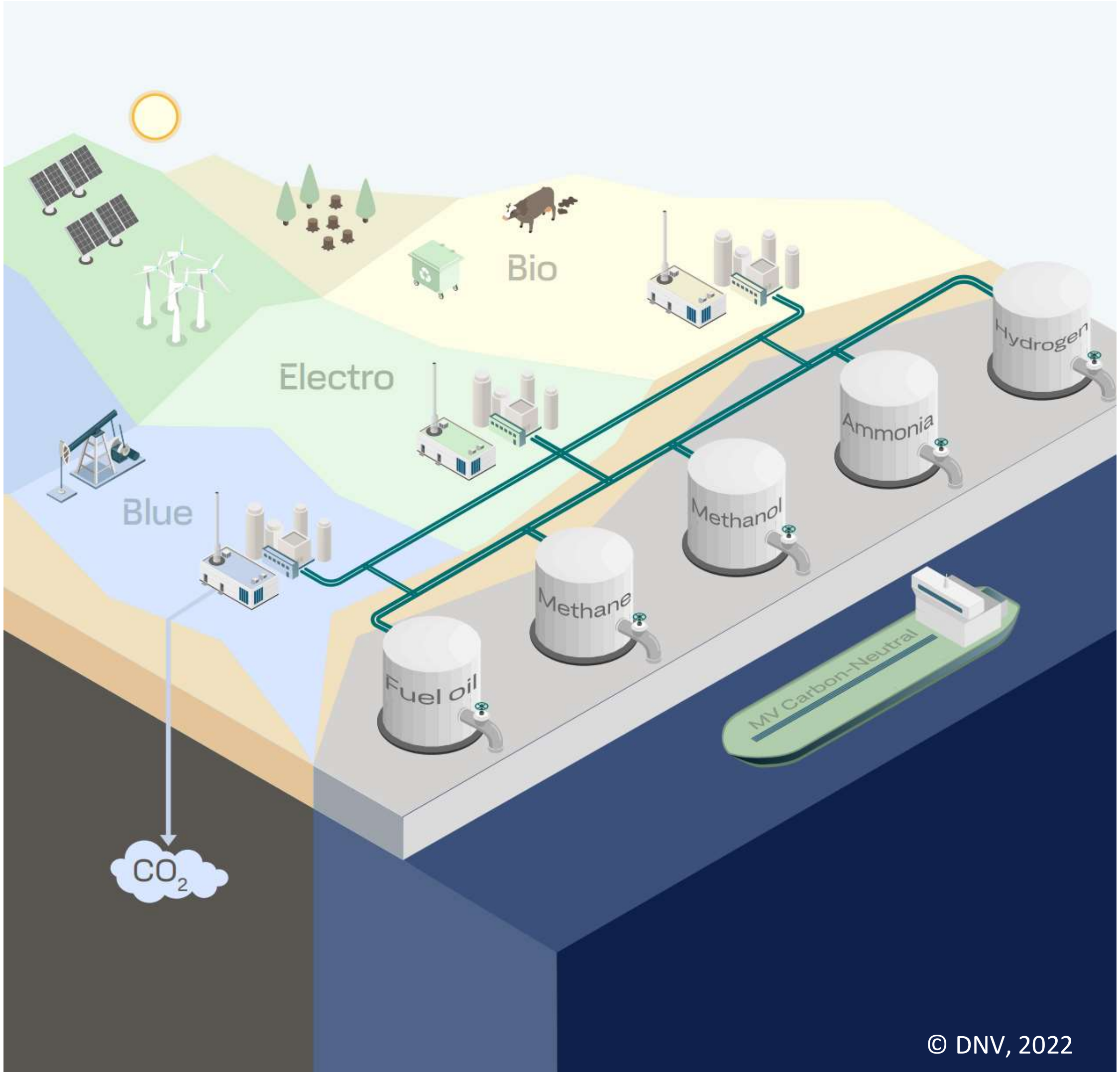
Nordic Roadmap

Future Fuels for Shipping



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Foreword

DNV and partners Chalmers, IVL Swedish Environmental Research Institute, MAN Energy Solutions, Menon, and Litehauz have been tasked by the Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers to develop a Nordic Roadmap for the introduction of sustainable zero-carbon fuels in shipping. The overall aim of the project is “to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero emission shipping”.

To support this overall aim, DNV is responsible for Task 2-A: AIS Analysis of Nordic Ship Traffic and has prepared this report. Chalmers, IVL, MAN Energy Solutions, Menon, and Litehauz have contributed with valuable input.

October 14th, 2022

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Senior Engineer, DNV

NORDIC ROADMAP FOR THE INTRODUCTION OF SUSTAINABLE ZERO-CARBON FUELS IN SHIPPING

AIS Analysis of Nordic Ship Traffic

The Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers

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EXECUTIVE SUMMARY

DNV with partners have been assigned the *Nordic Roadmap project*[1] by The Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers. The project has an overall aim "to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero emission shipping". In reply to the defined scope of work, this report summarizes the results from Task 2A of the project - AIS[2] analysis of the Nordic ship traffic and energy use. The purpose of Task 2A analysis is to map the energy consumption and emissions from Nordic ship traffic[3], provide a description of the geographical distribution of the ship traffic, and identify dominating ship routes and potential demand of sustainable zero-carbon ship fuels. The analysis also provides a basis for further work in the Nordic roadmap project, as well as constituting a part of the knowledge foundation for decision makers to enable the fuel transition in shipping in a Nordic context.

What we did

This report has established an AIS-based fuel consumption and emission inventory for Nordic ship traffic in 2019. The modelling framework used in this study is centred around DNV's MASTER[4] model and DNV's Green Shipping Corridor Model (GSCM). A voyage-based modelling approach is applied, splitting traffic into three ship traffic types (domestic Nordic, intra Nordic and Nordic international), with breakdown on six ship categories, further split into 17 specific ship types, and seven ship size segments. The report provides the overall picture including domestic traffic. However, intra Nordic and Nordic International ship traffic is in focus, mainly due to this being a focus point in the Nordic roadmap. The voyage-based approach allows us to assess the feasibility of sustainable zero-carbon fuels in the fleet, identify potential green shipping corridors and potential energy hubs in the Nordic. In addition to findings on ship traffic types and sailing patterns, our analysis results include longlists of potential green shipping corridors. With the term *potential green shipping corridor*, we refer to ship routes between two or more ports with highly regular ship traffic patterns and significant ship energy demand. As such, the AIS analysis provides information useful for selecting ship categories and ports for initial green shipping corridors and green pilot projects.

Note that there are some uncertainties related to the modelled results. The uncertainties are mainly related to quality of input data, the applied model algorithms to estimate energy consumption, fuel consumption and emissions, and the systematics for distribution of modelled results on individual ship voyages and potential green corridors.

A wide range of definitions of *maritime green corridors* exists. This project uses the Clydebank Declaration[5] definition of *green shipping corridors*, stating that green shipping corridors as "zero-emission maritime routes between two (or more) ports." The signatories of the Clydebank Declaration commit to develop at least six green shipping corridors between two (or more) ports by 2025 and "many more" by 2030. A simplified sketch of the value chain of a green shipping corridor is illustrated in Figure A. It is important to note that the Clydebank Declaration covers only the port-to-port element of the value chain, and effort to decarbonization the overall transport system (or value chain) will be needed.

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[1] https://futurefuelsnordic.com/

[2] Automatic Identification System (AIS)

[3] The term *Nordic ship traffic* includes all ship voyages (trips between two ports) involving at least one Nordic port

[4] Mapping of Ship Tracks, Emissions and Reduction Potentials

[5] Policy Paper COP 26: Clydebank Declaration for green shipping corridors, signed by 22 countries. COP 26: Clydebank Declaration for green shipping corridors - GOV.UK (www.gov.uk)

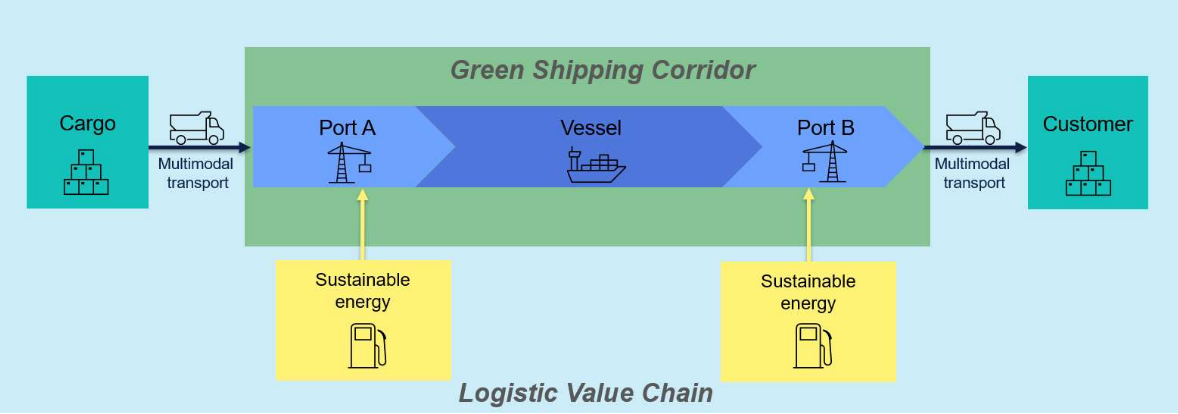

Figure A. Simplified sketch of the green shipping corridor system, based on the Clydebank Declaration.

What we found

Overall number of ships and energy consumption

Throughout the base year of 2019, approximately 8900 unique vessels having an IMO number were involved in voyages defined as Nordic ship traffic (i.e., ships with at least one port call in a Nordic country during the year). The total fuel consumption for this Nordic ship traffic is estimated to approximately 8.64 Mtoe (millions ton of oil equivalent), adding up to 26.8 million tonnes of CO_2 emissions.[6] With our definition of Nordic ship traffic, this includes the total fuel consumption for all voyages, also those with destination outside of Nordic waters.

An overview of overall results for Nordic ship traffic is given in Table A, distributed by the six main ship categories. By number of vessels, more than 50% of the ships are *cargo vessels* and *wet and dry bulk vessels*[7], which dominate fuel consumption and emissions with a total of 54%. The ranking of ship categories by energy consumption in Nordic ship traffic is followed by passenger vessels with around 19% of fuel consumption and emissions, work/service vessels (15%), fishing vessels (7%) and cruise vessels (6%). The passenger vessels represent about 9% of the total number of vessels involved in Nordic ship traffic but represent 19% of the emissions. Work/service vessels have the highest total time spent in Nordic ship traffic. Like passenger vessels, most of the ships in the work/service category continuously operate in Nordic traffic through the year. The same applies for the fishing vessels, which are observed (AIS observed time) in Nordic traffic to same degree as the cargo vessels, although the number of cargo vessels is almost the double of the number fishing vessels.

Table A. Overview of Nordic ship traffic, fuel consumption and CO_2 emissions (2019).

Ship category	No of vessels	Sailed distance (mill. nautical miles)	AIS observed time, sailing and in port (mill. hours)	No. of voyages	Energy consumption (Mtoe)	Share of CO_2 emissions (%)
Cargo vessels	2584 (29%)	227	490	130 200	2.39	28 %
Wet and dry bulk vessels	2160 (24%)	136	247	42 300	2.24	26 %
Passenger vessels	804 (9%)	29	375	298 600	1.66	19 %
Cruise vessels	155 (2%)	8	24	9700	0.54	6 %
Work / service vessels	1972 (22%)	538	610	124 200	1.27	15 %
Fishing vessels	1211 (14%)	214	490	59 300	0.55	7 %
Totals	**8886 (100%)**	**1152**	**2235**	**664 300**	**8.64**	**100 %**

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[6] CO_2 factors (tonne CO_2 per tonne fuel) used in this estimate is MGO/MDO: 3.206; electricity from grid (battery-powered ferries): 0; LNG: 2.75

[7] Cargo vessels are ships carrying *unitized cargo*, such as containers, while wet and dry bulk vessels carry solid or liquid *loose cargo*, such as grain or oil products. In this report, the category *cargo vessels* include the ship types *container ship, general cargo ship, refrigerated cargo ship* and *ro-ro cargo ship*. The category *wet and dry bulk vessels* include the ship types *bulk carrier, chemical tanker, crude oil tanker, gas tanker* and *oil product tanker*.

