

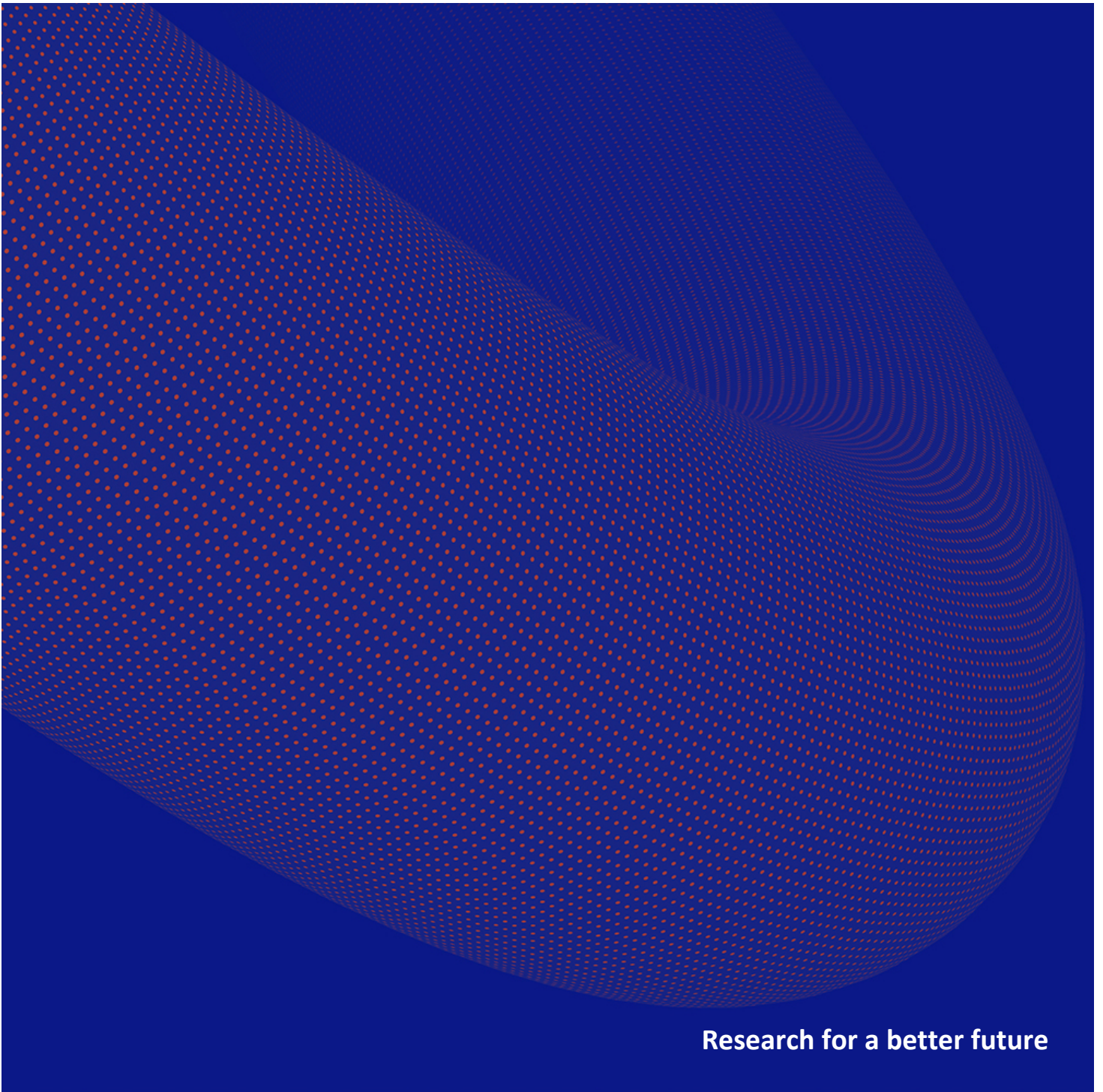


Estimation of Energy Demand in the Norwegian high-speed Passenger Ferry Sector Towards 2030

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Research for a better future

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Summary: The study described in this report is financed by FME NTRANS, User case 3: Radical transition in transport, Pilot 1 Hydrogen value chain. The main goal of this study is to map and estimate hydrogen consumption in the Norwegian high-speed passenger ferry sector towards 2030. In the study two alternative zero emission solutions are evaluated; batteries with fast charging from grid, and fuel cells and hydrogen produced from a green source. A method is developed to estimate which ferry routes that may be suitable for hydrogen and which are suitable for battery electric. The energy consumption of each route is estimated based on distance travelled and estimated fuel consumption. The hydrogen consumption is mapped to a location based on end stops on current routes, and in time based on remaining contract periods of awarded tenders. The conclusion is that there is a large potential for zero-emission operation using battery and/or hydrogen technology: Out of the 96 routes investigated 51 routes can be hydrogen powered while 30 routes can be battery powered. Hence, most of the fossil fuel consumption may be replaced by zero-emission solutions by 2027. A total yearly energy consumption of 8710 tons of hydrogen, 44 GWh of electricity and 4.1 million litres of diesel is estimated for 2030. This represents a reduction of fossil fuels by 93%, based on an estimated diesel consumption of 56 million litres in 2021. This work is performed in coordination with the Hylnfra project, work package C, task C.1, coordinated by Arena Ocean Hyway Cluster.			
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Contents

1	Summary.....	2
2	Introduction.....	2
3	Methodology	3
3.1	Routes and fuel consumption.....	3
3.2	Tenders and contract periods.....	3
3.3	Bunkering and recharging locations	3
3.4	End stops and range requirements.....	3
3.5	Energy consumption per trip	4
3.6	Estimated required battery and charging installations	4
3.7	Estimated maximum battery capacity for each ship	4
3.8	Battery or hydrogen powered?	6
3.9	Yearly and average daily consumption	6
4	Results	6
4.1	Estimated energy consumption from high-speed vessels in Norway.....	6
4.2	Energy consumption per county municipality	9
4.3	Hydrogen consumption per harbour	10
5	Discussion	11
5.1	Recommendations.....	11
5.2	Uncertainties	11
6	Conclusion	12
7	Acknowledgements	12
8	References	13

1 Summary

The study described in this report is financed by FME NTRANS, User case 3: Radical transition in transport, Pilot 1 Hydrogen value chain. The main goal of this study is to map and estimate hydrogen consumption in the Norwegian high-speed passenger ferry sector towards 2030.

