Towards Ferry Electrification in the Maritime Sector

Journal: Energies (BF2), Section: electric Power and Energy system

Presenter:
Sadia Anwar

Links: https://www.mdpi.com/1996-1073/13/24/6506/htm

INSTITUT FOR FORRETNINGSUDVIKLING OG TEKNOLOGI
AARHUS UNIVERSITET
Interreg Öresund-Kattegat-Skagerrak
European Regional Development Fund
EUROPEAN UNION
Den erhvervsdrivende fond
Skagen Uddannelsescenter

Table of Content:

Abstract:

The objective of this research is to develop knowledge by examining the current state of affairs and provide, accordingly, abstract implementation guidelines for green transformation through vessel/ferry electrification.

A comprehensive study on the electrification of vessels, in industry as well as in academia, is performed.

A comparison of various pure electric and hybrid vessels in terms of certain performance attributes, such as battery capacity, passenger and cargo capacities, and size (length) of the vessel, is performed.

Moreover, the distribution of vessels according to different countries and manufacturers is provided.

Finally, certain technical, operational, and legislative challenges are explored.

Key Words: energy storage systems; electrification; electric ferries; green energy; maritime industry

Introduction

The transportation of commodities (consumer goods) is important, and almost 80 percent of this transportation is carried out using vessels (ships)

The maritime industry has an impact on climate change, especially near coastal areas

Europe has approximately 900 ferries (including freight and passenger transport), which accounts for more than 70% of the world's journeys

Fossil fuels are used in most of the ferries and cause emissions such as CO2, SO2, and NOX. These emissions have a direct effect on human health when the ferry is berthed

The above explanation urged the international marine organization (IMO) to implement certain emission regulations

European ferries and vessels do not have the required specifications to counter growing environmental concerns.

Furthermore, there is an increasing trend towards the electrification of ships through a hybridization process

Despite the great importance of ferry electrification, there are certain challenges preventing the successful implementation of this technology

Ferry crews require training in order for them to be familiarized with the technical, operational, and safety issues of the new system

State of the art:

The state-of-the-art to address the aforementioned technical, operational, legal, and human challenges has been reviewed and summarized in Table

Table 1. Classification of review surveys on various aspects of green transformation.

S. No.	Category	Reference	Years
1	Electric propulsion	[18,20]	2020
2	Micro-grids	[19,24]	2019
3	Energy storage	[21,23]	2018, 2020
4	Fuel cell-battery hybrid/full battery powered ships	[22,25]	2020
5	Zero-emission ships	[26,27]	2019, 2020

Limitations in the existing surveys

various review articles that have been recently published on different aspects of an end-to-end green transformation system.

These aspects include onboard electric propulsion systems, micro-grids, energy storage systems, fuel cell-battery hybrid/full battery powered ships, and zero-emission ships. Even though the review articles on these aspects have provided great insights in terms of knowledge development for a dedicated or particular aspect of the system, the implementation of these systems (electrification for green transformation) may generally require an abstract implementation guide that can briefly provide an overview (end-to-end knowledge) of the complete system.

Contributions

In order to address the identified limitations, this article has reviewed the state-of-the-art in ferry electrification by examining various aspects of different available commercial vessels (through the internet).

systematic data collection, a comprehensive analysis has been performed to extract the useful information. The extracted information allows us to depict various trends such as the countrywide electrification of vessels, leading companies, hybridization versus pure electric ships, size (length) and speed of vessels, passenger and car carrying capacities, battery type and capacity, and so on.

The knowledge developed in this article provides a holistic view of the current state of affairs to researchers and practitioners of the domain.

An Eco-Friendly Hybrid Propulsion System

The purpose of this section is to provide fundamental concepts related to the electrification of ferries for green transformation.

charging system at the port that is used to charge the batteries of the vessel from the grid during docking.

Several renewable energy sources which include: (1) wind energy, (2) photo-voltaic (PV) energy, (3) and energy from surface waves. The energy can be stored in an ESS (consisting of battery banks) when the supply is greater than the demand.

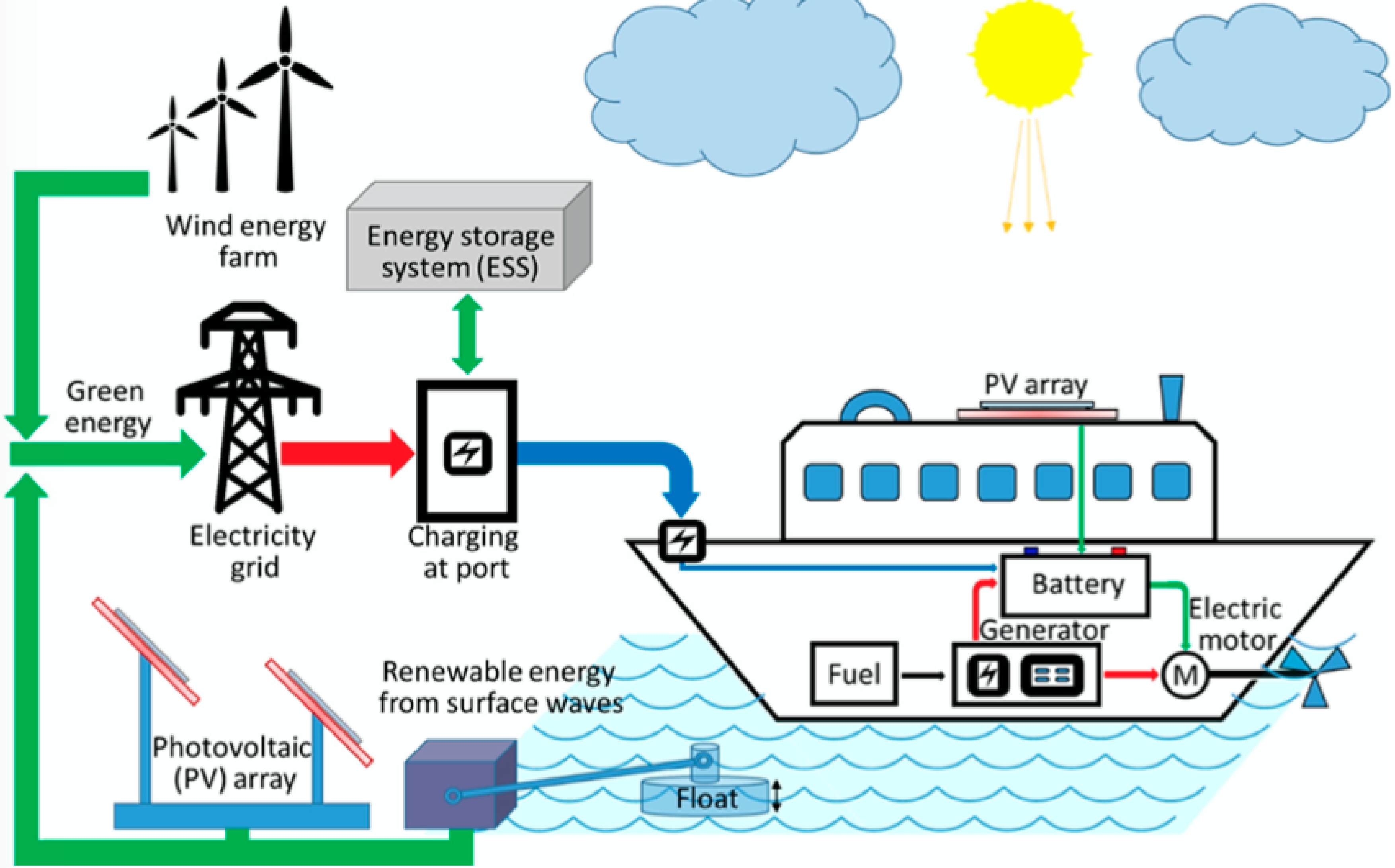


Figure 1. An eco-friendly hybrid propulsion system.

