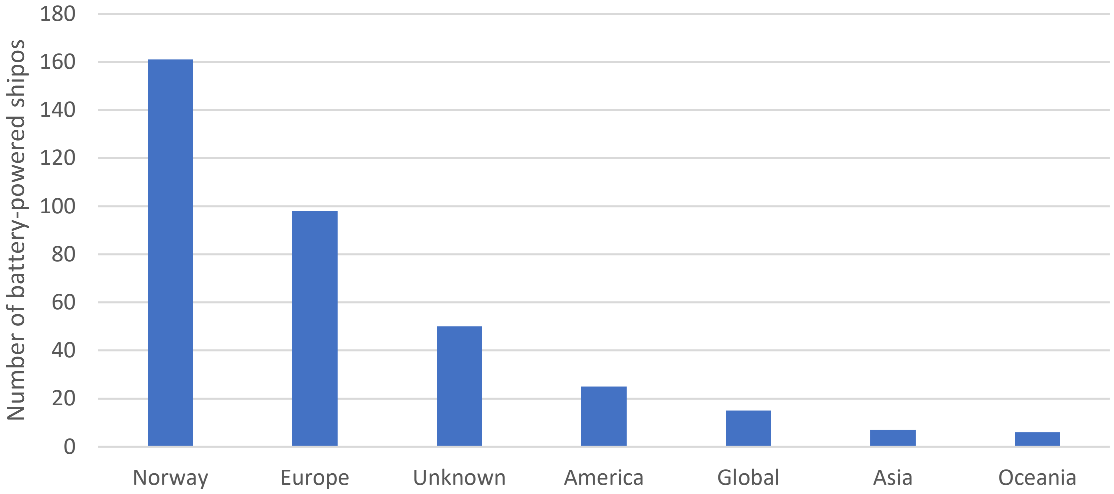

Figure 7 Most battery-powered ships are in Norway and Europe. Graph adapted from (25)

3. Case studies

As illustrated in the previous section, battery-powered ships are rising in numbers. Figure 8 shows a heat map of the locations of existing battery-powered ships (full-electric and hybrid) in Europe. Norway boasts the most battery-powered ships, but Denmark and the UK also have several of them. For each of these countries, a case study of an electrified ferry is presented. These ferries are generally quite large, but smaller ferries and vessels can be electrified as well. Two manufacturers of electric boat drives are discussed, with several interesting implementations.

Battery-powered ferries

Figure 8 Most battery-powered ships in the EU are found in Norway, the UK and Denmark. Data source: (25)

Norway

The Ampere ferry was the first ferry ever to be electrified in 2015 in the fjords of Western Norway. There, it crosses the 6 km distance between Lavik and Oppedael year-round, 34 trips a day, at an average speed of 14 knots. With its length of more than 80 m, it can carry up to 360 passengers, 120 cars and 8 trucks. The hull is made from aluminium instead of steel to reduce the overall weight. Furthermore, LED lighting, solar panels and a heating, ventilation and air conditioning system with waste recovery system are implemented to reduce energy consumption even more (27). The ship is propelled by two 450 kW electric motors powered by 1000 kWh of lithium-ion batteries, which are recharged at shore while unloading by a battery of 260 kWh.

The ship is a result of a competition organised by the Norwegian government in 2011 to develop a sustainable ferry service. Norled won, which allowed them concession rights to operate the route until 2025. In 2014, the Ampere received the 2014 Ship of the Year award at the SMM trade fair in Hamburg(24). Since it is battery-powered, the Ampere reduces CO_2 emissions by 95% or 570 tonnes of CO_2 and costs by 80% compared to conventional fuel-powered ferries. Furthermore, the noise is reduced as well as the diesel fumes, improving passenger comfort. The Ampere serves as the first pilot study proving that battery-powered ferries can significantly reduce emissions and costs. The success has not gone unnoticed with an additional 53 order placed in 2018 (28). This also fits with Norway's vision to electrify two thirds of its car ferries by 2030, according to Prime Minister Erna Solberg (29).

Denmark

Siemens, one of the companies behind the first electric ferry in Norway, published a study in 2016 on the potential for Denmark to electrify its 52 ferries operating among 42 domestic routes (30). They looked at the technical feasibility, the economic sense, and the environmental impact and found that 7 out of 10 ferries could be profitably replaced by electric counterparts. This would result in a return of DKK 35 million per year over a 10-year period and a reduction of 50 000 tonnes of CO_2 emissions per year.

Denmark has taken their advice to heart as in 2019, the largest electric ferry to date, called Ellen, sailed 22 nautical miles between the southern Danish ports of Fynshav to Soby. This €21.3 million project was funded by the European Commission and industry as part of the Horizon 2020 programme. The 60 m long ferry can carry up to 200 passengers and 30 vehicles over 41 km without recharging. It does this at a speed of around 15 knots, which cuts the travel time to 55 minutes, down from the 70 minutes with a conventional ferry. This ferry also makes use of lightweight materials, aluminium was used to create the bridge and deck furniture made from recycled power instead of wood, to reduce the power consumption. Two 750 kW propulsion and two thruster electric motors propel the ferry forward, while docking is assisted by 250 kW bow thrusters to help increase manoeuvrability and energy efficiency as they are only used in port. These electric motors are powered by two 2150 kWh batteries, good for a total of 4.3 MWh, making it the largest known maritime battery capacity, and the first in the world to have no emergency generator (31). Ellen prevents 2000 tonnes of CO_2 emissions per year compared to a fuel-powered counterpart. Since there is no engine room and the battery system is fully automated, the ferry operates at 25% of the cost of a similar diesel vessel and can break even in 4 to 5 years (32).