Energy consumption distributed by traffic type

The assessment of ship traffic has been made through detailed analysis of voyages to and from Nordic ports. The voyages allocated to Nordic ship traffic are categorised into three traffic types:

- *Domestic Nordic traffic:* voyages between ports in the one and same Nordic country,
- *Intra Nordic traffic:* voyages between ports in two different Nordic countries, and
- *Nordic international traffic:* voyages to/from a Nordic port from/to a port in a non-Nordic country.

As shown in Figure B (left), Nordic international ship traffic represents 58% of the total energy consumption, followed by Nordic domestic (32%) and intra Nordic traffic (10%). Cargo and wet and dry bulk ships dominate energy consumption for international traffic, as shown in Figure B (right).

The Nordic international ship traffic includes relatively large vessels and ships involved in voyages to and from continental Europe and long-haul voyages to and from other continents. The long-haul voyages constitute around 24% of the Nordic international energy consumption, and voyages between the Nordics and Europe the remaining 76%. Voyages between Nordic countries and *north-west Europe* and between Nordic countries and *the Baltics* are responsible for 54% and 9% of the energy consumption by Nordic international ship traffic, respectively.

Ro-Pax (i.e., ferries carrying passengers and vehicles) is the dominating ship *type* within the *ship category passenger* and has the largest contribution to CO_2 emissions from intra Nordic ship traffic. This traffic is dominated by the relatively large Ro-Pax vessels, between 25 000 – 100 000 GT[8], operating on routes between two Nordic countries. For passenger ships, domestic and Nordic international traffic also represent a substantial share of the total energy consumption, as seen in Figure B (right).

The ship categories work/service (aquaculture vessels, offshore ships, tugs, work ships) and fishing have the primary share of their energy consumption from domestic traffic.

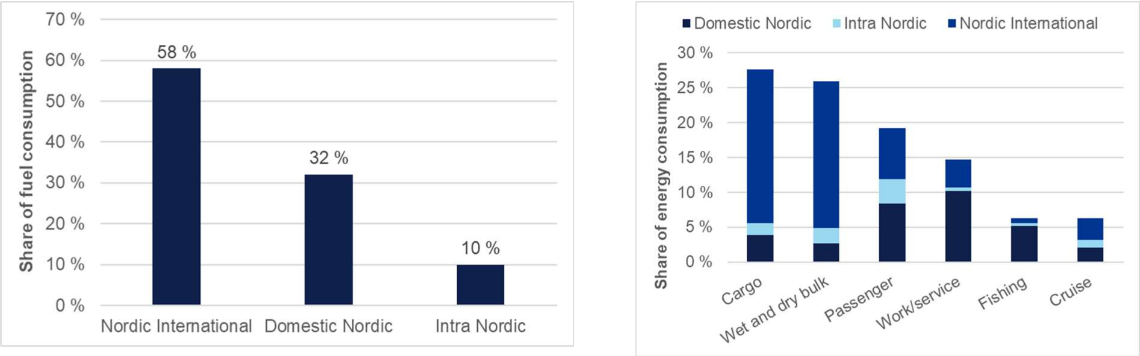

Figure B. Distribution of energy consumption between Nordic ship traffic types; overall (left) and split by ship category (right). 2019 data.

Through a screening of the feasibility of sustainable zero-carbon fuels, we find that around 3% of the total energy consumption of Nordic ship traffic may be covered by battery electric ships - primarily domestic traffic but also some intra Nordic - and close to 40% has a theoretical potential to be covered by hydrogen. This is mainly due to Nordic regions and northern continental Europe being geographically close. The remaining of the fleet needs higher energy density fuels such

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[8] Gross tonnage (GT) is a measure for the ship size, expressed as the ship's overall internal volume

as methanol, ammonia or biofuels to be decarbonized. A high theoretical hydrogen potential does not necessarily imply that this will be the option preferred by shipowners planning specific ship projects.

Potential Nordic green shipping corridors and energy hubs

Identification and selection of green shipping corridors is crucial to accelerate the uptake of sustainable zero-carbon fuels and generate sustainable operations that can be transferred to other routes and for lessons to learn. Based on AIS-modelled energy consumption (fuel consumption) and ship characteristics, we identify routes that have a large annual energy consumption for the important ship categories Ro-Pax, cargo and wet and dry bulk, and involve port calls in more than one country. These routes are labeled *potential green shipping corridors* and summarized in Table B. In total, 81 routes are identified in this analysis. These constitute about 17% of the total energy consumption of Nordic ship traffic.

The intra Nordic and Nordic international Ro-Pax routes are primarily routes between two ports, while the cargo ship and wet and dry bulk ship routes are round trips involving both Nordic ports and ports in other European countries. Among the Ro-Pax routes, most have an energy demand per trip between 100 and 500 MWh, but there are also shorter routes with lower energy demand and 12 potential corridors are found potentially suitable for battery electrification. Cargo and bulk routes are mostly longer routes with energy demand above 500 MWh (round trip). Among the cargo and wet and dry bulk routes, the cargo routes are considerably more regular than wet and dry bulk routes, with a higher number of annual round trips and consequently representing a larger share of energy consumption.

Table B. Overview of routes selected as potential green shipping corridors.

Route type	Number of routes	Potential annual energy demand	
		Mtoe	% of Nordic ship traffic
Intra Nordic Ro-Pax routes	18	0.38	4.4%
Nordic international Ro-Pax routes	23	0.70	8.1%
Intra/international cargo routes	20	0.31	3.6%
Intra/international wet and dry bulk routes	20	0.07	0.8%
Total	**81**	**1.46**	**17%**

In terms of energy consumption of the selected potential green corridors, the ten most dominating Nordic ports are Helsinki, Hanko/Hangö, Göteborg, Stockholm, Oslo, Trelleborg, Åbo/Turku, Stockholm, Esbjerg and Malmö. Some ports are common for several of the routes. These ports can be denoted as *potential green energy hubs*. A potential green energy hub is a port with significant energy demand from ships sailing from that port, and thus having the *potential* to supply green energy to a future decarbonized fleet. In addition to serving the specific potential green shipping corridors with energy, several of these ports also may have the potential to provide energy also to other parts of ship traffic, e.g., local ship operations and domestic traffic (spin-off effects).

Alternatively, ports can be ranked by the total energy consumption of all domestic, intra Nordic and Nordic international voyages departing from that port, i.e., not limited to the selected potential green corridors. The top 10 Nordic ports in that respect are Helsinki, Göteborg, Mongstad, Stockholm, Tromsø, Bergen, Esbjerg, Oslo, Copenhagen and Tananger. The large share of domestic traffic in Norway is reflected by the presence of Norwegian coastal ports when ports are ranked in this way.

Details of the routes, including screening of regularity and fuel feasibility, and involved ports provided in this report is an important knowledge basis for the establishment of green energy hubs supplying Nordic ship traffic and will be further analysed in Task 2B (Infrastructure) of the Nordic Roadmap project.

What we recommend

The project task has identified 81 potential green shipping corridors with connection to the Nordic, covering 17% of the total fuel consumption in Nordic ship traffic. These 81 corridor candidates do all have different potential impact, fuel feasibility and maturity. Figure C shows the traffic pattern for all passenger vessels in parts of the Nordic region. For the establishment of initial green shipping corridors, we recommend that focus is put on the *intra Nordic Ro-Pax routes*. These routes account for 4.4% of the total energy consumption and emissions of Nordic ship traffic, involving relatively few ports and relatively few vessels operating on regular basis. The decarbonization of the Ro-Pax segment has already started, primarily through battery electrification of domestic and other short distance Ro-Pax routes.

The challenges and learnings from the decarbonization of intra Nordic Ro-Pax vessels can easily be transferred to the *Nordic international Ro-Pax routes*, which possess many of the same characteristics as the intra Nordic Ro-Pax routes in terms of ship sizes and sailing distances. These routes have in total more energy consumption than the intra Nordic Ro-Pax routes. Together with the intra Nordic Ro-Pax routes, these constitute 12.5 % of the total energy consumption of the Nordic ship traffic.

Beyond focusing on ro-pax routes, the focus should also be put on the cargo and bulk vessels operating on relatively fixed routes, and routes that involve few individual ports on the round trips. The total annual energy demand for a cargo route can be as high as for a Ro-Pax route, but fewer annual voyages, less regularity and several involved ports imply that the barriers are higher for the decarbonization of these routes.

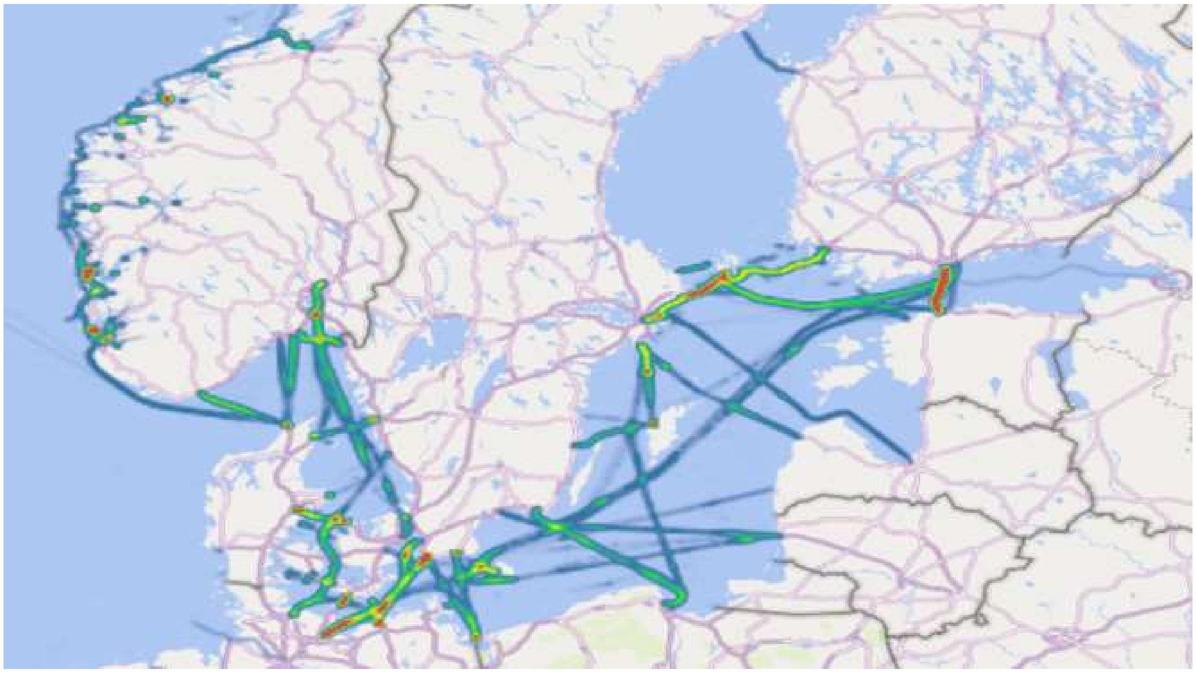

Figure C. Traffic patterns for all passenger vessels in parts of the Nordic region in 2019. Colouring indicates fuel consumption density at the given geographical location.

There are already multiple LNG capable vessels on Nordic Ro-Pax routes. Hydrogen and ammonia technologies are commercially immature. A realization of green shipping corridors between two (or more) ports *by 2025* will therefore most likely require ships fuelled by methanol or LNG (in bio or synthetic form to make them carbon neutral). This is mainly due to lack of the supply of other sustainable zero-emission fuels such as hydrogen an ammonia, and the time it takes to plan and build new vessels compatible with these fuels. A further key barrier to realization of green shipping corridors towards 2025 is the price gap that exists between fossil fuels and zero-carbon fuels.