Case example from the literature

24 m long ferry with a capacity of 48 passengers is provided, using the data from case study, a fixed speed of 10 knots is used in each case (hybrid/pure electric). The parameters (such as battery capacity, cost, weight, charging requirements) may vary and will depend upon a particular scenario/application. In either case (pure electric or hybrid), the battery discharge is considered to be up to 80% to ensure the battery life. In the first example, a full electric vessel that is equipped with a 500 kWh Lithium-ion (Li-ion) battery is considered. The vessel can travel up to 44 nautical miles (nm) on a single charge [32]. Hence, the pure electric vessel provides a good solution for green transformation

Second examle

In the second example, a hybrid vessel is considered with a medium sized 300 kWh Li-ion battery that can be used to travel up to 27 nautical miles (nm) on a single charge. Furthermore, to cover a larger distance, the support of gen-set is required.

Research Methodology

Mixed method approach

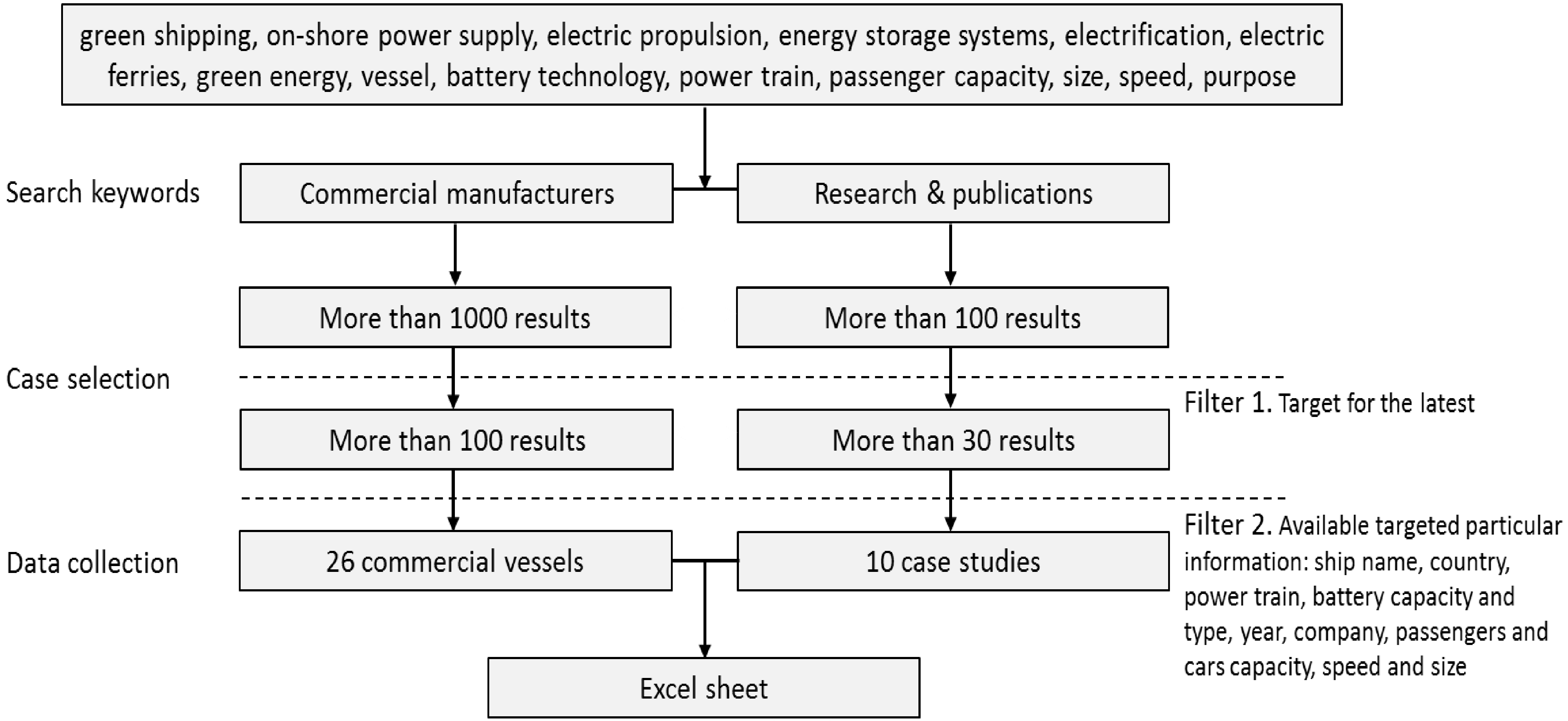
The research framework model in this article consists of three steps: (1) design research, (2) conduct research, (3) data analysis and conclusion.

Process	Research framework	
Design research	Research objective →	• Prepare with background investigation • Design research process framework
Conduct research	Literature review →	• Identify comprehensive cases from resources on the web • Examine and extract data from case resources
Data analysis & conclusion	Analyze data and draw conclusions →	• Visualize qualitative and quantitative data presentation (*) • Categorized by country & company wise electrification of ships (*) • Categorized by electric & hybrid vessels, battery capacity, vessel size (length) (*) • Categorized by power train, passengers / cargo carrying capacities & speed (*) • Identify current states of energy storage systems (*) • Identify key issues in green transformations (*)

Potential outcomes (*)

Conduct Research

These three steps are: (1) search keywords, (2) case selection, and (3) data collection.



Case selection: Vessels sesearch from 2008-2019, aiming for a holistic vision of the vessel, parameters: ship name, country, company, year, power train, types of battery used, battery capacity, passengers and cargo information, speed, and size, 26 vessels and 10 case studies for R&D purpose. Reason for 26 vessels selection?

Data collection: comprehensive review of papers, reports, websites, and online surveys, and a mixed method research approach. Documents were collated, and the relevant data extracted in an MS Excel spreadsheet in different columns. Subsequently, the target parameters were presented using tables. Limitations?

Data analysis: Graphical analysis, Material was clustered, and data organization and formatting according to the coding of the framework. Data is divided into the qualitative and qualitative as numeric and non-numeric values. Data is statistically analyzed in order to find the trends.

Results:

Data Extraction: Data from Websites of manufacturer

Table 2. Vessel study for battery technology towards electrification.

Ref. No.	Name	Country	Power Train	Battery (kWh)	Battery Type	Year	Company	Passengers	Cars	Speed (knots)	Length (m)
[40]	FSC Alsterwasser	Germany	Hybrid	200	Lead-Gel	2008	Zemships	100	-	8	25
[41]	Nemo H2	Nether-lands	Hybrid	70	-	2009	Govt. and Industry	87	-	9	22
[42]	Viking Lady	Norway	Hybrid	500	Li-ion	2009	Eidesvik	25	-	15.5	92
[46]	MV Hallaig	Scotland	Hybrid	700	Li-ion	2012	CalMac Ferries Ltd	150	23	9	43
[47]	MV Lochinvar	Scotland	Hybrid	700	Li-ion	2013	CalMac Ferries Ltd	150	23	9	43
[49]	Prinsesse Benedikte	Denmark	Hybrid	1600	Li-ion	2013	Scandlines	1140	364	18.5	142
[50]	Prins Richard	Denmark	Hybrid	1600	Li-ion	2014	Scandlines	1140	364	18.5	142
[51]	M/F Deutschland	Germany	Hybrid	1600	Li-polymer	2014	Scandlines	1200	364	18.5	142
[52]	M/S Sjovagen	Sweden	Electric	500	Li-ion	2014	Ballerina	150	-	8.5	24.5
[53]	Movitz	Sweden	Electric	120	NiMH	2014	Echandia Marine	100	-	9	22.8
[54]	MV Ampere	Norway	Electric	1000	Li-ion	2015	Norled	360	-	10	79
[55]	MV Island Clipper	Norway	Hybrid	875	Li-ion	2015	Inland Offshore Management AS	56	-	15	97
[61]	BB Green	Nether-lands	Hybrid	200	Li-ion	2015	Partly funded by an EU dev. project	100	-	30	22
[45]	Vision of the Fjords	Norway	Hybrid	600	Li-ion	2016	The Fjords	399	-	19.5	40
[48]	MV Catriona	Scotland	Hybrid	700	Li-ion	2016	CalMac Ferries Ltd	150	23	9	43
[56]	OV Bokfjord	Denmark	Hybrid	850	Li-ion	2016	Hvide Sande Shipyard	16	-	13.5	44
[62]	Aditya	India	Electric	50	Li-ion	2016	Kerala State Water Transport Dept.	75	-	7.5	21
[33]	MF Tycho Brahe	Denmark	Electric	4100	Li-ion	2017	Scandlines	1250	240	14.5	111
[34]	Elektra	Finland	Hybrid	1000	Li-ion	2017	Finferries	375	90	11	98
[57]	Viking Princess	Norway	Hybrid	511	Li-ion	2017	Eidesvik	28	-	11.4	90
[58]	Zhongtiandianyun 001	China	Electric	2400	Li-ion	2017	Guangzhou Shipyard International	-	-	7	70
[44]	Future of the Fjords	Norway	Electric	1800	Li-ion	2018	The Fjords	400	-	16	43
[59]	Enhydra	USA	Hybrid	160	Li-ion	2018	Red & White Fleet	600	-	13	39
[43]	Ellen	Denmark	Electric	4300	Li-ion	2019	EU H2020	200	-	21	60
[60]	MV Waterman	USA	Hybrid	80	Li-ion	2019	All America Marine, Inc.	150	-	15	21
[63]	MS Color Hybrid	Norway	Hybrid	5000	Li-ion	2019	Color Line	2000	-	17	160