The UK

In 2019, to reduce the emissions from the maritime sector, the UK government announced that all new ships for UK waters ordered from 2025 should be designed with zero-emission capable technologies (33). However, the feasibility and profitability still depend on the local conditions (e.g. distance, size, availability of renewables, changes to the electrical grid, etc.). If fully electric isn't possible, a hybrid solution might be preferable where the combustion engine can always work at its optimum. A vision shared by ferry operator Caledonian McBrayne who, besides operating the MV Lochnevis ferry to Off-grid Scottish Islands Eigg, Muck, Canna and Rum, also operates three hybrid ferries in Scottish waters. The ships incorporate a low-carbon hybrid system of traditional diesel power and 700kWh of electric lithium-ion battery power, which is charged overnight from a shore-side connection. The first hybrid ferry, MV Hallaig, was introduced in 2011. The second hybrid ferry is called MV Lochinvar, and the third ferry, MV Catriona, saw Scottish waves in 2016. MV Catriona is 43.5m long and can carry 150 passengers and 23 cars. The hybrid ships reduce fuel consumption up to 38% in comparison to its fossil-fuelled counterpart of the same size. This results in a reduction of more than 5500 tonnes of $C0_2$ per vessel over their lifetime (34).

Electrifying smaller vessels

Torqeedo

Founded in 2005 in Germany, Torqeedo stands for clean, sustainable mobility on the water. The company manufactures various electric and hybrid propulsion systems for different ship types and sizes. Their power output can vary from 1 kW for kayaks to up to 100 kW for smaller ferries. The latter is referred to as the 'Deep Blue (Hybrid) system', suitable for larger commercial vessels that require a longer range (35). The batteries are adapted from the automotive industry and enable motor-cruising for up to 50+ nautical miles. The integrated generator provides enough energy to cover even longer distances, if required.

An example is the ECOCAT, a ferry operating in the south of Spain on Mar Menor lagoon runs on 100% solar-electric power. Its normal operating speed is 7 knots and can cruise for eight hours without recharging. The boat is 18 m long, weighs 26 tons and can carry up to 120 passengers. It is propelled by two 50kW Deep Blue electric motors and eight 30.5 kWh batteries. Similarly, the 'Queen Elizabeth Dr.' which operates in Ottawa also has two 50 kW electric motors. The electric system cost $90 000 more than an equivalent diesel system but can save $26 000 per year in reduced fuel and maintenance cost, resulting in a break-even point of 3.5 years (35). Torqeedo has its eyes set on bigger boats like ferries and water taxis as they want to be a player when Amsterdam and Paris electrify their fleets. Amsterdam wants to gradually ban all combustion engines, cars and ships alike, starting from 2025. Paris aims to achieve this by 2030 (29).

Seine Alliance

The Black Swan will be the first vessel in the Seine Alliance boat fleet to be fully electrified in Spring 2020. The project was realised by a partnership between Renault and Green vision, where Renault provides second-life batteries from the Renault Kangoo Z.E. to drive the boat's electric motors and Green vision provides technical guidance to retrofit the boat (36). The batteries have a nominal power output of about 15 kW, which allows the boat to sail at 12 km/h, the limit in the waters of Paris. The 12 passengers can enjoy a 2 hours cruise before recharging, after which it takes 2 hours to recharge the batteries. By 2024, Seine Alliance wants to electrify its entire fleet as Paris is looking into ways of going full electric (37).

4. Recommendations

This report has until now identified promising alternative fuels and propulsion technologies for ferries and small vessels for the Off-grid Scottish Islands and has compared them from an economic, environmental, and technology maturity point of view. This led to the conclusion that battery-powered ships are the most recommended to decarbonise these islands. This was followed by an in-depth analysis of the state of battery-powered ships (full-electric and hybrid) in the world, supplemented with several case studies of successful implementations in Europe, which can serve as a guideline to the Off-grid Scottish Islands. This last section of the report goes deeper into two specific Off-grid Scottish Islands, Foula and Fair Isle, to see what type of vessel they currently use and compares this to the existing case studies discussed in section 3. Based on this, several specific recommendations are given.

Fair Isle has one ferry, called the 'Good Shepherd 4', which crosses the 24 Nm journey from Fair Isle to Shetland Mainland in about three hours at a speed of ten knots. It does this three times per week in the summer and once a week in winter. The ship is 18.3 m long and can carry up to 12 passengers and one car. It is propelled by a 6-cylinder 12 litre combustion engine with 239 kW. Current community requirements demand that the vessel must become larger.

Foula's ferry is called 'New Advance' and operates from Foula Harbour to Walls on Shetland mainland in about 2h25 at a speed of 8 knots. Like the Good Shepherd, the New Advance also operates a return service three times per week. The ship is 11 m long and can carry up to 10 tonnes, 12 passengers and 4 crew members. It is propelled by two 63 kW combustion engines.

Considering the ship dimensions, the power requirements and the travel distance of the Off-grid Scottish Island ferries, the Deep Blue Hybrid system of Torqeedo might offer a solution. This is a hybrid solution with a power output of up to 100 kW, ideal for smaller ferries. The ECOCAT, for example, can carry as much load as the New Advance, travels at a similar speed and has a similar power output. Hybrid solutions could fare better as they might be required by the Maritime and Coastguard Agency (MCA) as a fail-safe propulsion system. In this sense, seeking contact with the ferry operator Caledonian MacBrayne offers a pathway to reduce maritime emissions since they have already implemented three hybrid ferries and also operate the MV Lochnevis ferry that travels to the Off-Grid Scottish Islands of Muck, Canna, Eigg, and Rum.

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