In the study two alternative zero emission solutions are evaluated; batteries with fast charging from grid, and fuel cells and hydrogen produced from a green source. A method to estimate which routes that may be suitable for hydrogen and which are suitable for battery electric has been developed. The energy consumption of each route is estimated based on distance travelled and estimated fuel consumption. The hydrogen consumption is mapped to a location based on end stops on current routes, and in time based on remaining contract periods of awarded tenders.

A total of 96 routes were investigated, out of which 51 routes has the potential to be operated on hydrogen and 30 routes using batteries electric. Most of the fossil fuel consumption may be replaced by zero-emission solutions by 2027. A total yearly energy consumption of 8710 tons of hydrogen, 44 GWh of electricity and 4.1 million litres of diesel is estimated for 2030. This represents a reduction of fossil fuels by 93%, based on an estimated diesel consumption of 56 million litres in 2021.

The dataset developed in this work are published together with this report¹.

This work was performed in coordination with the HyInfra project, work package C, task C.1, coordinated by Arena Ocean Hyway Cluster. The HyInfra project aims to estimate consumption from all domestic maritime consumers towards 2030. By April 2020 reports have been generated for high-speed passenger ferries (C.1), car ferries (C.2), the Coastal Express Route Bergen-Kirkenes (C.3), offshore sector (C.4) and other known projects (C.5). In addition, all consumers have been visualized on an interactive map. All resources are available on the members area on their website².

2 Introduction

Norway has set ambitious goals for reduction of greenhouse gas (GHG) emissions from the transport sector. High-speed passenger ferries play an important role in the Norwegian public transportation system, but is unfortunately the mode of transport with highest associated CO₂ emissions per passenger-km [1].

There are about 100 high-speed passenger ferry routes in Norway that in total consume about 56 million litres of diesel per year. This is equivalent to about 0.7% of the petroleum products sold in Norway. [2].

The large fuel consumption in a high-speed ferry and the fact that a ferry returns to the same port(s) daily, throughout the year, is an excellent starting point to establish a cost-effective hydrogen infrastructure. The high-speed ferry will ensure a stable long-term consumption, which is essential to establishment of the first hydrogen infrastructure.

The main objective of this study is to: (1) Estimate which high-speed passenger ferry routes may be fuelled by hydrogen, (2) Estimate the hydrogen consumption, (3) Identify suitable locations, and (4) Identify possible start-up times with hydrogen for each route.

¹ <https://hdl.handle.net/11250/274236>

² <https://www.oceanhywaycluster.no/membersarea>

3 Methodology

3.1 Routes and fuel consumption

This study is based on the route descriptions and diesel consumption data provided in the report “Battery/fuel cell fast ferry” written by Selfa Arctic and funded by the Norwegian NOx-fund [2].

The accuracy of the fuel consumption data in the report depends on which county it is located. Oslo/Akershus and Sør-Trøndelag declared actual diesel consumption for 2015. Finnmark, Nordland, Møre og Romsdal, Sogn og Fjordane and Hordaland declared the total distance travelled. For Troms, Nord-Trøndelag, Rogaland and Vestfold the distance travelled was estimated in the report.

The report states that diesel consumption estimates were conservative, but realistic. Our consideration is that the fuel consumption data is very high. A modern high-speed catamaran with passenger capacity of 290 has a diesel consumption of about 18-20 L/NM at 35 knots, while this report states 27.5 L/NM. Therefore, in order to take a conservative approach, all consumption data is multiplied with a correction factor of 0.65. An exception is made for routes in Oslo/Akershus and Sør-Trøndelag, where the exact consumption data had been declared by the counties. For these routes the data was assumed to be accurate and general improvements in energy efficiency would lead to 10% reduction in consumption, justifying a correction factor of 0.9.

Routes with diesel consumption of less than 20.000 L/year were not evaluated.

3.2 Tenders and contract periods

In this study it has been assumed that each route will change to a zero-emission alternative at the end of its existing contract period. The responsible County Municipality, existing contract operator and tender periods were collected from the document “Markedsoversikt båt og ferje 2019” published by the association Public Transport Norway [3].

For routes where only end of contract year is given, it is assumed 31st of December. For all contracts with extension options it is assumed that options are declared. This is considered a conservative approach regarding the actual start-up time with hydrogen.

It is assumed that no conversion to zero emission technologies will be performed in 2021. This is due to the development and construction time required to start operation with a zero-emission high speed vessel. The earliest possible start-up time with zero-emission solutions is assumed to be 2022.

3.3 Bunkering and recharging locations

During a high-speed ferry route, the time available for bunkering or charging under way is very short, or nearly non-existent. Increasing the waiting time at intermediate stops will significantly increase travelling time. Furthermore, intermediate stops are very often located on islands and remote places, where it can be assumed that charging is not possible due to weak electrical grids. In this study it is therefore assumed that all bunkering and recharging must occur at the route end stops.

3.4 End stops and range requirements

For each route the end stops have been determined manually from available timetables. If one of the end stops is on an island it is assumed that charging or bunkering is not possible there, and all consumption is allocated to the remaining end stop. In this case the required range or route sailing distance is doubled. Otherwise, it is assumed that the total consumption is shared equally between the two end stops.

3.5 Energy consumption per trip

The diesel consumption (L/trip) is calculated from route distance (NM), diesel consumption (L/NM) and the correction factor.