Research Case Studies

Last table provides the data, extracted directly from the websites of manufacturers, Below Table summarizes some important R&D projects.

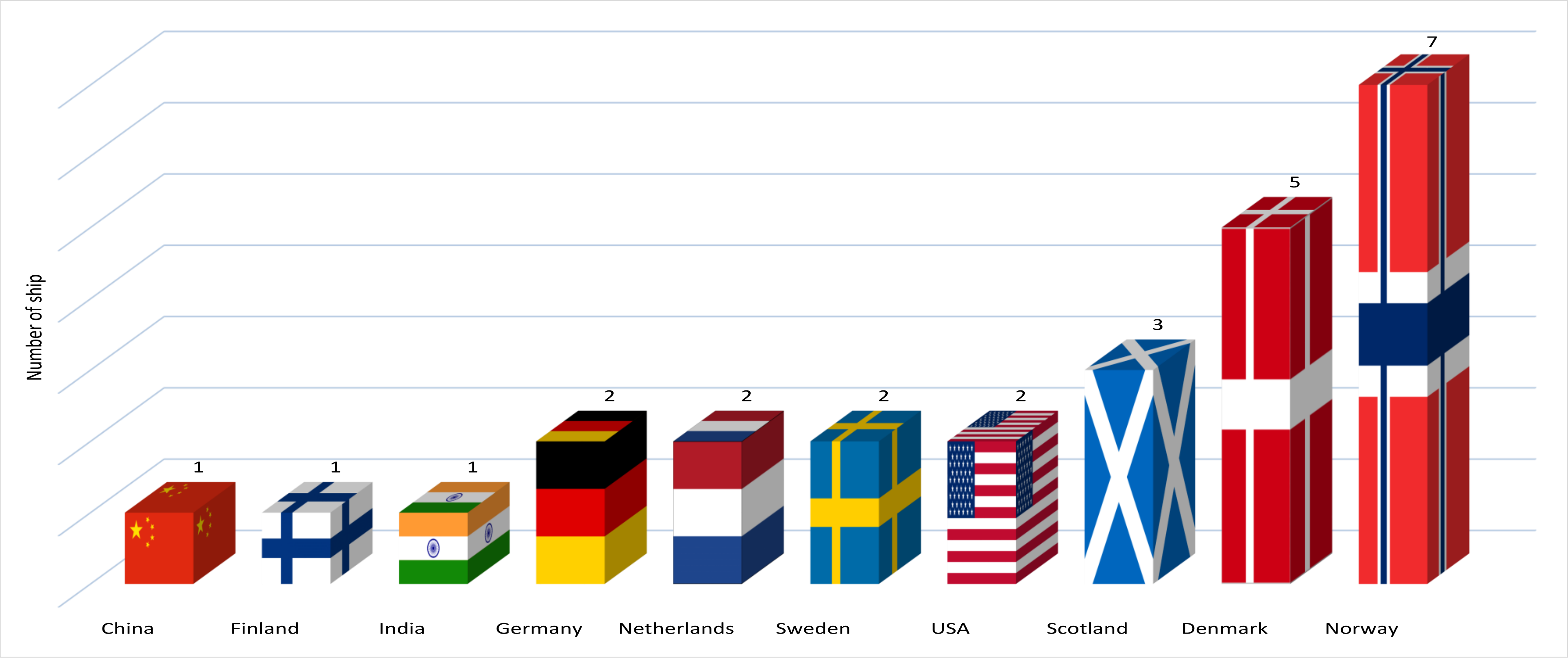
Table 3. Case studies through research and publications.

Ref. No.	Name	Country	Power Train	Battery (kWh)	Battery Type	Year	Project	Passengers	Cars	Speed (knots)	Length (m)
[66]	Glutra Ferry	Norway	Hybrid	-	-	2002	R&D	-	100	12	94.8
[64]	Boat	Italy	Electric	226.8	Li-ion	2011	R&D	-	-	6	-
[72]	Alsterwasser	Germany	Hybrid	200	Lead-Gel	2014	R&D	100	200	8	25
[32]	Typical Shuttle	Italy	Hybrid	500, 300, 160	Li-ion	2015	R&D	48	-	13	24
[67]	Hybrid ship	China	Hybrid	-	LiFePO4	2016	R&D	-	-	-	333
[68]	Alsterwasser	Germany	Hybrid	200	Lead-Gel	2016	R&D	100	-	8	25
[69]	Alsterwasser	Germany	Hybrid	200	Lead-Gel	2016	R&D	100	-	8	25
[71]	M/S Smyril	Denmark	Hybrid	300	Li-ion	2016	R&D	976	-	21	123
[65]	Bowen Ferry	Australia	Hybrid	13.7	-	2018	R&D	-	30	7	35
[70]	Skeena Queen	Canada	Hybrid	360	-	2019	R&D	600	-	14	110