The development and realization of initial green corridors depends on several additional aspects, not covered by our AIS analyses. From literature and internal work, five key enablers are driving the ship decarbonization via green shipping corridors, as illustrated in Figure D: 1) partnership and collaboration on supply and demand side to enable zero-carbon emission shipping; 2) actions helping to ensure demand for zero-carbon fuels; 3) increased availability of fuel and infrastructure to supply ships powered by zero-carbon fuels; 4) mechanisms for closing cost caps between conventional and zero-carbon fuels, and 5) setting onshore and onboard safety standard to ensure a safe transfer to zero-emission shipping.

In short, the key success factors are that the different actors *actually dare to commit* with respect to demand and supply of immature and expensive fuels with uncertain future availability. Such commitment is impossible without common understanding and upfront agreement between the actors on “how to do things”, including risk and cost sharing. This is also at the core of the Green Shipping Corridor approach, as DNV sees it: to establish the required level of understanding and agreement among the actors for a specific transport system (i.e., ship route(s)), such that the risk level becomes acceptable and commitment to the delivery and use of zero-carbon emission fuels is possible. In this picture, mitigation of the practical, organizational, legal and financial barriers are as important as the technical challenges. By placing the initial focus on tailormade commercial cases in a limited set of green corridors, these barriers may be overcome – and allow for learning and later generalization on a regional and global scale. As such green corridors may become key enablers to accelerate the uptake of zero-emission fuels.

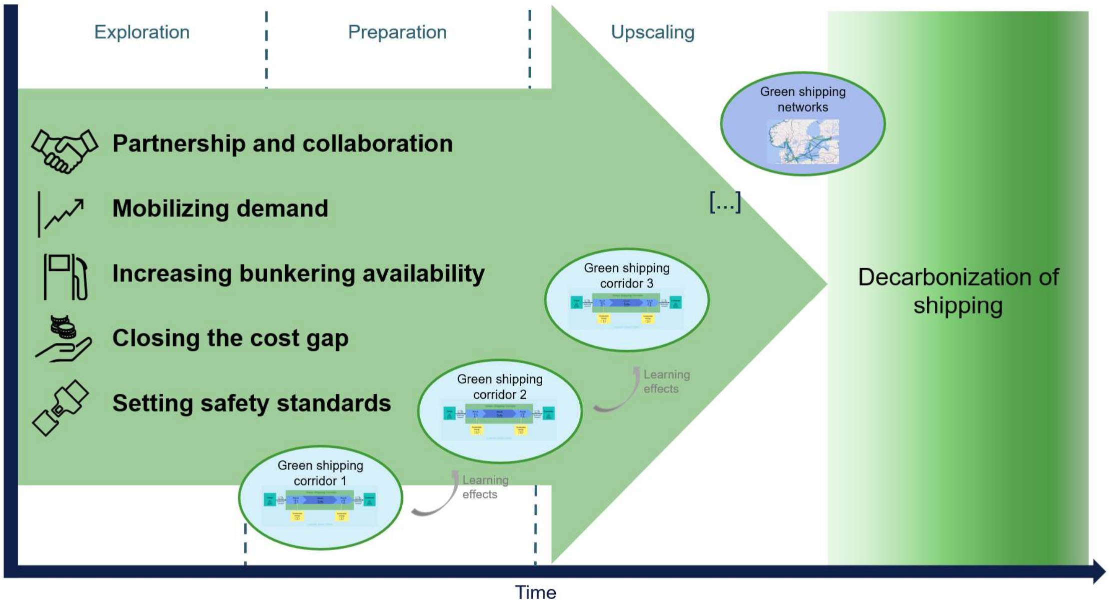

Figure D. Five key fundamentals are driving ship decarbonization via green corridors (Source: DNV, 2022).

Green shipping corridors can be categorized by feasibility and impact. Routes with high feasibility and low impact can give “quick” wins, paving the way and providing learning effects. Other routes with high impact might have lower feasibility and will require more support for realization. Shipping routes with high feasibility and high impact can be a possible game changer and should be prioritized in the development of corridors. To monitor the gradual development of green shipping corridors, a fuel transition barometer should be established, for example building on DNV’s barometer for Norwegian domestic shipping. The transition barometer, in combination with e.g., DNV’s Alternative fuel insight (AFI) platform[9], will provide the industry and policy makers with insight on speed and progress of the energy transition.

Further work based on the AIS analysis results

The results of the AIS analysis will be an important cornerstone in the development of the Nordic roadmap (Task 2C), and provided input to various project tasks, e.g., Task 1A (Scorecard), 1C (LCA) and 2B (Infrastructure). Having a breakdown on fuel consumption for domestic ship traffic, traffic between Nordic countries (intra Nordic) and Nordic international traffic will help in developing the future supply side, overall and for the individual Nordic countries. Our analysis has estimated the potential demand of various potential zero-carbon fuels, linked to ships and routes, and identified relevant green energy hubs and shipping corridors. The location of potential energy hubs in Nordic waters is vital information for further planning and development of infrastructure to supply the uptake of zero-emission fuels for green shipping corridors and other future demands.

The longlist of potential corridors identified through this AIS analysis will be shortened by the infrastructure analysis performed in Task 2B. When going from a longlist of potential green shipping corridors to a *shortlist* (i.e., corridors that can be chosen as early movers), other data and parameters such as addressed above (the five key fundamentals) should be considered. Having developed the shortlist of potential energy hubs in Task 2B, the related ship routes and potential green shipping corridors can be identified (the shortlisted corridors). The shortlisted potential green shipping corridors will be candidates for Nordic pilots (Task 3C) and being instrumental to overcome barriers as identified in Task 1A/2B for the selected fuels.

In the Nordic Roadmap (Task 2C), both short- and longlisted green shipping corridors and energy hubs will be addressed, defining long term goals and major actions and milestones essential to reach these goals and to overcome barriers for supplying sustainable zero-carbon fuels.

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[9] https://afi.dnv.com/

ABBREVIATIONS AND DEFINITIONS

AIS	Automatic Identification System.
Alternative fuel	An alternative fuel is a fuel not commonly used in the shipping industry today, i.e., a fuel with low commercially availability of both fuel technology and bunkering facilities.
GHG	Greenhouse Gas.
Green shipping corridor	*The Clydebank Declaration Definition*: Zero-emission maritime routes between two (or more) ports. Fully decarbonized fuels or propulsion technologies should not be capable of adding additional greenhouse gas (GHG) emissions to the global system through their lifecycle, including production, transport, and consumption.
GSCM	Green Shipping Corridor Model (DNV model).
GT	Gross tonnage; a measure of a ship's overall internal volume. It is useful since all ships possess this metric, unlike for example DWT (dead weight tonnage).
IMO	International Maritime Organization.
MASTER	Mapping of Ship Tracks, Emissions and Reduction potentials (DNV model).
MoU	Memorandum of Understanding.
Mtoe	Million tonnes of oil equivalent; a unit of energy.
MWh; TWh	Units of energy; 1 TWh (tera watt hours) equals 1 million MWh (mega watt hours).
Nordic ship traffic	All ship voyages involving at least one Nordic port.
Potential energy hub	Used in this report to denote a port with significant energy demand from ships sailing from that port, and thus having the potential to supply green energy to a decarbonized fleet.
Potential fuel demand	Fuel consumption from voyages leaving a specific port, calculated by use of AIS data.
Potential green shipping corridor	Used in this report to denote a ship route with significant ship energy demand, based on our ranking of ship voyages by annual energy consumption.
Ship voyage	One single trip between two ports.
Sustainable zero-carbon fuels	The term sustainable zero-carbon fuels are used to indicate fuels with potential zero climate impact throughout their lifecycle. Sometimes the term 'carbon-neutral fuels' is also used.

1 INTRODUCTION

This chapter presents the background for the report. Sub-chapter 1.1 presents the motivation of the project work and the structure of the report, and sub-chapter 1.2 introduces the *Green Shipping Corridor* concept.

1.1 Report motivation and structure

DNV with partners have been assigned the *Nordic Roadmap project*[10] by The Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers. The project has an overall aim “to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero emission shipping”. In reply to the defined scope of work, this report summarizes the analysis results from Task 2A of the project - AIS analysis of the Nordic ship traffic and energy use. The analysis maps the current status on energy consumption and emissions from ship traffic in the Nordics and provides a description of the geographical distribution of the Nordic ship traffic[11]. The understanding of Nordic ship traffic and its dominating ship types, trades, and routes, forms the basis for further analyses and evaluations in the Nordic roadmap project. It also constitutes a part of the knowledge foundation for decision makers to enable the fuel transition in shipping in a Nordic context.

The outcome from Task 2A will be used in Task 2B, considering infrastructure and bunkering challenges for selected fuels. Task 2A will also provide important input to the development of the Nordic Roadmap for infrastructure and supply of the potential zero-carbon fuels in Task 2C. The Nordic Roadmap will define long term goals and major actions and milestones to reach these goals and to overcome barriers for supplying new fuels. The AIS analysis will also provide information crucial for selecting segments and ports for initial green shipping corridors and pilot projects.

Green shipping corridors are considered to be important enablers for the wider uptake of sustainable zero-carbon fuels in shipping (see sub-chapter 1.2 for definition and status of green shipping corridors). In this report, we use the term *potential green shipping corridor* to denote a ship route with significant ship energy demand, based on our ranking of routes by annual energy consumption.

With DNV’s activity-based AIS models, we model energy consumption and emissions for each ship involved in Nordic ship traffic. We use AIS data and ship data for the year 2019. All ship voyages related to Nordic countries are included in the analysis – comprising three traffic types: domestic voyages, voyages between Nordic countries (*intra Nordic*) and voyages between Nordic countries and other countries. Using the model-based results together with information on the location of ports, we further identify specific routes and rank them based on annual energy consumption. We also do a screening of the feasibility of sustainable zero-carbon fuels[12], linked to ships and routes.

The report structure is as follows: The methodology is described in chapter 2. Chapter 3 gives an overall picture of the ship traffic in the Nordic, providing results of energy consumption and emissions, and how this is distributed by geographical location and among the various ship types. Chapter 4 breaks down the energy demand on the three traffic types, separating domestic, intra Nordic and Nordic-international sailing. The chapter also discusses the feasibility of sustainable zero-carbon fuels for the fleet, and selected ship segments suitable for potential green shipping corridors are further investigated. Chapter 5 presents longlists of potential Nordic green shipping corridors for selected ship types, where the fuel feasibility per potential corridor is also discussed. Chapter 6 provides an overview of potential energy hubs - dominating Nordic ports based on the analysis. Chapter 7 describes how the longlists of potential green shipping corridors can be used in the further roadmap work to obtain a shortlist of initial corridors. In this chapter, it is also discussed how these can be realized in light of the findings in this report. Further detailed results and information is found in the appendices.

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[10] https://futurefuelsnordic.com/

[11] *Nordic ship traffic* is all ship voyages (trips between two ports) involving at least one Nordic port

[12] The term sustainable zero-carbon fuels are used to indicate fuels with potential zero climate impact throughout their lifecycle.

1.2 Green shipping corridors: Definition and current status

The Clydebank Declaration[13] for green shipping corridors was launched at COP26, November 2021. Its signatories commit to develop at least six green shipping corridors between two (or more) ports by 2025 and "many more" by 2030. The declaration was signed by more than 20 countries, including the US, Japan, and Australia, as well as Denmark, Finland, Norway, and Sweden.