The diesel consumption is converted to energy consumption by multiplying with diesel density of 0.845 kg/L, diesel lower heating value of 11.86 kWh/kg, and an estimated average diesel engine efficiency of 37%.

The hydrogen consumption (kg/trip) is calculated by multiplying with hydrogen lower heating value of 33.3 kWh/kg, and an estimated average fuel cell efficiency of 50%.

3.6 Estimated required battery and charging installations

The required installed battery capacity if the vessel was to be operated with batteries is estimated by assuming a Depth of Discharge (DoD) of 60%. This is slightly higher than for car ferries, which typically operate with a DoD of 50%.

The selection of DoD is a design parameter that is based on an extensive evaluation of operational profile and battery degradation estimations. It could be possible to further increase the DoD, but this will cause significant increase in battery degradation. It is also important to keep a reserve energy capacity available in case of unforeseen circumstances or emergency situations.

The battery weight is estimated based on the product Corvus Dolphin Power, a Li-ion battery system designed for low-weight applications. This system has a weight of 375 kg per 47 kWh, equal to 8 kg/kWh [4].

For reference the required charging power required to recharge the trip energy in 15, 30, 60, or 120 minutes is also estimated. Very often a limiting factor with fast charging is the available charging power at the given location. A second limiting factor may be the power limit in the electrical connection between ship and the land facility.

Another alternative solution could be to swap batteries, but this has not been evaluated in this study. Battery swaps can potentially be faster than battery charging and will most likely requires less installed capacity in the local power grid. It could potentially also reduce battery degradation. However, such solutions are still only in the concept design phase and it has yet to be approved and tested. Hence, it is at this stage uncertain if swapping of battery modules t can be an acceptable solution.

3.7 Estimated maximum battery capacity for each ship

Calculating the exact maximum battery capacity for each ship is extremely challenging and would require detailed knowledge of the operational requirements and specific ship(s) operating each route. It would also be very time consuming and not possible within the scope of work in this study. Instead the maximum possible installed battery weight is estimated based on the only available information that tells something about the ship size, namely the passenger capacity (PAX).

A simplified methodology was developed by making a qualified guess that an upper limit of battery weight corresponds to 80% of the ship's dead weight tonnage (DWT). To correlate the known passenger capacity to DWT a sample of 10 vessels of various sizes were collected (Table 1). Based on this data a linear relationship between passenger capacity and DWT was established as shown in Figure 1. The resulting estimated battery weight for various vessel sizes based on their passenger capacity are presented in Table 2.

Table 1 Vessels used to identify correlation between passenger capacity and DWT [5-8]

IMO	Vessel name	Passenger capacity	DWT
9616814	Vingtor	290	40
9693850	Tyrhaug	275	32
9734953	Fjordlys	180	20
9372145	Rygercruise	120	16
9684861	Rygerøy	48	15
9750907	Rygerprins	97	12
9438963	Brage	147	19
9684885	Fjordbris	240	20
9605346	Falkefjell	125	18
9616826	Frøya	190	30

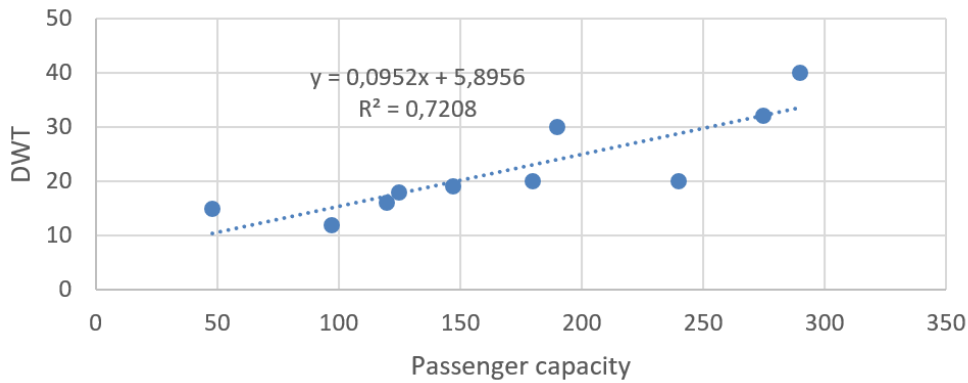


Figure 1 Relationship used between passenger capacity and DWT

Table 2 Example of estimated max battery weight

Passenger capacity	DWT	Factor	Upper limit battery weight (ton)
50	11	0.8	9
100	15	0.8	12
200	25	0.8	20
300	34	0.8	28

The battery installation would replace equipment such as main engines, auxiliary engines, exhaust systems, fuel storage, etc. For reference the M/S Valderøy with passenger capacity 199 has two MTU 10V2000 M72 engines for propulsion (3050 kg each), a John Deere 4045DFM50 auxiliary generator (437 kg) and 6000 L of diesel (5070 kg) [6]. It sums up to a total weight of 11607 kg, excluding other equipment such as the exhaust system. The function estimates a maximum battery weight of 20 tons, which is considerably higher than the diesel system weight.

This methodology is considered a conservative approach that favours selection of a battery system.

This methodology is applied on vessels carrying only passengers. Some of the routes operate with high-speed vessels that can carry both vehicles and passengers. A vessel carrying vehicles will have a higher DWT relative to passenger capacity. For these routes the vessels were identified, and DWT was entered manually.

3.8 Battery or hydrogen powered?

It is assumed that a battery solution is preferred if it is technically possible. For each route the minimum required battery capacity is compared to the upper battery weight limit for the ship. If the required installation is less than the upper limit the route is selected to be battery powered. Otherwise, it is assumed it will be hydrogen powered.

For a few routes a manual override function is used to force a hydrogen system. This can be done if the same vessel can serve several routes, where at least one would require a hydrogen system or the combined range requirements of several routes would lead to a higher required battery weight. It can also be done if a route is a typical rush hour route. In this case it would be a significant benefit if the vessel can perform as many trips as possible during the morning and afternoon hours, without being delayed by battery charging intervals between each trip.