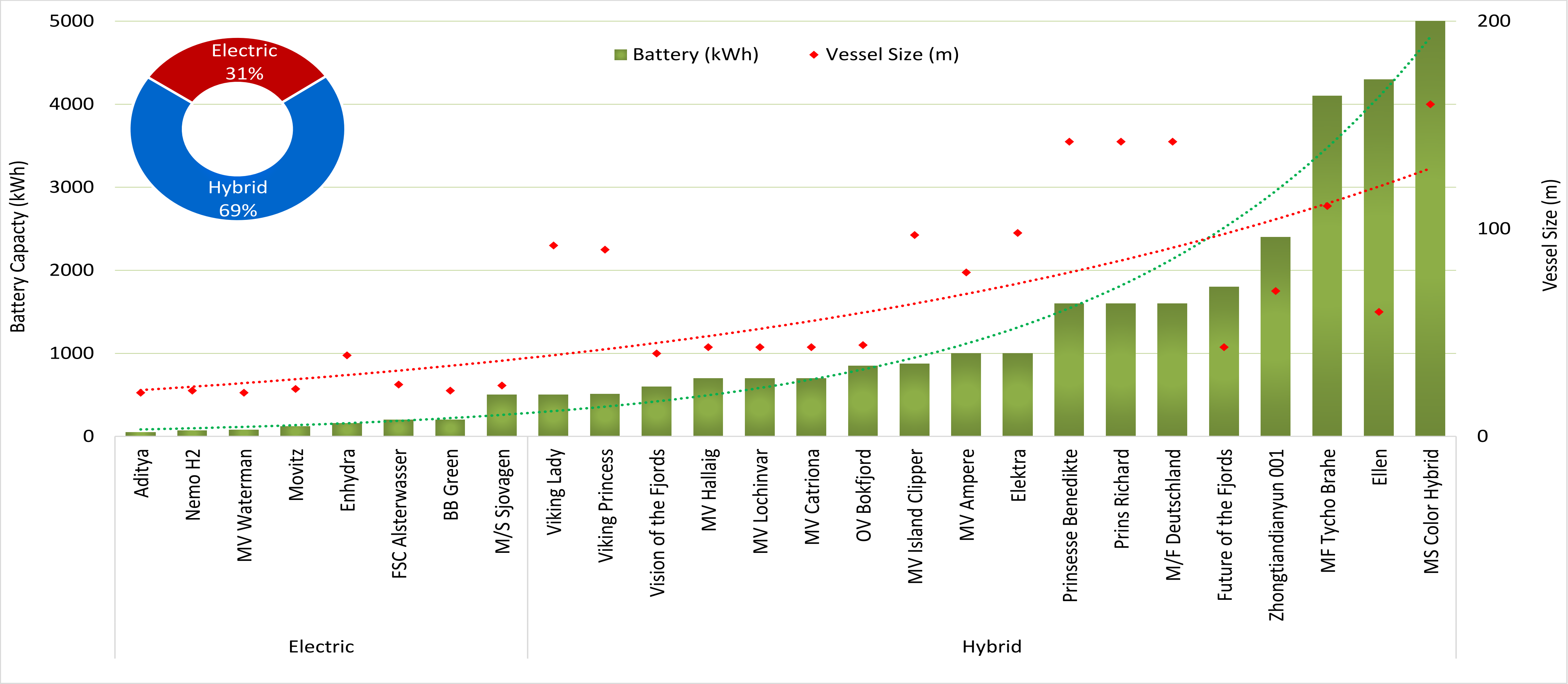
Data Synthesis:

Based on the data presented in the tables, interprets/synthesizes of the data to reveal some meaningful information.

Classification: Countrywide electrification of ships (2008-2019)



Second Classification: Electric and hybrid vessels (Battery capacity and vessel length)



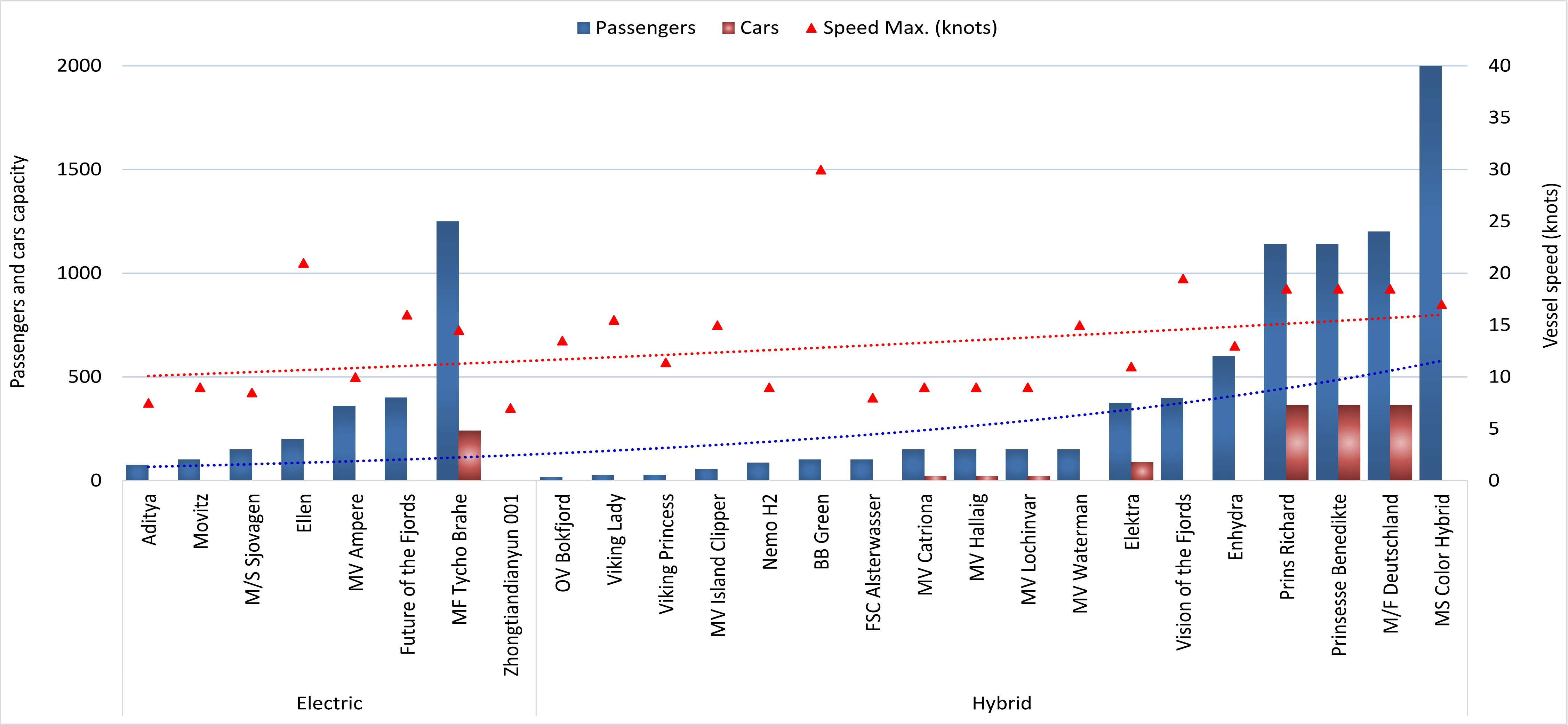
The battery capacity used in pure electric vessels is in the range of 50–500 kWh, with a median value of 140 kWh, while, in hybrid ships, the range is 500–5000 kWh, with a median of 1000 kWh.

From the analysis, it is clear that hybrid technology (used in 69% of the vessels) has an almost 10 times larger battery capacity compared to the pure electric vessels.

The pure electric vessel length is in the range of 21–39 m, with a median at 22 m, while the hybrid ship lengths are in the range of 40–160 m, with a median of 84.5 m.

The difference between lengths is at least twice at minimum range, while this difference in size becomes four times at maximum values. Finally, the green dotted line shows the trend of battery capacity in kWh for different electric and hybrid vessels, and the red dotted line shows the trend of vessel length for various electric and hybrid vessels.

Third classification: Electric and hybrid vessels (Passenger/car capacity and vessel speed