The Clydebank Declaration defines green shipping corridors simply as "zero-emission maritime routes between two (or more) ports". The signatories of the declaration recognize that fully decarbonized fuels or propulsion technologies should not lead to additional greenhouse gas (GHG) emissions to the global system through their lifecycle, including production, transport, or consumption. There are several other definitions of the term *green shipping corridor* (Global Maritime Forum, 2022a), and many parameters play a role to indicate whether a ship route is a favourable green shipping corridor. This project uses the Clydebank Declaration definition. A simplified sketch of the value chain of a green shipping corridor is shown in Figure 1-1. A green shipping corridor ecosystem involves cooperation between many actors, such as cargo owners, ports, vessel owners, charterers, operators, energy suppliers and others. It is important to note that while the Clydebank Declaration covers only the port-to-port element of the value chain, efforts to decarbonize the overall transport system (or value chain) will also be needed. For clarity, not all vessels transiting a green corridor would be required to be zero emission vessels or to participate in the partnerships.

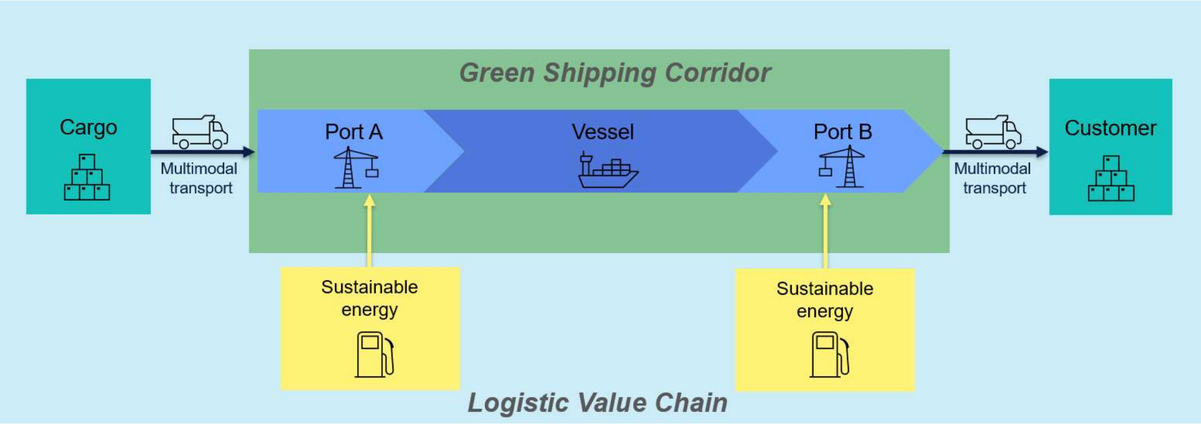

Figure 1-1. Simplified sketch of the green shipping corridor system, based on the Clydebank Declaration definition.

The green shipping corridor concept facilitates a parallel development of demand and supply of sustainable zero-emission shipping fuel at one individual trade route, solving the chicken-or-egg problem: Who must invest in technology first - the shipowner or the fuel supplier?[14] In practical terms, this means that the shipowner can rely on steady supply of a certain zero-emission fuel in one or each port on a route, while the fuel supplier has secured a demand and offtake from the shipowner. Green shipping corridors would be a result from partnerships and agreements between two or several ports, ship operators, and other stakeholders to decarbonize specific maritime trade routes. Voluntary participation by operators is an essential element for the successful establishment of green shipping corridors.

Shipowners have always gravitated towards solutions that are cheaper, more reliable, more efficient and needing less space onboard. Going forward, owners will still favour such solutions. The challenge is that zero-carbon emission fuels are typically more expensive, less mature, less efficient and require more space onboard. They also pose new safety

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[13] Policy Paper COP 26: Clydebank Declaration for green shipping corridors, signed by 22 countries. https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors

[14] https://www.ammoniaenergy.org/articles/green-maritime-corridors-a-catalyst-for-transition-to-green-shipping-fuels/

challenges and introduce significant supply-side problems. One of the key success factors to scale up sustainable zero-emission fuels in a transport system, is that the different actors actually *dare to commit* with respect to demand and supply of immature and expensive fuels with uncertain future availability. Such commitment is impossible without common understanding and upfront agreement between the actors on “how to do things”, including risk and cost sharing.

This is also at the core of the Green Shipping Corridor approach, as DNV sees it: to establish the required level of understanding and agreement among the actors for a specific transport system (i.e., ship route(s)), such that the risk level becomes acceptable and commitment to the delivery and use of zero-carbon emission fuels is possible. In this picture, mitigation of the practical, organizational, legal and financial barriers is as important as the technical challenges. By placing the initial focus on tailormade commercial cases in a limited set of Green Corridors, these barriers may be overcome – and allow for learning and later generalization on a regional and global scale. As such Green Corridors may become key enablers to accelerate the uptake of zero-emission fuels.

Green shipping corridors do already exist. As recently stated by the Norwegian newspaper Adresseavisen; “Ferry and high-speed light craft operator Norled was the first to establish a short version of Green Corridors when they started operating the battery-powered ferry Ampere in February 2015. It is still operating on the ferry connection Lavik-Oppedal in Sognefjorden, charging the batteries at each stop”. After this, about 60 more battery ferries have started operating in Norwegian fjords, and more than 20 are confirmed to be in operation within a few years. The Norwegian ferry network’s early uptake of zero-emission energy is a success not only because of zero emission requirements set by the Norwegian Road Administration and the county administrations in their public tenders for ferry routes (based on requests from the Parliament). It was also highly dependent on forward-looking (and risk accepting) ship operators and technology suppliers, as well as substantial funding of investment costs on ferries and charging infrastructure from the NOx fund[15] and ENOVA[16]. Each of these ferry connections is an example of a green corridor. In common, they illustrate that the public sector can play an important role in the enabling and phase-in period for uptake of new low emission technologies in shipping.

There are also examples of commercial cargo owners establishing green shipping corridors. ASKO, a grocery supplier, drives a project between Horten and Moss in Norway, where two autonomous electric vessels will transport cargo across Oslofjorden[17]. Yara Birkeland is another similar project, where an autonomous ready electric container vessel will transport fertilizer from Porsgrunn to Brevik[18], initiated by fertilizer producer Yara. HeidelbergCement and agricultural cooperative Felleskjøpet AGRI have established a joint effort requesting a zero-emission cargo ship. The companies are awarded for using their role as product owners to initiate the development of several different zero-emission solutions for larger ships with longer sailing distances[19]. These projects have received public financial support, enabling the phase-in of new zero-emission technologies in shipping. As such, these past development projects demonstrated the important role of the public support in the initial phase of establishing green shipping corridors. The example of ASKO, Yara and HeidelbergCement/Felleskjøpet show the extra effort, high costs and time demanding processes a cargo owner must overcome today to realize a green shipping corridor, even with financial support from the public. All three project examples have started as pilot studies in the Green Shipping Programme (GSP[20]), highlighting cooperation as a key element for realization.

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[15] The Business Sector`s NOx Fund, also called the NOx Fund, works to reduce emissions in the business sector in order to fulfill Norway's obligations in the Gothenburg Protocol. The NOx Fund was established in 2008. https://www.noxfondet.no/

[16] Enova SF is owned by the Ministry of Climate and Environment, contributing to reduce greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply.
https://www.enova.no/about-enova/

[17] ASKO, Logistics 2030 (from road to sea) - Green Shipping Programme

[18] Yara Birkeland, Yara Birkeland | The first zero emission, autonomous ship | Yara International

[19] HeidelberCement and Felleskjøpet, Sea transport of building materials and grain - Green Shipping Programme

[20] Green Shipping Programme (GSP) The world’s most efficient and environmentally friendly shipping - Green Shipping Programme

A handful of international green shipping corridors are already announced and are in the early planning phase. This includes the route from Port of Los Angeles to Shanghai in China (announced by the Green Ports Forums in January 2022)[21], the European Green Corridors Network (announced by the Maersk Mc-Kinney Moller's in March 2022), a Chilean Green Corridors Network and the Iron Ore Green Corridor between Australia and East Asia (these two also announced by The Maersk Mc-Kinney Møller Center for Zero Carbon Shipping in April 2022). The three latter corridors have no specific route specified. The UK Shore R&D programme also announced a British green corridor (May 2022)[22], while the International Transport Forum (ITF/OECD, 2021) has investigated green corridors from the port of Hamburg (June 2021)[23]. The European green corridors network is formed by port authorities of Gdynia, Hamburg, Rønne, Rotterdam, and Tallinn in Northern Europe and the Baltic Sea[24].

The cruise industry has established initiatives for decarbonization, and several ports and cruise companies support *the world's first cruise-led 'green corridor.'*[25] This initiative involves "the first mover commitment" by ports ranging from Seattle and Vancouver to Juneau, Alaska[26]. The port authorities of two of the largest bunker ports in the world, the ports of Singapore and Rotterdam, claim to establish the world's longest green corridor for shipping[27], with the first sustainable vessels sailing on the route by 2027. The two ports have signed a Memorandum of Understanding (MoU) and seek a broad coalition of stakeholders to cooperate towards transitioning low and zero carbon fuels. In addition, the MoU will create a digital trade lane with shared data, documentation, and standards to optimize efficiency, maritime safety, and the transparent flow of goods. Optimization of just-in-time port arrival of vessels and facilitation of the seamless movement of vessels and cargo are central parts of the project. It is to be noted that the port of Oslo recently made a high-level feasibility study related to use of hydrogen containers for container ships sailing between ports in Norway and Europe.

Undoubtedly, more green shipping corridors will be announced in the coming months and years. Shipping routes having scheduled traffic and high frequency of port calls will be attractive as first movers for the selection of green shipping corridors. Relevant ship types include vehicle and passenger ferries, container ships, and cruise ships. In addition, certain international dry and wet bulk routs served by tank (incl. shuttle tankers) and bulk ships may be attractive.

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[21] *Green Ports Forum, https://www.c40.org/news/la-shanghai-green-shipping-corridor/*

[22] *UK SHORE R&D programme, https://questions-statements.parliament.uk/written-statements/detail/2022-05-24/hcws50*

[23] *ITF/OECD (2021), https://www.itf-oecd.org/zero-carbon-supply-chains*

[24] Zero-carbon shipping centre and partners, *https://www.offshore-energy.biz/zero-carbon-shipping-centre-and-partners-initiate-european-green-corridors-network/*

[25] Cruise industry, *https://www.tradewindsnews.com/cruise-and-ferry/cruise-lines-and-ports-eye-us-west-coast-green corridor/2-1-1225622*

[26] *Cruise ports, https://www.maritime-executive.com/article/ports-and-cruise-lines-explore-pacific-northwest-alaska-green-corridor*

[27] Singapore and Rotterdam, https://gcaptain.com/singapore-and-rotterdam-to-establish-worlds-longest-green-shipping-corridor/

2 METHODOLOGY AND DATA

This chapter presents the methodology and data used by Task 2A for the analysis of Nordic ship traffic[28]. Firstly, the AIS-based modelling framework is introduced in sub-chapter 2.1. In sub-chapter 2.2, key performance indicators for assessing potential green corridors are presented. Finally, the chapter 2.3 discusses some uncertainties and quality considerations related to the use of AIS data.

2.1 AIS-based modelling framework

2.1.1 Overall approach

The AIS-based modeling approach used by Task 2A is illustrated in Figure 2-1, reflecting input data, models, and the output. In the following sections, the framework and modeling steps are outlined in more detail, incl. input data to the AIS analysis. The framework is centered around the DNV's *MASTER* model (Mapping of Ship Tracks, Emissions and Reduction potentials) and the *Green Shipping Corridor Model* (GSCM). The MASTER model uses ship movement data from the Automatic Identification System (AIS), detailed ship specific information and supporting data tables to estimate the energy demand, fuel consumption and emissions of each individual ship while sailing and when in port. The GSCM takes the MASTER model results further by modelling ship energy demand, fuel consumption and emissions for the individual ship voyages and port calls and creates statistics that enable for identification of shipping lanes and potential green shipping corridors.