3.9 Yearly and average daily consumption

The estimated yearly energy consumption is calculated from the yearly diesel consumption, multiplied with the correction factor and properties of diesel and diesel engine mentioned in chapter 3.5.

The yearly hydrogen consumption is the yearly energy consumption multiplied with hydrogen lower heating value and previously stated energy efficiency of fuel cell (50%).

The average daily hydrogen consumption is the yearly consumption divided by 365 days/year. The average daily consumption may be misleading for routes that are operated only during summer or have a significant difference between winter and summer operation.

4 Results

4.1 Estimated energy consumption from high-speed vessels in Norway

Out of the 96 routes presented in the “Battery/fuel cell fast ferry” report 51 were found to be suitable for hydrogen energy storage, and 30 suitable for battery energy storage. The remaining 15 routes were not applicable, due to discontinued routes or extremely low fuel consumption.

Figure 2 shows the estimated yearly energy supplied to the shaft by each energy carrier for high-speed passenger vessels in Norway.

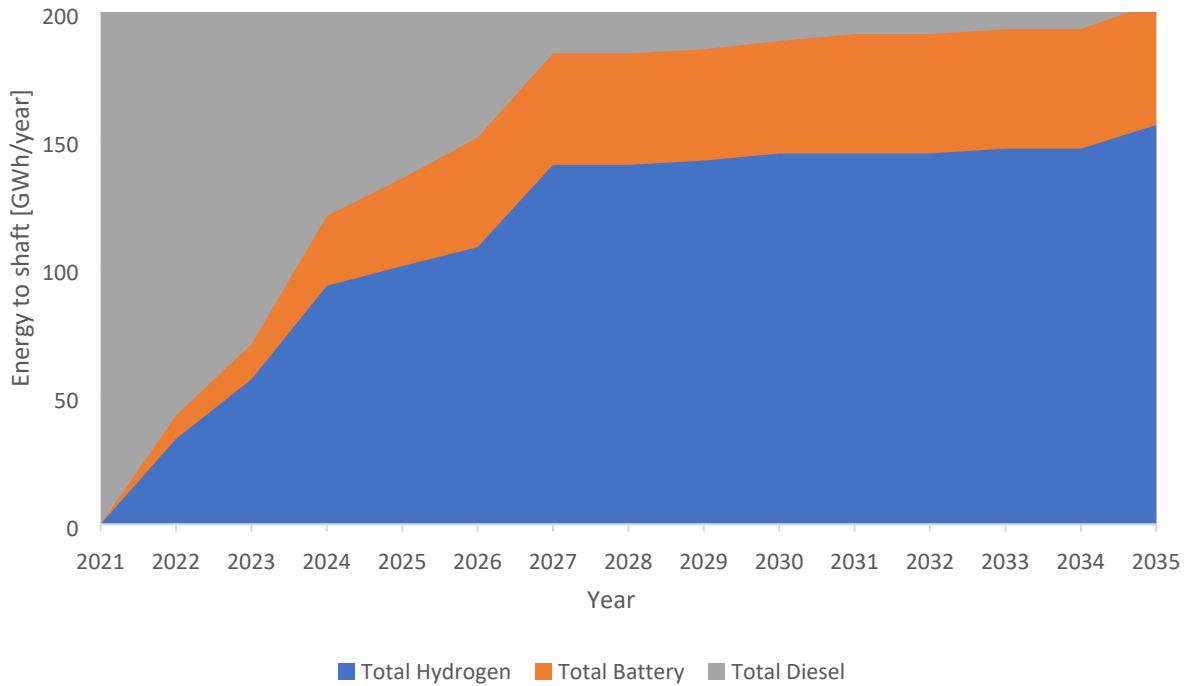


Figure 2 Estimated yearly energy supplied to shaft for high-speed passenger vessels in Norway

Figure 3 shows the estimated yearly hydrogen consumption for high-speed passenger vessels in Norway.

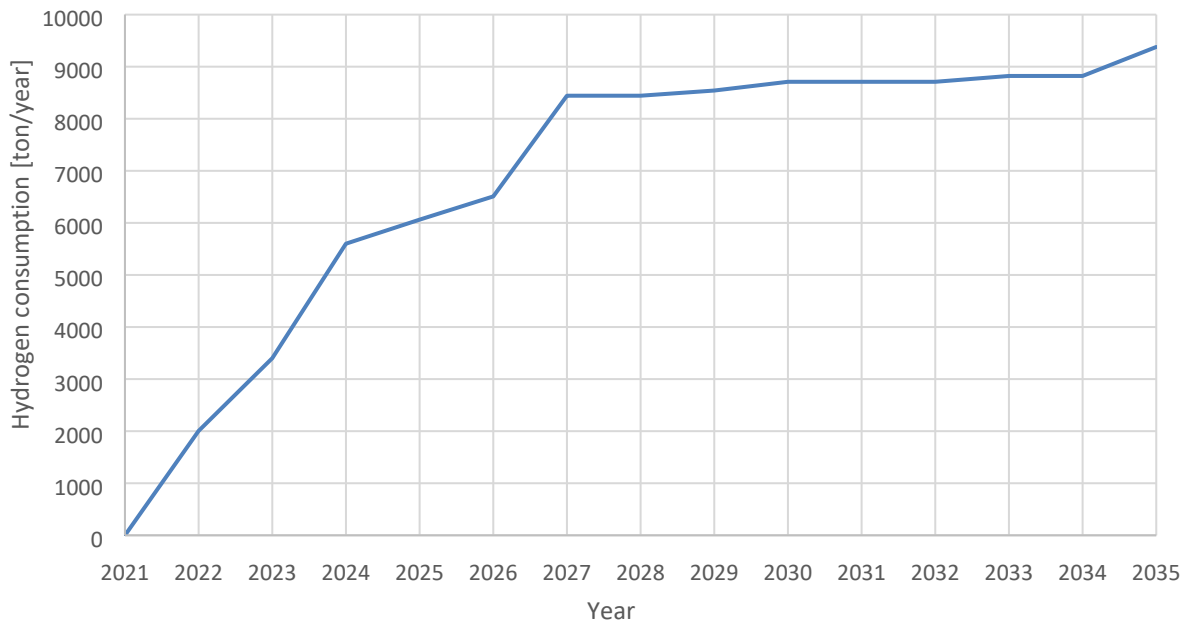


Figure 3 Estimated yearly hydrogen consumption for high-speed passenger vessels in Norway

Figure 4 shows the estimated yearly energy supplied to the shaft of high-speed passenger vessels with battery electric solutions in Norway. Note that losses during charging are not included, so actual energy required from the grid may be higher.