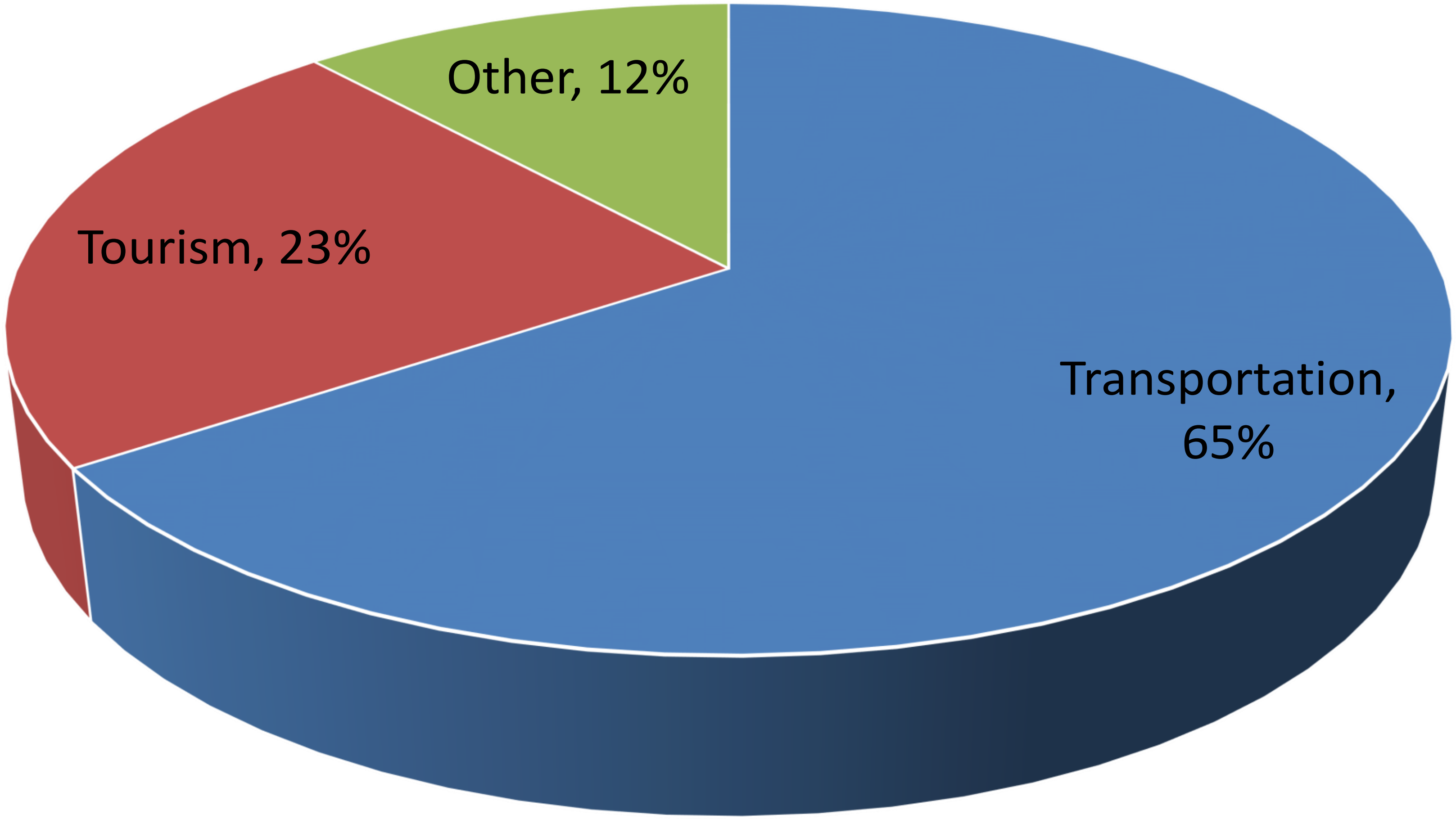
the passenger capacity of pure electric vessels is in the range of 75–1250, with a median value of 200 persons.

It is important to note that only some of the vessels (and not all the vessels) can also carry up to 240 cars. On the other hand, the hybrid vessels can transport 16–2000 passengers with a median value of 150 personnel, but in addition they can also carry 23–364 cars depending upon their size.

The speed of pure electric vessels is in the range of 7–21 knots, with a median value of 9.5 knots, while hybrid ships use 8–30 knots with a median value of 14.25 knots.

From the analysis, it can be seen that the speed of hybrid vessels is almost 1.5 times greater than that of pure electric vessels.

Classification four: three categories: (1) Transportation, (2) Tourism, and (3) Other.

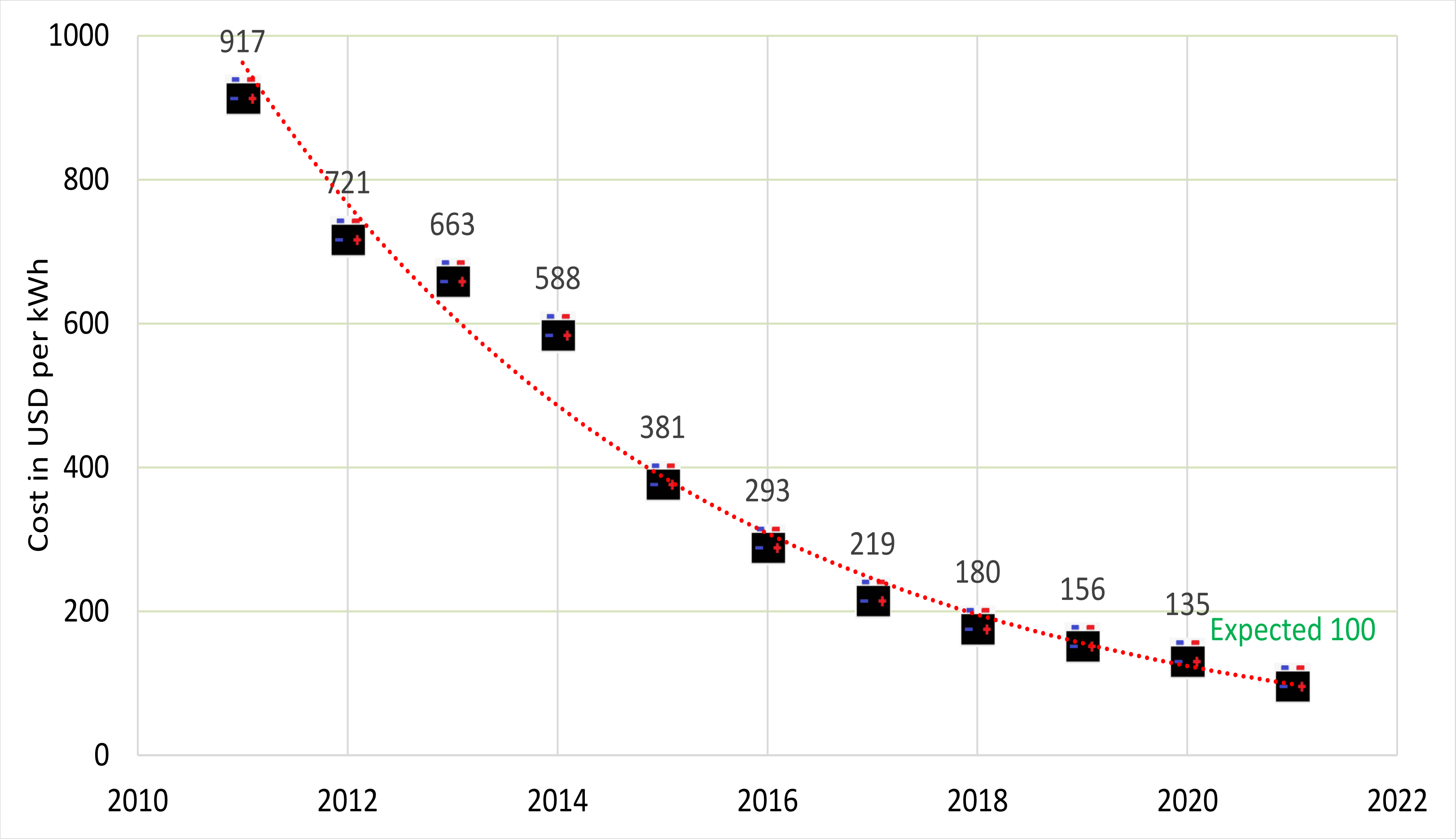


Transportation the widest use (65% of the total vessels).

In addition to the transportation of passengers, another major use of vessels is in the tourism sector. It has been found that 23% of the total vessels in the last ten years have been particularly designed for tourism.

Finally, the remaining 12% of vessels are used for miscellaneous applications such as a multi-purpose use or the offshore supply of oil and gas.