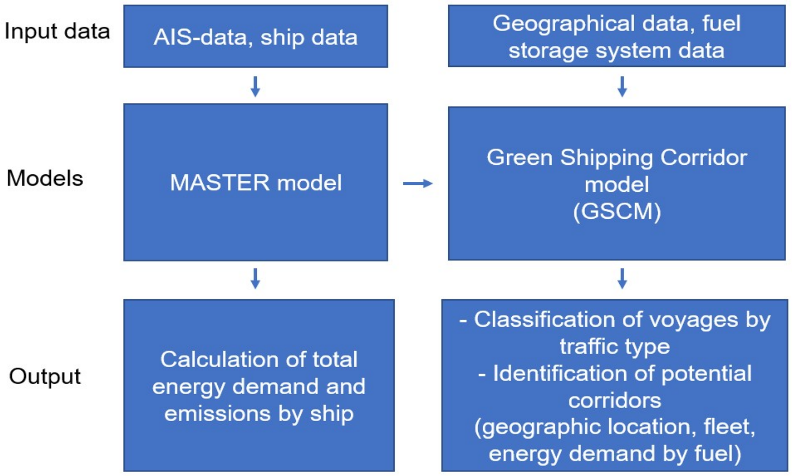

Figure 2-1. High level illustration of the AIS-based modelling framework used in Task 2A.

The *MASTER* model (DNV (2008), Mjelde, Martinsen, & Endresen (2014) and DNV GL (2018)) utilizes data from the AIS system, which provide a detailed and high-resolution overview of all ship movements, where sailing speeds, operating patterns, sailed distances (nautical miles) and time spent in various areas are identifiable for each ship for those ships having the AIS system installed[29]. The information from the AIS system is merged with technical databases for detailed information on the individual ship, such as installed power on main and auxiliary engines, boilers, machinery configurations, ship design speed, main fuel type, specific fuel consumption, tonnage, etc.

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[28] *Nordic ship traffic* is all ship voyages (trips between two ports) involving at least one Nordic port

[29] Carriage requirements for shipborne navigational systems and equipment, https://www.imo.org/en/OurWork/Safety/Pages/AIS.aspx

The AIS data enriched with ship register data, provides the basis for modelling the propulsion power demand for each individual AIS registered ship position. Translating the propulsion energy demand into fuel consumption, will also require input from the supply side (i.e., number of engines in operation, load on the engines, mechanical/diesel electric configurations, technologies, fuel types, etc.). Additional data and methods are needed when estimating the onboard auxiliary and boiler demands. This varies from ship to ship (i.e., transporting cargo, transporting passengers, service missions, etc.), ranging from providing a safe support for onboard systems to ensuring hotel facilities for crew and passengers. The auxiliary and boiler demands will also depend on operation mode, and for some ship type increase in port mode (i.e., under loading and unloading of cargo, crane operations, etc.). This allows for aggregation of results for individual ships, as well as ship types and ship size categories, geographical areas, and for detailed voyage analysis.

DNV's *Green Shipping Corridor Model* (GSCM) model (e.g., DNV GL, 2020; DNV GL, 2018a; Menon, DNV GL and TØI, 2020) uses the results from the *MASTER* model further by calculating ship energy demand, fuel consumption and emissions for all the voyages carried out by the individual ships. The ports are defined as geographical shapes, and the model uses port stop detection routines to isolate the individual voyage start and end. The time of departure, arrival, voyage speed profile, calculated sailing time and distance, and estimated energy consumption is logged. Based on energy use and ship operational characteristics, we analyze the applicability of potential zero-carbon fuels (potential energy demand) on the fleet, evaluate a geographical distribution of bunkering hubs and identify potential green corridors. KPIs for the assessment of potential Nordic green shipping corridors is described in sub-chapter 2.2.

The GSCM model has been developed by DNV and builds on work and analysis of the Norwegian car ferry sector, with the purpose of identifying the potential for full electric ferry operations, emission reductions potentials, investment costs requisite for upgrading the power infrastructure and CO_2 abatement costs (DNV GL, 2015; DNV GL, 2020a; Menon, DNV GL and TØI, 2020). To visualize the modeling results and to analyze the voyage of potential for the green corridors, a Power BI dashboard is developed. The results presented in this report cover extracts of the GSCM results developed for Task 2A.

Using the MASTER model and GSCM for individual ships sailing in Nordic waters, we provide the following assessments and results:

- Analysis of Nordic ship traffic energy consumption and emission distributed by ship categories and size categories, defined in sub-chapter 2.1.2.
- Identification of Nordic ship traffic and classification of traffic types, with input and approach as described in sub-chapter 2.1.3.
- Assessment of the feasibility of potential sustainable zero-carbon fuels[30] for ships, with input and approach as described in sub-chapter 2.1.4.
- Assessment of initial Nordic green shipping corridor candidates, and the related green energy hubs, by ranking the frequently traveled routes and ports by total energy demand and other parameters, further described in sub-chapter 2.2.

AIS data for 2019 is used for this analysis. The reason for using 2019 as base year is that the ship traffic for some specific ship categories in 2020 and 2021 was heavily affected by the Covid-19 pandemic and thereby less representative for future shipping activities. The Covid-19 had particularly an impact on the passenger and cruise ships.

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[30] The term sustainable zero-carbon fuels are used to indicate fuels with potential zero climate impact throughout their lifecycle.

2.1.2 Definition of ship categories, ship types and size segments

In this report, the results are aggregated on 6 *ship categories*, 17 specific *ship types* and 7 *size segments* based on gross tonnage (GT)[31,32], as shown in Table 2-1. The specific ship types are lumped together in ship categories for convenience and report readability. Throughout the report, we primarily mention the ship superior ship categories, but mention the specific ship types where this is appropriate. The specific ship type for each individual ship in the dataset is based on ship type specifications registered in IHS Fairplay[33]. Some of the ship types, typically fishing and work vessels are only found in the smaller ship size segments.

Table 2-1. Definition of ship categories, ship types and size segments.

Ship category	Ship type	Ship size segments (GT)
Cargo vessels	Container ship	All ship types are divided into these size categories: < 1 000 GT 1 000 – 5 000 GT 5 000 – 10 000 GT 10 000 – 25 000 GT 25 000 – 50 000 GT 50 000 – 100 000 GT > 100 000 GT
	General cargo ship	
	Refrigerated cargo ship	
	Ro-ro cargo ship	
Wet and dry bulk vessels	Bulk carrier	
	Chemical tanker	
	Crude oil tanker	
	Gas tanker	
	Oil product tanker	
Passenger vessels	Ro-pax	
	High speed passenger vessel	
	Other passenger ship	
Cruise vessels	Cruise ship	
Work/service vessels	Aquaculture vessel	
	Offshore vessel	
	Other activities (incl. tugs, work boats etc.)	
Fishing vessels	Fishing vessel	

2.1.3 Defining Nordic ship traffic types

Figure 2-2 illustrates the approach for identifying Nordic ship traffic types through voyage analysis.

The first step for the voyage analysis is to identify all unique ships that has operated in any Nordic economic zone (*EZ*) in 2019, and cluster all AIS position records and modelled results into individual ship voyages between two ports. Secondly, every voyage that involves a Nordic port call will be included the Nordic ship traffic analysis, and voyages not involving Nordic port calls are excluded from further analysis. Finally, the voyages allocated to Nordic ship traffic are categorised into one of the following three traffic types, as defined in Table 2-2: *domestic*, *intra Nordic* and *Nordic international* voyages. *Nordic ship traffic* is defined as ship voyages between or within the Nordic countries or the *entire voyage* to and from Nordic port and ports outside the Nordic countries. In this way, we can trace the ship all the way to end ports outside of the Nordic region, acknowledging that decarbonization measures taken in the Nordic countries may also affect these ships and voyages.

We calculate the energy consumption of each voyage from start port to end port and the total energy consumption aggregated within the three traffic categories. We can thereby analyze how the various ship categories, ship types and size segments contribute to energy consumption and emissions in these. DNV has done this in several analyses for

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[31] For reference, the median LOA (ship length) of the ships in our data material within the various size groups is approximately: < 1000 GT: 32 m, 1000 - 5000 GT: 88 m, 5000 - 10000 GT: 124 m, 10000 – 25 000 GT:170 m, 25 000 – 50 000 GT: 200 m, 50 000 GT – 100 000: 250 m, and > 100 000 GT: 320 m.

[32] Gross Tonnage (GT) is a measure of a ship's overall internal volume. It is useful since all ships possess this metric, unlike for example DWT (dead weight tonnage).

[33] Lloyd's Register of Ships IHS Markit, https://ihsmarkit.com/products/maritime-ships-register.html.

Norwegian waters as a basis for analyzing measures to achieve national emission targets for domestic shipping (e.g., Menon, DNV GL and TØI (2020) and DNV GL (2020a).

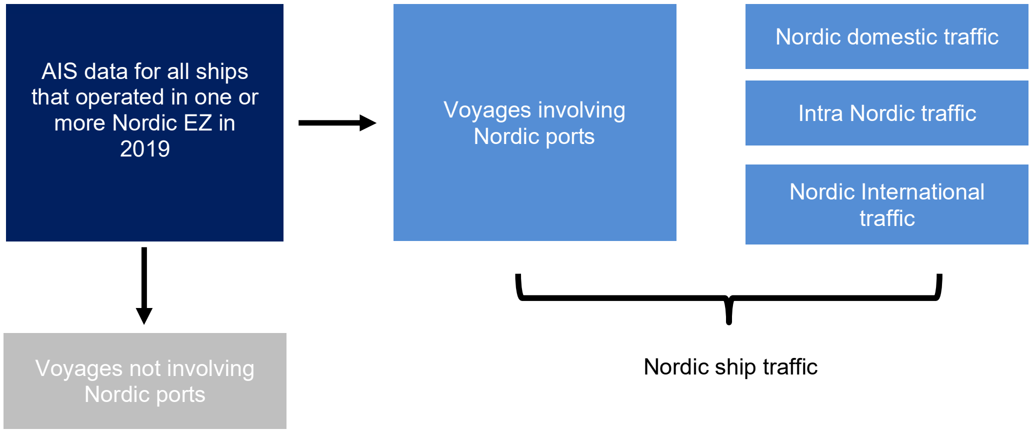

Figure 2-2. Illustration of method to identify Nordic ship traffic by analysis of ship voyages.

Table 2-2. Voyage based definition of traffic types for Nordic ship traffic.

Traffic type	Definition
Nordic domestic traffic	Voyage between ports in the one and same Nordic country
Intra Nordic traffic	Voyage between ports in two different Nordic countries
Nordic international traffic	Voyage to/from a Nordic port from/to a port in a non-Nordic country

Table 2-3 provides the number of unique of ports per Nordic country included in the analysis, which includes berths and anchorages, as well as sub-ports (e.g., separate geographical locations identified as different ports within the same city). The identification of ship anchorage areas, ports and berth locations are established through automatic detection of AIS ship positions combined with geographical data. A location is identified as a port when at least two unique ships with an IMO number within a year call at the location. The precision of the port identification algorithm relies on the AIS data coverage in the area, which is expected to be similar in the different Nordic countries. The high number of ports identified in Norway is primarily due to the country’s long coastline, and high short sea/coastal shipping activity leading to ship calls across many locations.

Table 2-3. Number of ports per Nordic country included in analysis.

Country	Number of ports
Denmark	151
Greenland	34
Faroe Islands	27
Finland including Åland	130
Iceland	51
Norway	1247
Sweden	247

The identification of ports makes it possible to identify detailed ship traffic patterns. However, to simplify when looking at the overall picture, we have grouped the port locations and assigned each to one of the following geographical regions, also shown in Figure 2-3:

- *Denmark West:* From and including Hirtshals going west and south; *Denmark East:* East of Hirtshals and going south
- Entire *Faroe Islands*
- *Finland South:* Finland East and South until and including Raumo; *Finland North*: Finland North of Raumo; *Finland – Åland*
- Entire *Greenland*
- Entire *Iceland*
- *Norway East-South:* Along Norwegian coast from East until and including Egersund; *Norway West:* Further along Norwegian coast until and including Trondheim; *Norway North:* Norway North of Trondheim
- *Sweden West-South:* Along Swedish west coast until and including Ystad; *Sweden East:* East and North of Ystad until and including Gävle; *Sweden North:* Further north of Gävle
- *Europe Baltic*: Baltic countries; *Europe North-West:* Northern Europe including UK; *Europe South:* Southern Europe including France
- *Russia*
- Other continents: *Africa*; *Asia*; *North America*; *Oceania*; *South America*

Figure 2-3. Defined geographical regions for the analysis.