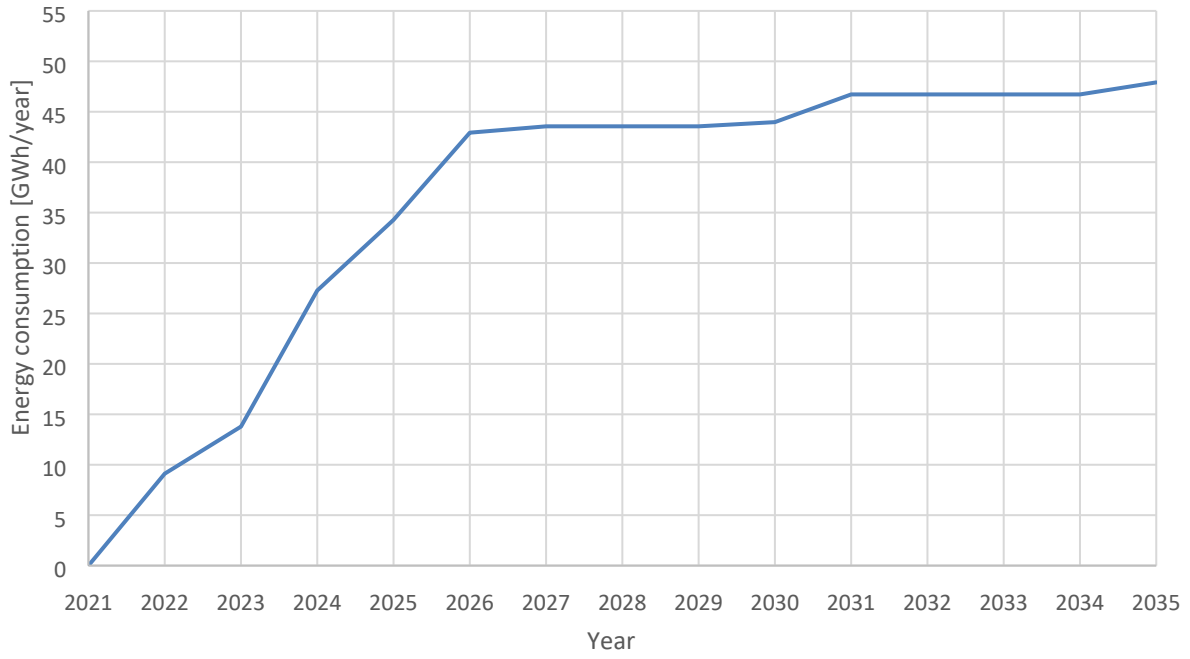


Figure 4 Estimated yearly energy supplied to shaft by battery for high-speed passenger vessels in Norway

Figure 5 shows the estimated yearly diesel consumption for high-speed passenger vessels in Norway.

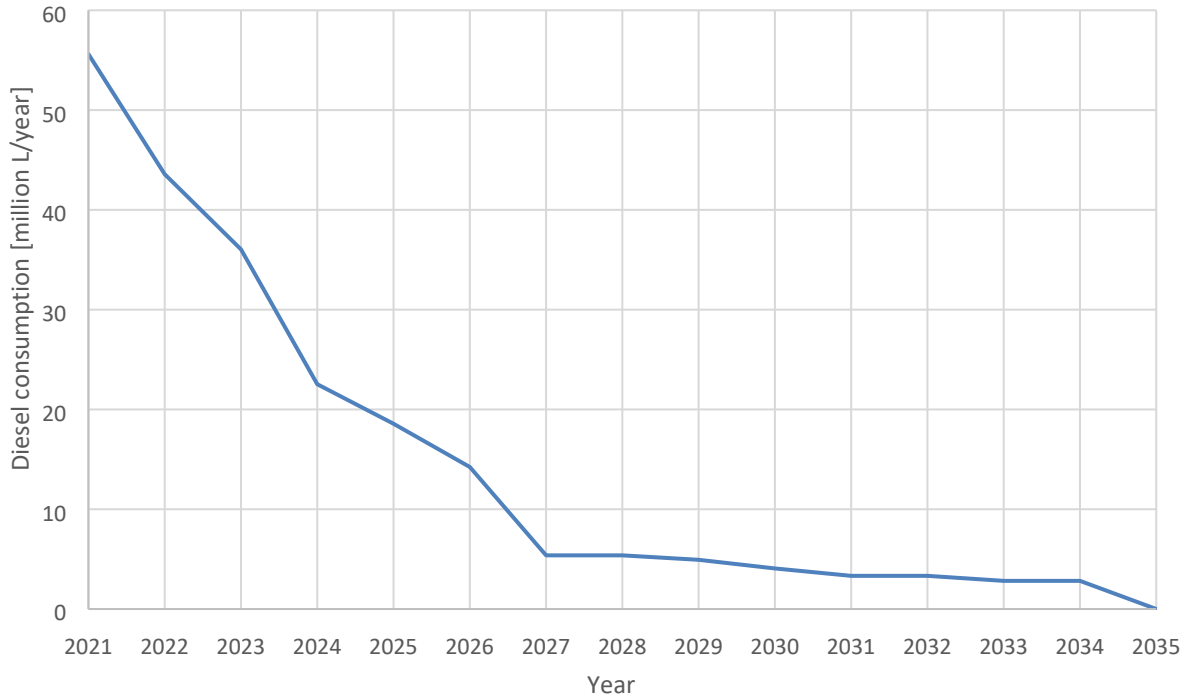


Figure 5 Estimated yearly diesel consumption by diesel powered high-speed passenger vessels in Norway

4.2 Energy consumption per county municipality

Figure 6 shows estimated yearly hydrogen consumption by high-speed passenger vessels for each county municipality towards 2035. It is possible to accelerate the transition to hydrogen power by not utilizing the extension options in the existing contracts. This is especially relevant for contracts ending after 2027.