From the study of state-of-the-art commercial vessels in Table 2 and the case studies in Table 3, we found that battery technology has moved from lead-acid to Li-ion One of the major reasons for this is the cost, which has declined from USD 917 to USD 135 in the last decade and is expected to be reduced to USD 100 in 2021



Performance

operating temperature; therefore, proper cooling is required for battery life as well as for safety. Popular methods include (1) air cooling, (2) liquid cooling (direct and indirect), and (3) fin cooling. Each has trade-offs that include cost, complexity, and power requirements.

From an implementation point of view, air cooling is the most inexpensive and simplest technique and depletes the most parasitic power. Liquid cooling is more effective but is also more complex and costly; however, maximum temperature difference can be achieved using indirect liquid cooling.

Finally, fins are used for heat removal with uniformity, but extra weight is added in the system compared with the above two methods

The heat dissipated by the battery requires suitable ventilation, otherwise the battery system gets overheated, which not only provides poor performance but also becomes a safety concern.

Discussion:

It is based on Current state of affairs, Challenges and emerging trends

Norway, Denmark, and Scotland are the leading countries for green energy transformation and have designed at least one ferry per year over the last five years.

The market share of pure electric ferries is 31% compared to hybrid, i.e., 69%.

Pure electric ferries can only travel for short distances due to battery charging requirements,

hybrid vessels use battery technology at lower speeds and in urban areas, especially during docking.

Batteries are heavy and have a large volume, the length of pure electric vessels is small (in the range of 21–39 m), with an average length of 22.5 m compared to the hybrid vessels, which are long (from 40–160 m), with an average length of 84.5 m.

The speed of electric ferries is 7.5–30 knots, with an average speed of 9 knots, while the speed of hybrid vessels is from 7–21 knots with an average speed of 14.75 knots.

The battery capacity of pure electric vessels is 50–500 kWh, with an average of 140 kWh, while hybrid vessels have 500–5000 kWh, with an average of 1000 kWh.

From the analysis it is clear that the maximum range in terms of the battery capacity of pure electric vessels is equal to the minimum range in terms of the battery capacity of hybrid vessels, while the average value is also seven times larger; however, both types of vessels use Li-ion battery types, mainly because of economic constraints.

The passenger capacity of pure electric ferries is 75–600, with an average of 100 persons, while the capacity of hybrid ferries is 16–2000 persons, with an average of 360 persons.

In addition, they can carry several cars in the range of 23–364. The main use of electric and hybrid vessels is in transportation and tourism, i.e., 65% and 23%, respectively, while

Challenges: several challenges associated with the technology, and these can be classified as technical, operational, and legislations.

Technical: Grid reinforcement or the setting up of a specialized grid station that can be utilized for charging purposes is required. The grid station design depends upon several factors, e.g., the type and energy requirements of the vessel and duration of stay at the port, as well as the distance between two ports.

It is quite possible that the energy from renewable resources would be being generated but not consumed completely. Therefore, high-capacity battery banks could be used to store renewable energy in different intervals of time at a constant low power.

Although the stored power (in battery banks at the port area) can be supplied to the ships' ESS for rapid charging, investment is required to set up renewable energy resources and ESS at the port area

Suitable insulation is required between these charging systems and the ESS.

Appropriate firefighting systems would also be needed to handle emergency situations.

Operational:

Battery technology has improved in the last few years, but the energy density is still too low.

Increasing the number of batteries in a vessel is not a practical solution due to size and weight limitations.

Although the materials to design the Li-ion battery are available, scientists have concerns about the availability of materials to design Li-ion batteries; however, this scarcity can be covered by the recycling/waste management of these batteries at the end of life, but this is still a challenge

During disassembling and crushing, the physical materials and chemicals may cause bad effects on human health and, therefore, standard recycling methods should be followed for this purpose in order to get maximum economic value with minimum environmental impacts.

Legislations:

Green transformation through electrification of vessels is a relatively new technology, suitable education and the training of crew members is also required for better performance and safety.

The cost (economic) issues are critical and must be addressed to drive ship owners (operators) to go for green transformation,

There are certain areas where legislation from concerned authorities is required. Typical examples of these areas are environmental impact, investment payback time, modification of existing/design of electric ferries, use of renewable energy, grid station setup, charging mechanisms and energy storage systems in port areas, recycling of batteries, and so on.

Conclusions:

From the results, it is clear that Norway and Denmark are the leading countries in ship electrification; however, there are several worldwide companies working on electrification.

Currently, almost two-thirds of the electrified ships operate in hybrid mode, while the remaining are pure electric.

In addition, pure electric ships are not being used for larger distances due to frequent charging requirements, while the hybrid ships are still used for longer distances.

Due to the smaller size of pure electric ferries, their passenger capacity is less compared to hybrid ships.

Moreover, the major use of electric vessels is in transportation and tourism. Although significant inroads have already been made towards green transformation, a lot still needs to be done.

The knowledge developed in this article can serve as one of the steps in implementation guide for policymakers, academia, and other stakeholders for green energy implementation in the maritime sector by reducing emissions and noise while improving performance and comfort.

References

- *Environmental Sciences*; Elsevier: Amsterdam, The Netherlands, 2019. [CrossRef]
- European Commission, SEC (2005) 1133. Available online: https://ec.europa.eu/transparency/regdoc/rep/2/2 005/EN/2-2005-1133-EN-1-0.pdf (accessed on 10 October 2020).
- Gagatsi, E.; Estrup, T.; Halatsis, A. Exploring the potentials of electrical waterborne transport in Europe: The E-ferry concept. *Transp. Res. Procedia* **2016**, *14*, 1571–1580. [CrossRef]
- Sciberras, E.A.; Zahawi, B.; Atkinson, D.J. Reducing shipboard emissions–Assessment of the role of electrical technologies. *Transp. Res. Part D Transp. Environ.* **2017**, *51*, 227–239. [CrossRef]
- European Seaports Organisation: ESPO Annual Report for 2006—2007, May 2007. Available online: https://www.espo.be/media/espopublications/annualreport2007.pdf (accessed on 10 October 2020).
- Klebanoff, L.; Pratt, J.; Leffers, C.; Sonerholm, K.; Escher, T.; Burgard, J.; Ghosh, S. Comparison of the greenhouse gas and criteria pollutant emissions from the SF-BREEZE high-speed fuel-cell ferry with a diesel ferry. *Transp. Res. Part D Transp. Environ.* **2017**, *54*, 250–268. [CrossRef]
- *Energies* **2020**, *13*, 6506 19 of 22
- Merien-Paul, R.H.; Enshaei, H.; Jayasinghe, S.G. In-situ data vs. bottom-up approaches in estimations of marine fuel consumptions and emissions. *Transp. Res. Part D Transp. Environ.* **2018**, *62*, 619–632. [CrossRef]
- McArthur, D.P.; Osland, L. Ships in a city harbour: An economic valuation of atmospheric emissions.
- *Transp. Res. Part D Transp. Environ.* **2013**, *21*, 47–52. [CrossRef]
- Winnes, H.; Styhre, L.; Fridell, E. Reducing GHG emissions from ships in port areas. *Res. Transp. Bus. Manag.*
- **2015**, *17*, 73–82. [CrossRef]
- Valladolid, P.G.; Tunestål, P.; Monsalve-Serrano, J.; García, A.; Hyvönen, J. Impact of diesel pilot distribution
- on the ignition process of a dual fuel medium speed marine engine. *Energy Convers. Manag.* **2017**, *149*,
- 192–205. [CrossRef]