2.1.4 Assessment of the feasibility of zero-carbon fuels for single ships

The alternative fuel technologies *battery electrification, hydrogen, ammonia* and *methanol* all have lower energy density (energy contained per volume) than conventional fuel oil. In addition, the storage tanks contain more material, e.g., for keeping the fluid compressed or liquefied, consists of more steel. This implies that the onboard alternative energy storage system will occupy more space than conventional fuel tanks when covering the same amount of energy. The same applies for LNG, which is not assessed in this study but widespread in shipping. Figure 2-4 shows the volumetric energy density of selected fuel storage systems.

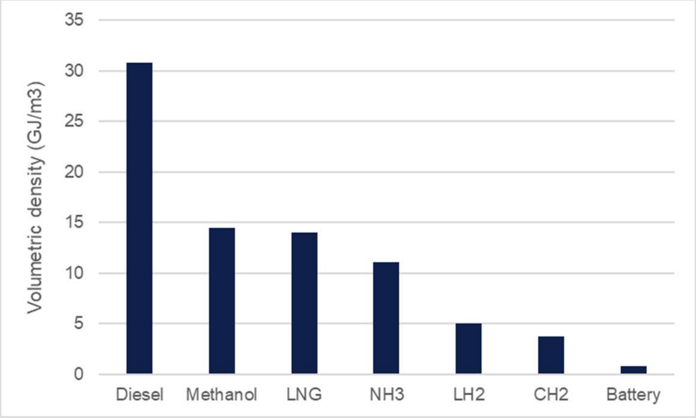

Figure 2-4. Volumetric energy density of alternative fuels[34], including tank system (LH2 – liquefied hydrogen gas, CH2 – compressed hydrogen gas at 700 bar, NH3 - ammonia) (MariGreen, 2018).

Although there are many parameters that determine whether a fuel or technology is feasible for a given ship of a certain type and operation, the required sailing range and speed and hence the energy density is of major importance. We therefore do an analysis of energy needed per voyage for each ship, to determine if the different fuel options are feasible for this ship. The energy consumption of each voyage will, amongst other internal and external factors, mainly depend on the ship operational profile, weather conditions, given by sailing distance, engine power curve and sailing speed. By *this ship,* we mean a ship with the same characteristics in terms of type, size and sailing pattern as the existing ship identified through the MASTER and GSCM model. It is not necessarily feasible to retrofit all existing ships to new technologies and fuels.

The following approach is used for the feasibility assessment: First, the ship energy demand and fuel consumption for each individual voyage is calculated. Then, the energy demand sufficient to cover 90% of all voyages becomes the *dimensioning energy demand* for the ship voyage, i.e., the amount of energy that must be able to be stored in the fuel tanks / battery onboard. This is illustrated in Figure 2-5 for a 11 000 GT cargo ship sailing between ports in northern continental Europe and southern Scandinavia. Here, 90% of the voyages have an energy need of 200 MWh or less; this is then chosen as the dimensioning energy demand.

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[34] The higher efficiency of battery-electric operation (higher energy output than ICE) is reflected in the number for battery in the figure. If fuel cell applications are used for one of these fuels, the volumetric density in terms of *energy output* for that fuel would be relatively higher than shown in the figure.

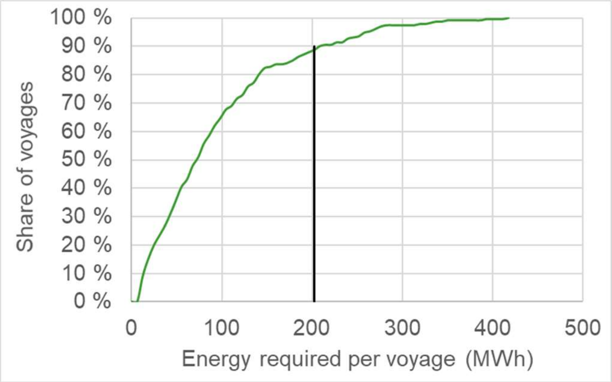

Figure 2-5. Share of voyages and corresponding maximum required energy per voyage (green line), and maximum required energy for 90% of voyages (black line), for a 11 000 GT cargo ship sailing between ports in northern continental Europe and southern Scandinavia.

Secondly, we calculate the amount of energy carrier (installed battery capacity, compressed hydrogen, ammonia or methanol) that needs to be stored onboard to meet the dimensioning energy demand and calculate the volume and mass of this fuel including tank system, using the values from Figure 2-4. The volume of this fuel system is then compared with the ship's gross tonnage (GT), which is a measure of the overall internal volume of the ship. The mass is compared with the ship's dead weight tonnage (DWT), a measure of the carrying weight capacity of a ship. We call this fraction the *fuel storage ratio* (FSR), expressed as FSR_V *= fuel system volume / GT* and FSR_m *= fuel system mass / DWT*. We find the average *FSR* for conventional fuel oil ($FSR_{V, FO, average}$ and $FSR_{m, FO, average}$) for all ships in the fleet, and thereafter compare the $FSR_{V, AF}$ and $FSR_{m, AF}$ (AF = alternative fuel) to $FSR_{V, FO, average}$ and $FSR_{m, FO, average}$ *respectively.* If FSR_{AF} is less than three times $FSR_{FO, average}$ for a ship, we assume that the given alternative fuel is feasible for that ship.

It should be noted that this is a simplified method for assessing fuel feasibility of a large fleet of ships, without assessing each ship and route in detail. It should be noted that the feasibility analysis does not tell if ship owners will actually prefer e.g. compressed hydrogen – if feasible - over ammonia or methanol. The choice depends on other aspects such as availability, safety aspects, onboard investment and fuel cost considerations and allowed bunkering intervals and duration. To have a definite answer for each ship and route, more detailed feasibility analysis is typically carried out, also taking these other aspects into account. More space allocated for fuel storage will lead to a changed ship design, and it is difficult to say generally how this will affect for example ship size, cargo space etc. This will also certainly differ between ship types. Also, if a fuel is found feasible for a given ship with this method, this does not imply that it is necessarily feasible to *retrofit that specific ship* to the alternative technology. It is rather assessed to be feasible for a ship with similar characteristics and operational profile as the analyzed ship. With this approach, we reflect that it is not only the distance that determines the suitability of different fuels, but also the speed and size of ship, which are also determines the energy consumption. Although smaller ships typically travel lower distances than large ones, there is considerable variation in the fleet and relatively small vessel can sail long distances, especially for ship types such as offshore and fishing.

The most important aim of the feasibility analysis is to assess how large part of the fleet has the potential to be battery electrified, while it is of secondary importance to assess which of the sustainable zero-carbon fuels will be feasible; hydrogen, ammonia or methanol. All these fuels have hydrogen as basis and most of the energy required in the production of these fuels is spent for producing hydrogen (Hoecke et al., 2021).

2.2 KPIs for assessing potential Nordic green shipping corridor candidates

As described in chapter 1, by *potential green corridor* we mean a ship route between two or more ports with regular and frequent ship traffic and thus large annual energy consumption, favorable for establishing an initial market for green transport by ship. However, for a potential green corridor to be realized as a green corridor, where sustainable zero-carbon fuel is used, a range of different criteria needs to be fulfilled. The criteria cannot be assessed by AIS analysis alone and include includes among others stakeholder engagement, willingness or ability to cover the additional cost of decarbonization and so on. The selection process for establishing of initial green shipping corridors is crucial, to ensure the specific routes are feasible to implement, and capable of generating sustainable operations that can be copied to other routes and used as lessons to learn. A new study has already analyzed 10 shortlisted corridors against certain impact and feasibility criteria (Global Maritime Forum, McKinsey & Company, 2021).

In our analysis we establish a *longlist of potential Nordic green shipping corridors* based on key performance indicators (KPIs) related to the actual ship traffic pattern and energy demand extracted from the AIS analysis. The voyage analysis allows us to identify routes and calculate each their annual energy consumption, as well as to identify other route characteristics. Based on this, we establish a *longlist* of potential corridors, ranked by the annual total energy consumption, and assign them with the following KPIs:

- *Annual energy consumption*: This then reflects the CO_2 emission reduction potential. Large energy volumes significantly impact GHG emissions, but at the same time, it can be demanding to initiate as first mover.
- *Regularity*: This is expressed by the number of voyages per year, and number of unique ships sailing the route.
- *Feasibility of fuels*: This is given by the assessment of which fuels are feasible for the route. It should be noticed that the feasibility assessment might change with maturing fuel technology and availability of fuels. For a route to be realized as a green corridor within a few years, this is especially critical. In this study the fuel feasibility screening result is indicated as *Level 1*, *Level 2* or *Level 3* for each route. *Level 1* indicates all fuel options are feasible, including battery electrification, *Level 2* indicates the potential is limited to compressed hydrogen or higher energy density technologies and *Level 3* denotes that only high energy density option (e.g. methanol or ammonia) is feasible.
- *Spin-off potential*: The list considers mainly intra Nordic traffic and some Nordic International traffic. However, there are possible spin-off effects for routes that start, end, or move between potential energy hubs that also have the ability to serve a considerable part of domestic or other traffic. This indicator is expressed as low, medium or high[35]. The indicator signalizes that minimum one of the ports in the potential corridor has the given level of spin-off potential. For example, vessel types such as fishing vessels or offshore service vessels mainly sail in and out of the same port and will primarily bunker at this location. This is an additional advantage for an energy hub, giving it the opportunity to serve both corridor routes and local ship operations. This additional advantage is referred to as a "spin-off effect". Note that the spin-off potential is evaluated on "a large scale", where the indicator takes the total of all Nordic ship traffic into account. However, some ports may have other spin-off potential that is important for the local surroundings (e.g., fishing on Iceland), which is not reflected by the spin-off indicator, unless the energy consumption of this traffic constitutes a significant share of Nordic ship traffic overall.

Chapter 7 discusses how the longlist of potential Nordic green corridors will be used as a starting point for further assessing their feasibility, narrow the list further down to a shortlist.

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[35] The indicator for spin-off potential for a given route is based on the total annual (2019) fuel consumption in the ports, excluding the fuel consumed by the given corridor route. 'High' spin-off potential indicates that at least one port in the route serves other voyages with an annual fuel consumption higher than 75 000 ton, 'medium' indicates a fuel consumption in the range of 25 000-75 000 ton, while 'low' indicates that all ports in the given route have a total annual fuel consumption lower than 25 000 ton.

2.3 Uncertainty and quality considerations of modelled results

Quality assurance and control efforts have been taken to minimise the uncertainties in the modelled results. The uncertainties are mainly related to quality of input data, the applied model algorithms to estimate energy consumption, fuel consumption and emissions, and the systematics for distribution of modelled results on individual ship voyages and potential green corridors. Frequent update of the databases, validation and calibration routines are established to secure that the input data hold highest possible standard.

From the MASTER model, the estimated energy consumption, fuel consumption and emissions for cargo carrying ships correspond well with reported data from the IMO Data Collection System (DCS) and the reported results from the EU's MRV scheme. A deviation of up to 5% is observed when comparing a large dataset of modelled results with reported data form DCS and EU-MRV (Longva & Sekkesæter, 2021). However, large uncertainties could occur for individual ships, and particular for non-cargo ships. This is in line with the activity-based modelling and uncertainties related to the use of AIS data as reported by the Fourth IMO GHG study (Faber et al., 2020). Similar error sources and quality considerations for AIS data are also reported by the UN Statistics Wiki (2020). We expect that potential errors in the data sources and AIS modelled results will not have significant impact on the modelled results.