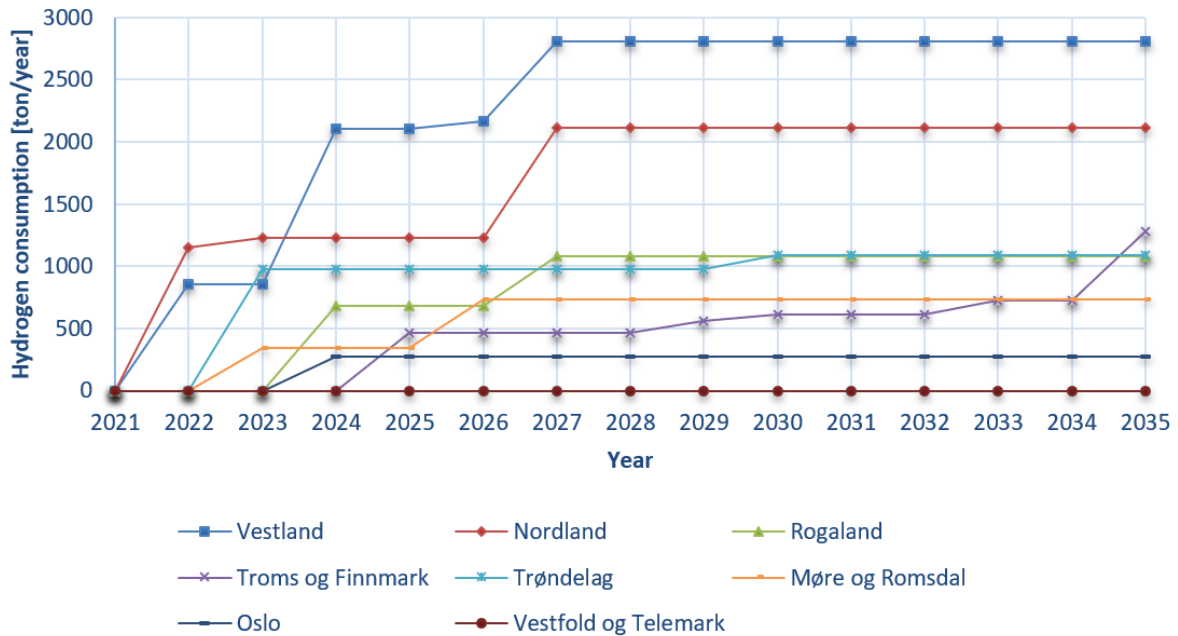


Figure 6 Estimated yearly hydrogen consumption per county municipality

Figure 7 shows estimated yearly energy supplied to the shaft by battery electric high-speed passenger vessels for each county municipality towards 2035. Note that these numbers do not include losses from charging. The actual energy consumed from the grid will therefore be higher.

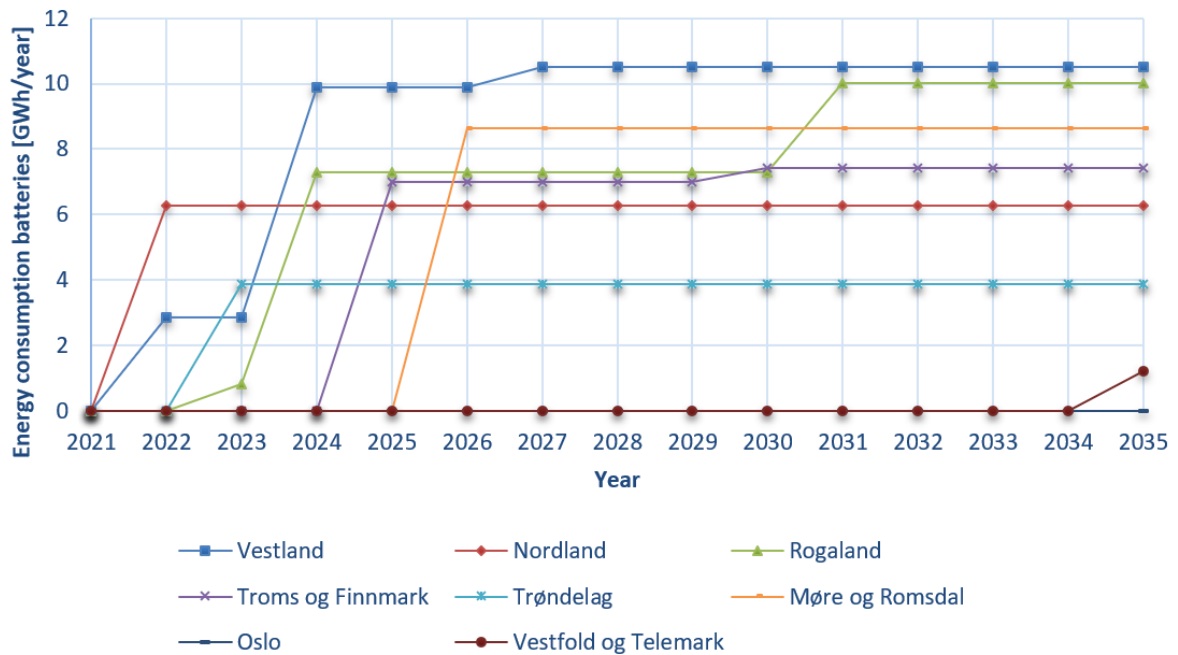


Figure 7 Estimated yearly energy to shaft supplied from batteries per county municipality

Figure 8 shows estimated yearly diesel consumption by high-speed passenger vessels for each county municipality towards 2035. It is possible to accelerate the transition to zero-emission solutions by not utilizing the extension options in the existing contracts. This is especially relevant for contracts ending after 2027. All routes could potentially be zero emission by the end of 2031.