- Livanos, G.A.; Theotokatos, G.; Pagonis, D.-N. Techno-economic investigation of alternative propulsion
- plants for Ferries and RoRo ships. *Energy Convers. Manag.* **2014**, *79*, 640–651. [CrossRef]
- Nielsen, R.F.; Haglind, F.; Larsen, U. Design and modeling of an advanced marine machinery system including waste heat recovery and removal of sulphur oxides. *Energy Convers. Manag.* **2014**, *85*, 687–693.
- [CrossRef]
- Papanikolaou, A.; Eliopoulou, E. The European Passenger Car Ferry Fleet-Review of design features
- and stability characteristics of pre-and post SOLAS 90 Ro-Ro Passenger ships. In Proceedings of the Euroconference on Passenger Ship Design, Construction, Safety and Operation, Anissaras-Crete, Crete, Greece, 15–17 October 2001.
- Hansen, J.F.; Wendt, F. History and state of the art in commercial electric ship propulsion, integrated power systems, and future trends. *Proc. IEEE* **2015**, *103*, 2229–2242. [CrossRef]
- Dedes, E.K.; Hudson, D.A.; Turnock, S.R. Assessing the potential of hybrid energy technology to reduce exhaust emissions from global shipping. *Energy Policy* **2012**, *40*, 204–218. [CrossRef]
- Ling-Chin, J.; Roskilly, A. Investigating a conventional and retrofit power plant on-board a Roll-on/Roll-off cargo ship from a sustainability perspective–A life cycle assessment case study. *Energy Convers. Manag.* **2016**, *117*, 305–318. [CrossRef]
- Kim, H.; Koo, K.Y.; Joung, T.-H. A study on the necessity of integrated evaluation of alternative marine fuels. *J. Int. Marit. Saf. Environ. A*ff. *Shipp.* **2020**, *4*, 26–31. [CrossRef]
- Nguyen, H.P.; Hoang, A.T.; Nizetic, S.; Nguyen, X.P.; Le, A.T.; Luong, C.N.; Chu, V.D.; Pham, V.V. The electric propulsion system as a green solution for management strategy of CO2 emission in ocean shipping: A comprehensive review. *Int. Trans. Electr. Energy Syst.* **2020**, e12580. [CrossRef]
- Kumar, D.; Zare, F. A comprehensive review of maritime microgrids: System architectures, energy efficiency, power quality, and regulations. *IEEE Access* **2019**, *7*, 67249–67277. [CrossRef]
- Nuchturee, C.; Li, T.; Xia, H. Energy efficiency of integrated electric propulsion for ships–A review. *Renew. Sustain. Energy Rev.* **2020**, *134*, 110145. [CrossRef]
- Groppi, D.; Pfeifer, A.; Garcia, D.A.; Krajacˇic´, G.; Duic´, N. A review on energy storage and demand side management solutions in smart energy islands. *Renew. Sustain. Energy Rev.* **2020**, *135*, 110183. [CrossRef]
- Ma, S.; Lin, M.; Lin, T.-E.; Lan, T.; Liao, X.; Maréchal, F.; Yang, Y.; Dong, C.; Wang, L. Fuel cell-battery hybrid systems for mobility and off-grid applications: A review. *Renew. Sustain. Energy Rev.* **2020**, *135*, 110119. [CrossRef]
- Mutarraf, M.U.; Terriche, Y.; Niazi, K.A.K.; Vasquez, J.C.; Guerrero, J.M. Energy storage systems for shipboard microgrids—A review. *Energies* **2018**, *11*, 3492. [CrossRef]
- Fang, S.; Wang, Y.; Gou, B.; Xu, Y. Toward Future Green Maritime Transportation: An Overview of Seaport Microgrids and All-Electric Ships. *IEEE Trans. Veh. Technol.* **2019**, *69*, 207–219. [CrossRef]
- Jeong, B.; Jeon, H.; Kim, S.; Kim, J.; Zhou, P. Evaluation of the lifecycle environmental benefits of full battery powered ships: Comparative analysis of marine diesel and electricity. *J. Mar. Sci. Eng.* **2020**, *8*, 580. [CrossRef]

- Koumentakos, A.G. Developments in Electric and Green Marine Ships. *Appl. Syst. Innov.* **2019**, *2*, 34. [CrossRef]
- Pfeifer, A.; Prebeg, P.; Duić, N. Challenges and opportunities of zero emission shipping in smart islands: A study of zero emission ferry lines. *eTransportation* **2020**, *3*, 100048. [CrossRef]
- Malla, U. Design and sizing of battery system for electric yacht and ferry. *Int. J. Interact. Des. Manuf. (IJIDeM)* **2020**, *14*, 137–142. [CrossRef]
- *Energies* **2020**, *13*, 6506 20 of 22
- Solar Irradiance. Available online: http://www.solarelectricityhandbook.com/solar-irradiance.html (accessed on 10 October 2020).
- Enevoldsen, P. Onshore wind energy in Northern European forests: Reviewing the risks. *Renew. Sustain. Energy Rev.* **2016**, *60*, 1251–1262. [CrossRef]
- Toffoli, A.; Bitner-Gregersen, E.M. Types of ocean surface waves, wave classification. *Encycl. Marit. Offshore Eng.* **2017**, 1–8. [CrossRef]
- Bianucci, M.; Merlino, S.; Ferrando, M.; Baruzzo, L. The optimal hybrid/electric ferry for the liguria Natural Parks. In Proceedings of the OCEANS 2015-Genova, Genova, Italy, 18–21 May 2015; pp. 1–10.
- MF Tycho Brahe—Battery-Electric Car-Ferry. Available online: https://deif-cdn.azureedge.net/v-dj18h6oak hn2/-/media/files/publications/tycho-brahe/tycho-brahe-uk-lowresnewversion082018.pdf?la=en&hash=C 5B875A237038D5868BABB833AE839773301A158 (accessed on 10 October 2020).
- Elektra—Hybrid-Electric Ferry. Available online: https://www.ship-technology.com/features/elektra-finland s-first-hybrid-electric-ferry/ (accessed on 10 October 2020).
- MAN Energy Solutions. Available online: https://greece.man-es.com/docs/librariesprovider11/uptime-anyt ime---l2330-6th-june/6_hybrid-solutions-batteries-pto-gensets-mzjr.pdf?sfvrsn=f020c0a2_2 (accessed on 30 November 2020).
- Scapens, R.W. Doing case study research. In *The Real Life Guide to Accounting Research*; Elsevier: Amsterdam, The Netherlands, 2004; pp. 257–279. [CrossRef]
- Rashid, M.; Anwar, M.W.; Khan, A.M. Toward the tools selection in model based system engineering for embedded systems—A systematic literature review. *J. Syst. Softw.* **2015**, *106*, 150–163. [CrossRef]
- Amjad, A.; Azam, F.; Anwar, M.W.; Butt, W.H.; Rashid, M. Event-driven process chain for modeling and verification of business requirements–a systematic literature review. *IEEE Access* **2018**, *6*, 9027–9048. [CrossRef]
- Rashid, M.; Imran, M.; Jafri, A.R.; Al-Somani, T.F. Flexible architectures for cryptographic algorithms— A systematic literature review. *J. Circuits Syst. Comput.* **2019**, *28*, 1930003. [CrossRef]
- FCS Alsterwasser—Zemships. Available online: https://ec.europa.eu/environment/life/project/Projects/index .cfm?fuseaction=home.showFile&rep=file&fil=Zemships_Brochure_EN.pdf (accessed on 10 October 2020).