For the Green Shipping Corridor Model applying a voyage approach, additional uncertainties relate to for example the identification of ports, particular the smaller once. As the identification is based on various maritime sources, including AIS data when ships have zero speed for certain time periods, we expect for this study that the relevant ports are covered in this study.

3 OVERALL PICTURE OF NORDIC SHIP TRAFFIC

With 2019 as reference year, this chapter provides results from AIS-based analyses and modelling for vessels that have been active in Nordic ship traffic[36]. The analysis of Nordic ship traffic includes operational statistics and modelling of the energy demand, fuel consumption and CO_2 emissions for individual ships, following the methodology described in sub-chapter 2.1. The results are provided with breakdown on 6 ship categories[37], 17 specific ship types and 7 ship size segments based on gross tonnage (GT). This chapter gives an overview of Nordic ship traffic and shows aggregated modelled energy consumption and emissions. In chapter 4 we analyse how the traffic is distributed between the three traffic types: *Nordic domestic*, *intra Nordic* and *Nordic international*.

As currently the fuel mix for Nordic shipping is mostly fossil based (except of the battery electric car ferries operating in domestic routes), the energy estimates presented in this chapter indicate the necessary volumes overall and by ship types to be replaced by carbon neutral fuels if the fuel mix should be fully decarbonized. However, the future energy demand will also depend on developments such as improved energy efficiency, change in seaborne trade, change in ship sizes and speed profiles and logistics performance.

3.1 Activity and voyage statistics, fuel consumption and CO_2 emissions

Throughout the base year of 2019, a total number of some 12 500 unique vessels having an IMO number[38] was observed being inside the Nordic economic zones. This number includes all vessels observed within the geographical area, covering both Nordic ship traffic (voyages to or from Nordic ports) and non-Nordic ship traffic (cf. definitions in chapter 2.1.3).

Approximately 8900 of the identified vessels were involved in voyages defined as Nordic ship traffic (i.e., ships with at least one port call in at least one Nordic country), and thus form the basis of further analysis in this study. The remaining 3600 vessels observed engaged solely in *transit* shipping, meaning they passed through Nordic waters without entering port. The modelled energy demand, fuel consumption and emissions are for the individual ships allocated to voyages, and port calls in the Nordic countries, as described in sub-chapter 2.1.2. The total fuel consumption for the Nordic ship traffic is from the MASTER model estimated to approximately 8.64 Mtoe (millions ton of oil equivalent), adding up to 26.8 Mtonne (million tonnes) of CO_2 emissions[39]. Other works have previously developed AIS-based ship traffic and emission inventories for the whole of or parts of Nordic waters (e.g. Mjelde, Martinsen, & Endresen, 2014; Gells et al., 2021; Schwarzkopf et al., 2021 and Raut et al., 2022). Gells et al. (2021) estimated for the year 2015 a fuel consumption of 9.6 Mtonne and a CO_2 emission of 30.3 Mtonne CO_2. However, with their approach all traffic within Nordic waters as defined by a geographical rectangle is included. Hence, it is not directly comparable to our voyage-based estimates. Furthermore, with a similar approach Schwarzkopf et al. (2021) estimated 44 Mtonnes CO_2 in 2015 for the North Sea and Baltic Sea regions.

Compared to the total global CO_2 emission inventories from shipping of around 1000 Mt CO_2 as reported by the 4th IMO GHG study (Faber et al., 2020)[40], the Nordic ship traffic accounts for almost 3%. In the results presented below, we only provide emission estimates for CO_2 and no other greenhouse gases.

Table 3-1 presents an overview of the Nordic ship traffic with number of ships involved, sailed distances, AIS observed hours, number of voyages identified, fuel/energy consumption and share of CO_2 emissions split on the ship categories. The total energy consumption for the Nordic ship traffic is about 8.6 Mtoe (million tonnes of oil equivalents), equal to

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[36] *Nordic ship traffic* is all ship voyages (trips between two ports) involving at least one Nordic port

[37] Passenger vessel, Cruise vessel, Cargo vessels, Dry and Wet bulk vessels, Work and service vessel and Fishing vessel

[38] IMO ship identification number scheme - IHS Fairplay is the originating source for the IMO Ship Number. The numbers are issued from the global maritime databases maintained by IHS Fairplay and consist of a unique seven digit number. IHS Fairplay manages this scheme on behalf of the IMO.

[39] The main fuel of each ship determines the CO2 factor (kg of CO2 per kg fuel) used. MGO (marine gas oil): 3.206, LNG (liquefied natural gas): 2.75, Residual fuel: 3.114.

[40] IMO: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

about 100 TWh. By number of vessels, more than 50 % of the ships are cargo and bulk ships. The majority of cargo ships is general cargo ships (1979 ships). These categories also dominate fuel consumption and emissions with a total of 54 %, followed by passenger vessels with around one fifth of emissions. However, the 804 passenger ships constitute only 9 % of the total number of ships involved in Nordic ship traffic, still carrying out most of voyages[41]. This is followed by work/service vessels (15 % of emissions), fishing vessels (7 %) and cruise vessels (6 %). More details of the traffic characteristics of the various ship categories will be shown and discussed in chapter 4. Work/service vessels have the highest share of time spent in Nordic traffic, due to the high number of vessels, most of the having a continuous presence in Nordic waters through the year. The same applies for the fishing vessels category, which is observed in Nordic traffic to same degree as the cargo vessels, although this category is almost double in number, compared to fishing vessels.

Table 3-1. Overview of Nordic ship traffic* (2019) with number of ships involved, sailed distances, AIS observed hours, number of voyages identified, fuel consumption and share of CO_2 emissions split on the main ship categories.

Ship category	No of vessels	Sailed distance (mill. nautical miles)	AIS observed time, sailing and in port (mill. hours)	No. of voyages	Fuel consumption (Mtoe/TWh)	Share of CO_2 emissions (%)
Cargo vessels	2584 (29%)	227	8.2	130 200	2.4 / 27.9	28 %
Wet and dry bulk vessels	2160 (24%)	136	4.1	42 300	2.2 / 25.6	26 %
Passenger vessels	804 (9%)	29	6.2	298 600	1.7 / 19.8	19 %
Cruise vessels	155 (2%)	8	0.4	9700	0.5 / 5.8	6 %
Work / service vessels	1972 (22%)	538	10.2	124 200	1.3 / 15.1	15 %
Fishing vessels	1211 (14%)	214	8.2	59 300	0.5 / 5.8	7 %
Totals	**8886 (100%)**	**1152**	**37.3**	**664 300**	**8.6 / 100**	**100 %**

* *Nordic ship traffic* is all ship voyages (trips between two ports) involving at least one Nordic port

Figure 3-1 shows the fuel consumption by ship category (left plot) and by size category (right plot). It should be noted that 60 % of ships are below 5000 GT, while around three fourths of fuel consumption are for ships above 5000 GT (cf. details in Appendix B1). Ships in the largest ship category, ships above 100 000 GT, constitute 1 % of the total number of ships, but the category has almost as high total fuel consumption as the ships below 1000 GT, constituting 29 % of ships.

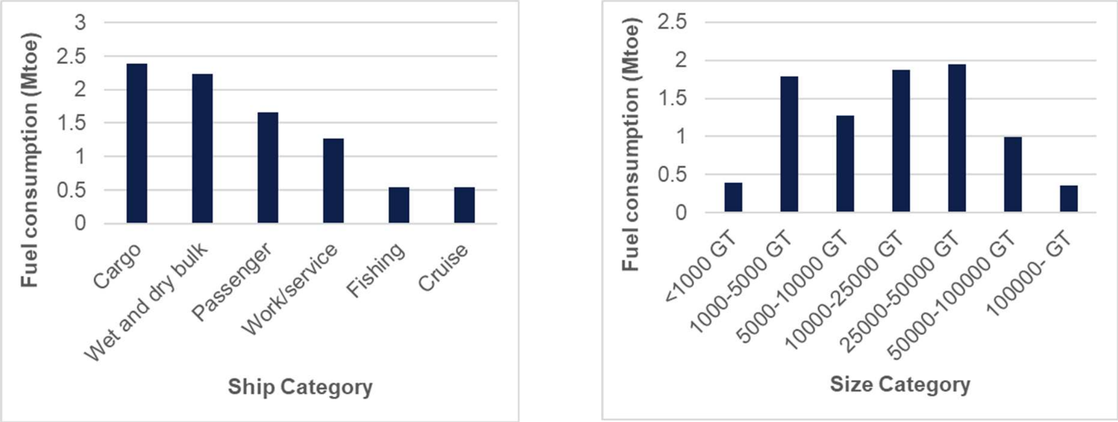

Figure 3-1. Fuel consumption (Mtoe) distributed among ship categories (left) and size categories (right).

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[41] The number of voyages is underestimated for passenger vessels (especially high-speed passenger vessels and small Ro-Pax ferries), due to the time resolution of the AIS data not capturing all port stays with a duration below 10 min.

The six ship categories are subdivided into specific ship types, and the fuel consumption of these is shown in Figure 3-2. The dominating ship type in terms of fuel consumption is Ro-Pax ships (493 unique ships). The high number of general cargo vessels (1979) explains their significant contribution. Ro-Ro ships is relatively low in number of ships (271) – still, the fuel consumption of Ro-Ro ships is around the same as for chemical tankers (786 unique ships). This is due to Ro-Ro ships having a larger share of their operations in Nordic traffic, while chemical tankers have more of their operation outside of the Nordics (more details on the ship's share of fuel consumption in Nordic waters are found in chapter 4)

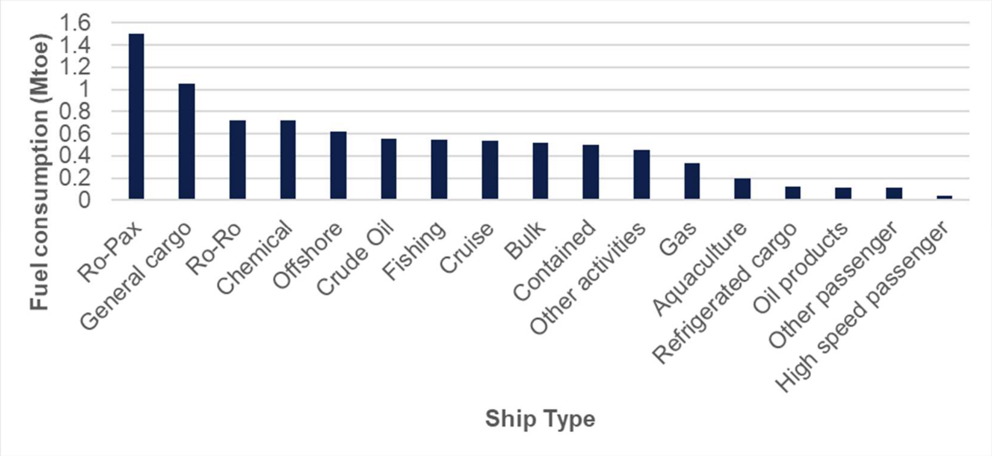

Figure 3-2. Fuel consumption distributed by ship type (the six ship categories subdivided as defined in Table 2-1).

Figure 3-3 presents the seasonal variations of Nordic ship traffic. For passenger ships and especially for cruise ships, there is increased activity both in terms of number of voyages and fuel consumption from May to August/September, while the activity throughout the year is more constant for the other categories.