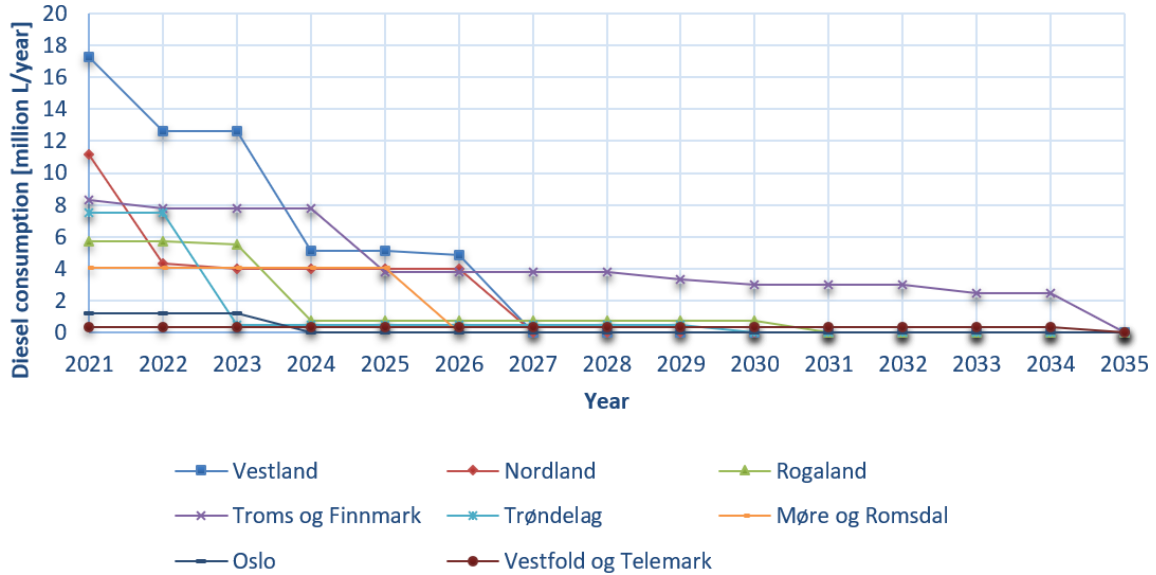


Figure 8 Estimated yearly diesel consumption per county municipality

4.3 Hydrogen consumption per harbour

Figure 9 shows estimated average daily hydrogen consumption per harbour towards 2030 for harbours with consumption higher than 350 kg/day in 2030.

It should be noted that the selected harbours are end stops on existing routes today. In the future it may be very beneficial to adjust these routes so that more routes have the same end stop in order to increase the hydrogen consumption. Higher consumption will lower the hydrogen cost. For example, the consumption in the harbours of Selje and Florø could be merged in this way.

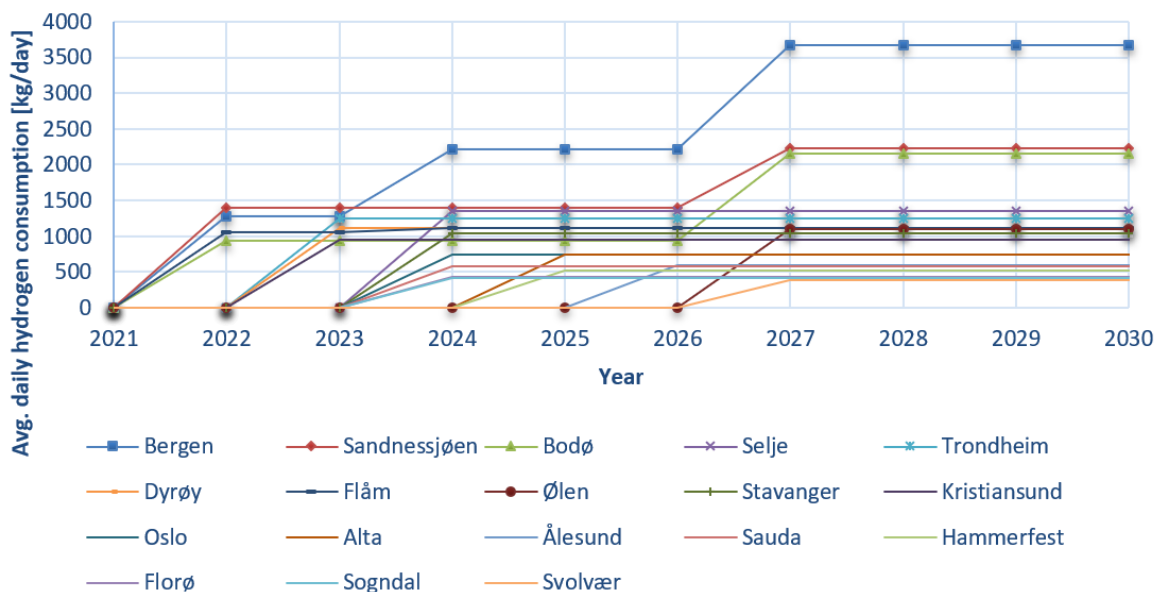


Figure 9 Average daily hydrogen consumption per harbour >350 kg/day in 2030

5 Discussion

5.1 Recommendations

In this study it is assumed that each county municipality require zero-emission solutions at the end of current tender contract periods. It is also assumed that all contract extension options are declared. It will have a large negative impact on the rate of change to zero emission solutions if new contracts are signed with conventional fossil technology, as tender periods are often 8-10 years.