- Nemo—First Fuel Cell Boat. Available online: https://www.reuters.com/article/us-dutch-fuelcell-idUSTRE5
- B83HD20091209 (accessed on 10 October 2020).
- Viking Lady—Offshore Supply Vessel. Available online: https://www.ship-technology.com/projects/viking-
- lady/ (accessed on 10 October 2020).
- Ellen—The World’s Largest E-Ferry. Available online: https://www.euronews.com/2019/11/25/me
- et-ellen-the-world-s-largest-e-ferry-connecting-two-danish-islands-without-emitting-any (accessed on
- 10 October 2020).
- The Future of the Fjords—All Electric Sight Seeing Vessel. Available online: https://www.ship-technology.co
- m/projects/future-of-the-fjords-sightseeing-vessel (accessed on 10 October 2020).
- Vision of The Fjords—The Hybrid Ferry. Available online: https://www.vatnahalsen.no/en/vision-fjords
- (accessed on 10 October 2020).
- MV Hallaig—Caledonian Maritime Assets Ltd. Available online: https://www.cmassets.co.uk/project/mv-ha
- llaig (accessed on 10 October 2020).
- MV Lochinvar—Caledonian Maritime Assets Ltd. Available online: https://www.cmassets.co.uk/project/mv-
- lochinvar/ (accessed on 10 October 2020).
- MV Catriona—Caledonian Maritime Assets Ltd. Available online: https://www.cmassets.co.uk/project/mv-
- catriona/ (accessed on 10 October 2020).
- MV Prinsesse Benedikte—Hybrid Ferry. Available online: https://www.scandlines.com/about-scandlines/ab
- out-scandlines-frontpage/ferries-and-ports/prinsesse-benedikte (accessed on 10 October 2020).
- MV Prins Richard—Hybrid Ferry. Available online: https://www.scandlines.com/about-scandlines/about-sc
- andlines-frontpage/ferries-and-ports/prins-richard (accessed on 10 October 2020).
- M/F Deutschland—Scandlines Deutschland GmbH. Available online: http://www.ferry-site.dk/ferry.php?id
- =9151541&lang=en (accessed on 10 October 2020).
- M/S Sjovagen—Electric Powered Ferry. Available online: https://www.greenport.com/news101/europe/new
- -electric-ferry-unveiled-in-sweden (accessed on 10 October 2020).

- Movitz—The World ́s First Supercharged Ferry. Available online: https://echandia.se/echandia/projects/mo vitz/ (accessed on 10 October 2020). Ampere—A Battery-Electric Ferry. Available online: https://archive.nordregio.se/en/Publications/Publication s-2016/GREEN-GROWTH-IN-NORDIC-REGIONS-50-ways-to-make-/Clean-tech-and-renewable-energy --/Amper/index.html (accessed on 10 October 2020).
- MV Island Clipper—Offshore Service Vessel. Available online: https://www.islandoffshore.com/vessel/mv-i sland-clipper (accessed on 10 October 2020). OV Bokfjord—Multipurpose Vessel. Available online: https://hvsa.dk/portfolio_page/ov-boekfjord/ (accessed on 10 October 2020).
- Viking Princess—Hybrid Energy System on Board the Offshore Supply Vessel. Available online: https: //newpowerprogress.com/offshore-supply-vessel-goes-hybrid/ (accessed on 10 October 2020). Zhongtiandianyun 001—Electric Cargo Ship. Available online: https://plugboats.com/china-launches-electri c-cargo-ship-to-carry-coal/ (accessed on 10 October 2020).
- Enhydra—Hybrid Ferry. Available online: https://www.greenbiz.com/article/future-ferries-electric-too (accessed on 10 October 2020). MV Waterman—Passenger Catamaran Ferry. Available online: https://www.pacmar.com/story/2019/04/01/fe atures/propulsion/693.html (accessed on 10 October 2020).
- BB Green—Electric Commuter Ferry. Available online: https://www.volvopenta.com/marinecommercial/en -en/news/2017/june/bb-green-electric-commuter-ferry-awarded-electric-and-hybrid-pro.html (accessed on 10 October 2020).
- Aditya—Solar-Powered Ferry. Available online: https://en.wikipedia.org/w/index.php?title=Aditya_(boat)& oldid=954179830 (accessed on 10 October 2020). MS Color—Hybrid Ferry. Available online: https://www.ship-technology.com/projects/color-hybrid-ferry/ (accessed on 10 October 2020).
- Spagnolo, G.S.; Papalilo, D.; Martocchia, A. Eco friendly electric propulsion boat. In Proceedings of the 2011 10th International Conference on Environment and Electrical Engineering, Rome, Italy, 8–11 May 2011; pp. 1–4. Al-Falahi, M.D.; Nimma, K.S.; Jayasinghe, S.D.; Enshaei, H.; Guerrero, J.M. Power management optimization of hybrid power systems in electric ferries. *Energy Convers. Manag.* **2018**, *172*, 50–66. [CrossRef] Meek-Hansen, B. Fuel cell technology for ferries. In Proceedings of the IMTA Conference, Gold Coast: Marintek, Ottawa, ON, Canada, 22–24 October 2002; pp. 1–12.
- Diab, F.; Lan, H.; Ali, S. Novel comparison study between the hybrid renewable energy systems on land and on ship. *Renew. Sustain. Energy Rev.* **2016**, *63*, 452–463. [CrossRef] Bassam, A.M.; Phillips, A.B.; Turnock, S.R.; Wilson, P.A. An improved energy management strategy for a hybrid fuel cell/battery passenger vessel. *Int. J. Hydrog. Energy* **2016**, *41*, 22453–22464. [CrossRef]
- Bassam, A.M.; Phillips, A.B.; Turnock, S.R.; Wilson, P.A. Development of a multi-scheme energy management strategy for a hybrid fuel cell driven passenger ship. *Int. J. Hydrog. Energy* **2017**, *42*, 623–635. [CrossRef] Feng, Y.; Chen, L.; Dong, Z. Modeling, Simulation and Assessment of a Hybrid Electric Ferry: Case Study for Mid-Size Ferry. In Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Anaheim, CA, USA, 18–21 August 2019; p. V009T012A028. Bassam, A.; Phillips, A.; Turnock, S.; Wilson, P.A. Design, modelling and simulation of a hybrid fuel cell propulsion system for a domestic ferry. In Proceedings of the 13th International Symposium on PRActical Design of Ships and Other Floating Structures (PRADS’ 2016), Copenhagen, Denmark, 4–8 September 2016; Technical University of Denmark: Lyngby, Denmark, 2016; pp. 545–553.

- Bassam, A.; Phillips, A.; Turnock, S.; Wilson, P.A. Design, modelling and simulation of a hybrid fuel cell propulsion system for a domestic ferry. In Proceedings of the 13th International Symposium on PRActical Design of Ships and Other Floating Structures (PRADS' 2016), Copenhagen, Denmark, 4–8 September 2016; Technical University of Denmark: Lyngby, Denmark, 2016; pp. 545–553.
- Han, J.; Charpentier, J.-F.; Tang, T. An energy management system of a fuel cell/battery hybrid boat. *Energies* **2014**, *7*, 2799–2820. [CrossRef]
  Leading Companies in Lithium Ion Battery Market. Available online: https://www.aheadintel.com/leading-companies-lithium-ion-battery-market/ (accessed on 30 November 2020).
- Lithium-Ion Battery Costs and Market. Available online: http://enerjiye.com/wp-content/uploads/2018/12/battery-market.pdf (accessed on 30 November 2020).
  Dai, Q.; Kelly, J.C.; Gaines, L.; Wang, M. Life cycle analysis of lithium-ion batteries for automotive applications. *Batteries* **2019**, *5*, 48. [CrossRef]

-

- Martinez-Laserna, E.; Sarasketa-Zabala, E.; Stroe, D.-I.; Swierczynski, M.; Warnecke, A.; Timmermans, J.-M.; Goutam, S.; Rodriguez, P. Evaluation of lithium-ion battery second life performance and degradation. In Proceedings of the 2016 IEEE Energy Conversion Congress and Exposition (ECCE), Milwaukee, WI, USA, 18–22 September 2016; pp. 1–7.
- Gaines, L.; Richa, K.; Spangenberger, J. Key issues for Li-ion battery recycling. *MRS Energy Sustain.* **2018**, *5*. [CrossRef]
- Oliveira, L.; Messagie, M.; Rangaraju, S.; Sanfelix, J.; Rivas, M.H.; Van Mierlo, J. Key issues of lithium-ion batteries–from resource depletion to environmental performance indicators. *J. Clean. Prod.* **2015**, *108*, 354–362. [CrossRef]
- Chen, D.; Jiang, J.; Kim, G.-H.; Yang, C.; Pesaran, A. Comparison of different cooling methods for lithium ion battery cells. *Appl. Therm. Eng.* **2016**, *94*, 846–854. [CrossRef]

Thank you