Extension options are often 2 years or more and result in the old contract being continued (with the same fuel consumption) for the length of the extension. Even though options are often declared, it is possible to accelerate the change to zero-emission solutions by not declaring them.

Since most of the vessels will be replaced in the period 2022 to 2027 it will be highly beneficial to gain operational experience with hydrogen on high-speed vessels as early as possible. It is also important to note that postponing the early introduction of a hydrogen solution in the period from 2022 to 2024 can lead to production capacity issues for the shipyards the following years.

As shown in section 4.3 the hydrogen consumption per harbour is not optimal if the old route plans are continued. When replacing the routes with hydrogen fuelled alternatives one should consider planning the routes so that end stops and hydrogen consumption are concentrated in only a few locations. Maximising hydrogen production will lead to optimized production plants and lower hydrogen cost.

5.2 Uncertainties

There are many uncertainties with the methodology chosen in this study. The largest being the method to estimate maximum installed battery capacity based only on passenger capacity. A proper evaluation of this would require detailed analyses of each ship type, route plan and local weather conditions. The estimated selection of which routes will be hydrogen or battery powered should not be considered final. If the ratio of required battery capacity over maximum possible capacity is very high (i.e. several hundred percent) it indicates a high probability for hydrogen. If the ratio is very low (i.e. <50%) it indicates a high probability for a battery solution. A ratio near (above or below) 100% means the selection is very uncertain.

The correction factor used for calculating diesel consumption from [2] is also uncertain. This method is more accurate for the larger ships where actual consumption data have been provided.

An important source of uncertainty is the fact that some routes are operated by more than one ship. Furthermore, the ships may have very different operating characteristics. In this study it is assumed that only one ship operates on each route, with a fixed energy consumption per unit distance travelled.

It should be noted here that it is important to consider that one ship may serve several routes. This is not captured in this work. If a ship serves two routes, each requiring an acceptable battery installation, the combined range requirements may lead to a demand for a hydrogen solution instead.

In some cases, the route should offer as many departures as possible during rush hours (morning/afternoon). The methodology of this report does not capture this requirement. A battery solution may easily require a 15-30 minutes charging period between each departure, while a hydrogen solution could potentially operate continuously during the rush hours and refuel later at a more convenient time. In this case a battery electric ship would require a higher passenger capacity, or perhaps two ships instead of one, to serve the same number of passengers. Therefore, a hydrogen solution may be preferable.

Finally, this study does not consider new technologies that has not yet been tested. This includes for example battery swapping and hydrofoil solutions. Both technologies, if successful, could lead to a higher share of battery electric solutions.

6 Conclusion

An analysis of the energy consumption and type of zero-emission energy carrier to be used has been carried out for all high-speed passenger vessel routes in Norway. For each route the bunkering locations and estimated start-up year with a hydrogen or battery electric solution has been determined.

The main motivation for this study was to provide an overview of the high-speed passenger vessel market and its future demands for hydrogen fuel, in order to be able to plan an overall Norwegian hydrogen infrastructure.

The study shows that there is a large potential for zero-emission vessels using battery and/or hydrogen technology: Out of the 96 routes investigated 51 routes can be hydrogen powered while 30 routes can be battery powered. 15 routes were not considered in the study as these have been/will be discontinued or represent a very low consumption.

The conclusion is that most of the fossil fuel consumption may be replaced by zero-emission solutions by 2027. A total yearly energy consumption of 8710 tons of hydrogen, 44 GWh of electricity and 4.1 million litres of diesel is estimated in 2030. This represents a reduction of fossil fuels by 93%, based on an estimated diesel consumption of 56 million litres in 2021.

7 Acknowledgements



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8 References

1. Thune-Larsen H HR, Hovi I B, Eriksen K S. Energy efficiency and CO2 Emissions in the Norwegian transport sector 1994-2050 [Online report]. Oslo: Institute of Transport Economics; 2009 [cited 2020 Apr 20]. Available from: <https://www.toi.no/transport-models/energy-efficiency-and-co2-emissions-in-the-norwegian-transport-sector-article28258-1261.html>.
2. Ianssen C ST, Ianssen E. Battery/fuel cell fast ferry [Online report]. Trondheim/Sandtor: Selfa; 2016 [updated 2017; cited 2020 Apr 20]. Available from: <https://www.nho.no/samarbeid/nox-fondet/artikler/rapporter/>.
3. The Norwegian Public Roads Administration. Samlet oversikt over alle ferjesamband [Excel sheet online]. Norway: The Norwegian Public Roads Administration; 2020 [updated 2020 Feb 03; cited 2020 Apr 21]. Available from: <https://www.vegvesen.no/fag/trafikk/ferje/markedsoversikt>.
4. Corvus Energy. Corvus Dolphin Energy - Corvus Energy [Internet]. Norway: Corvus Energy; 2020 [cited 2020 Apr 21]. Available from: <https://corvusenergy.com/products/corvus-dolphin-energy>.
5. MarineTraffic. Vessels Database [Internet]. UK: MarineTraffic; 2020 [cited 2020 Apr 21]. Available from: https://www.marinetraffic.com/en/data/?asset_type=vessels&columns=shipname.
6. Skipsrevyen. Båtomtaler [Internet]. Bergen: Skipsrevyen; [updated 2020; cited 2020 Apr 21]. Available from: <https://www.skipsrevyen.no/batomtaler>.
7. Norled. Informasjon om hurtigbåter i Norled [Internet]. Bergen: Norled; 2017 [cited 2020 Apr 21]. Available from: <https://www.norled.no/om-norled/kontakt-Norled/kontakt-hurtigbater>.
8. Rødne Fjord Cruise. Våre båter [Internet]. Stavanger: Rødne Fjord Cruise; 2020 [cited 2020 Apr 21]. Available from: <https://rodne.no/vare-bater>.

This report and its dataset is published here:

<https://hdl.handle.net/11250/2653026>

The publications from the HyInfra project is found here:

<https://www.oceanhywaycluster.no/membersarea>

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