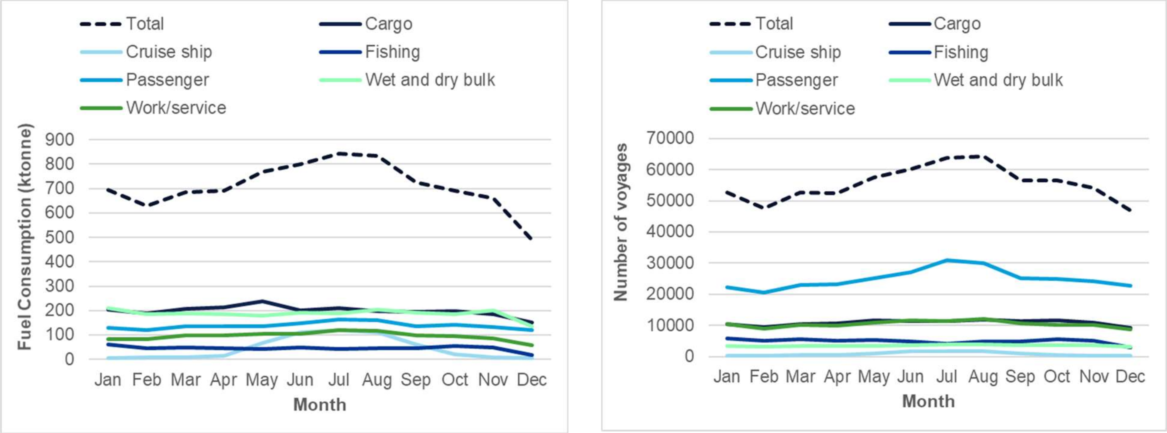

Figure 3-3. Monthly distribution of Nordic ship traffic, given by fuel consumption (left) and number of voyages (right).

3.2 Geographical distribution of AIS modelled fuel consumption

This sub-chapter presents an overview of the main ship traffic patterns for the approximately 8900 vessels that have been identified to sail on Nordic voyages[42] in 2019. The remaining 3600 vessels, sailing through the Nordic waters without having a single Nordic port stop in 2019, are excluded.

The ship traffic patterns include all ship movements for these 8900 vessels (being in Nordic domestic, intra Nordic or Nordic international traffic and when passing through the Nordic waters on some of their voyages), but geographically limited to latitude 53ºN – 90ºN and longitude 75ºW – 35ºE. This area embraces all member countries in the Nordic region and some open sea areas outside or between the respective country economic zones. The geographical distribution of modelled fuel consumption with major shipping routes (fuel density map) and border lines for economic zones is shown in Figure 3-4. It should be noted that density, using fuel consumption as statement of value, will favour tight shipping lanes (i.e. traffic separation schemes or narrow shipping lanes) and large ships operating at high speed (large fuel consumers). There are also seasonally variations in the traffic patterns, which are not reflected in the figure but was briefly addressed in the previous chapter.

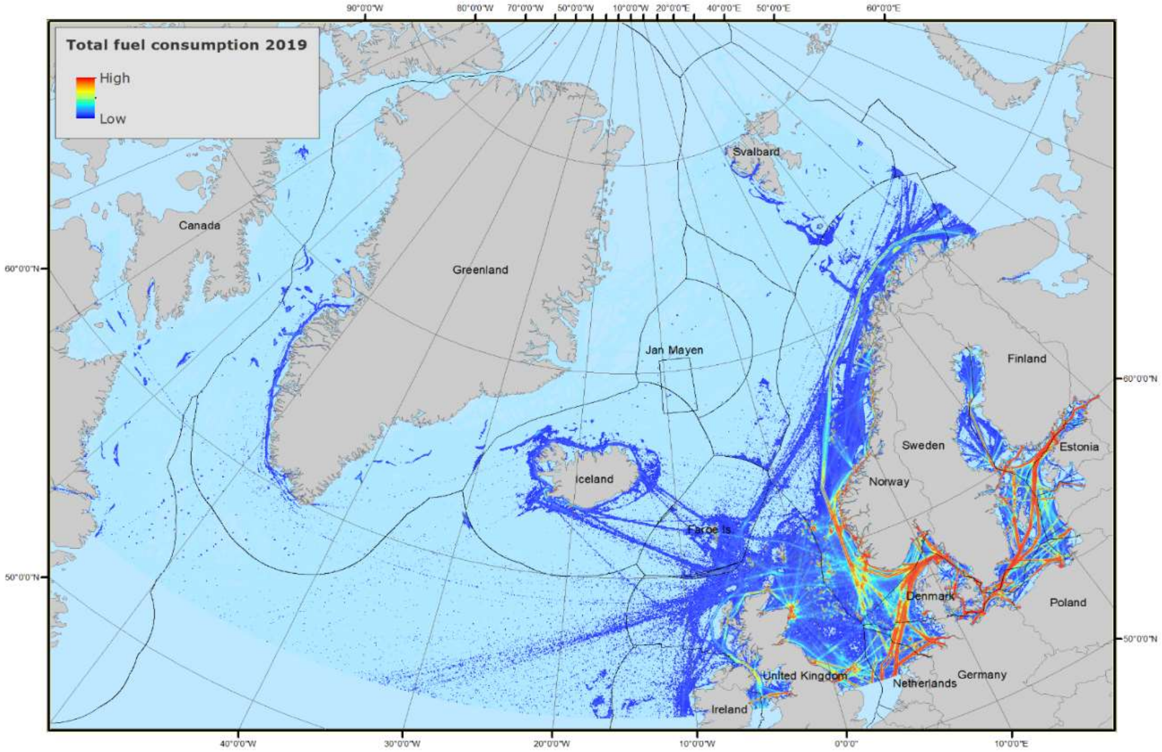

Figure 3-4. Ship traffic in the region, comprising all traffic for ships that have been involved in Nordic ship traffic (voyages involving at least one Nordic port) during 2019. Colouring indicates fuel consumption density at the given geographical location and the thin black lines shows the economic zones of each country.

The figure shows that the high-density areas of ship traffic, with appurtenant fuel consumption and emissions, are situated in the southern part of Norway, around Denmark and in various trading routes in the Baltic Sea. The major shipping route to and from the Nordic waters goes through the English Channel, with multiple port locations in Norway,

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[42] This means ships that have had at least one port call in a Nordic port during 2019, i.e. have at least one voyage defined as *Nordic ship traffic* in this analysis

Denmark, Sweden, and Finland. Ship traffic to European ports, Baltic countries and Russia is also highly visible. The 2019 statistic from Eurostat[43] on total goods handled (gross weight) in all ports by Nordic countries shows that Norway dominates by total gods handled in the Nordic countries, followed by Sweden and Finland. The Eurostat figures split on inwards and outwards gods shows that Norway also dominates on the outwards transport of gods, almost twice compared to Sweden. For the inwards transport of goods Sweden dominates followed by Norway. A country-by-country description of Nordic ship traffic can be found in Appendix B6.

A more detailed geographical distribution of the AIS-based modelled fuel consumption in the high population density areas North Sea, in Kattegat, and the Baltic Sea the is shown in Figure 3-5.

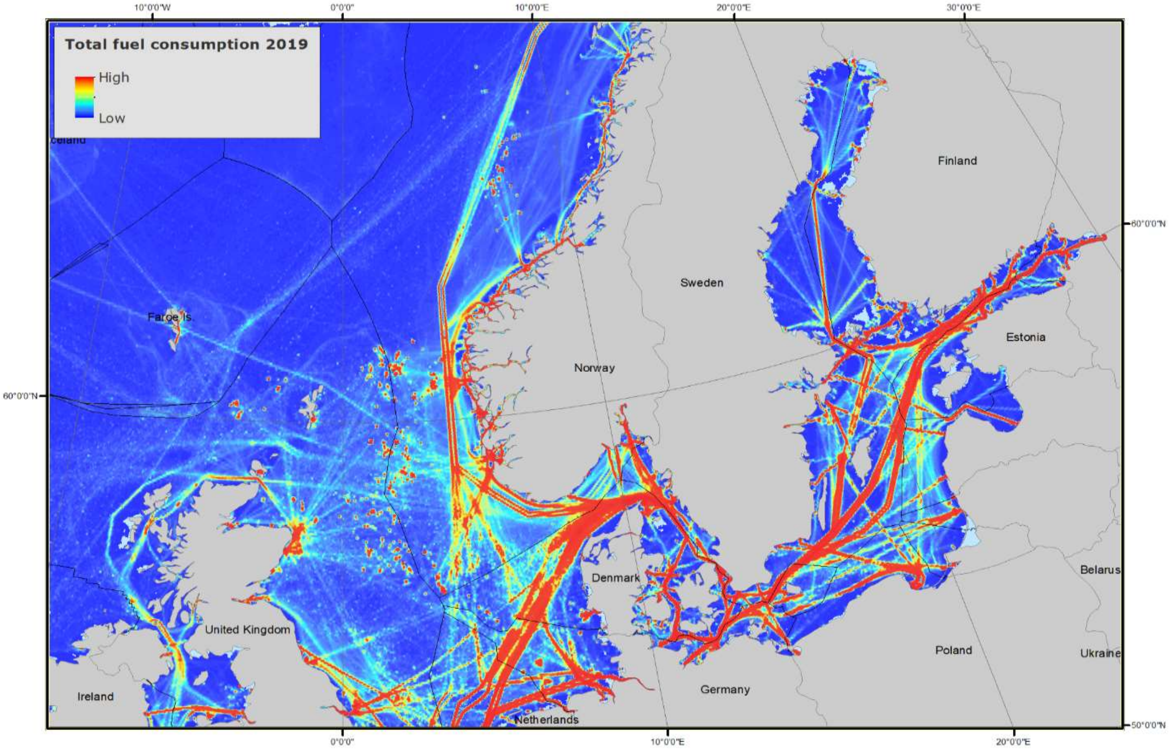

Figure 3-5. Traffic patterns for all vessels in the North Sea, in Kattegat, and the Baltic Sea – 2019. Colouring indicates fuel consumption density at the given geographical location.

The following sub-chapters provides density maps for the six ship categories. Although we include traffic in all Nordic countries, including Greenland, in our analysis, some of the maps show only selected regions (where most of the traffic is found). It is referred to Appendix A for more maps, also showing fuel consumption density split between size segments for each ship category.

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[43] Eurostat: Country level - gross weight of goods handled in all ports, by direction, https://ec.europa.eu/eurostat/databrowser/view/MAR_MG_AA_CWHD__custom_3176053/settings_1/table?lang=en
https://ec.europa.eu/eurostat/web/transport/data/database

3.2.1 Passenger vessels

An overview of the ship traffic patterns for all passenger vessels is shown in Figure 3-6. The figure shows that the passenger vessels mainly operate in costal traffic patterns in Norway and in routes in the Baltic Sea. The passenger segment consists in vessels typically operating in scheduled traffic between two or a few port locations. There are passenger vessels operating on multiple port destinations, but such ships are a minority. Most of the passenger ships is Ro-Pax ships. The fuel consumption for all passenger vessels operating in Nordic ship traffic represents about 19 % of the totals, as presented in Table 3-1. The fuel consumption distributed by size is 13% (< 5000 GT), 8% (5000-10000 GT), 19% (10000-25000 GT), 50% (25000-50000 GT) and 10% (50000-100000 GT).

Figure 3-6. Traffic patterns for all passenger vessels – 2019. Colouring indicates fuel consumption density at the given geographical location.

3.2.2 Cruise vessels

An overview of the ship traffic patterns for all cruise vessels are shown in Figure 3-7. The figure shows that the cruise vessels has concentrated traffic patterns in the Baltic Sea and in the southern part of Norway. Major cruise ports within this high traffic areas are Helsinki (Finland), Mariehamn (Åland), Stockholm (Sweden), Copenhagen (Denmark) and Oslo, Stavanger, Bergen, Ålesund, Trondheim and fjords in Norway. The cruise traffic is also observed along the entire Norwegian coastline, on long haul voyages between the Nordic countries and on Nordic-international voyages as the cruise vessels comes into or leave the Nordic port destinations. The cruise vessels have some of the operations in relative remote areas, such as Svalbard, around Iceland and along the coast of Greenland. It should be noted that the cruise season is restricted, with high season being in the summer months, as shown in sub-chapter 3.1 (see Figure 3-3). The fuel consumption for all cruise vessels operating in Nordic ship traffic represents about 6% of the totals as presented in Table 3-1. The fuel consumption for cruise vessels distributed by size is 1% (<5000 GT), 4% (5000-10000 GT), 13% (10000-25000 GT), 18% (25000-50000 GT), 35% (50000-100000) and 29% (>100000 GT).

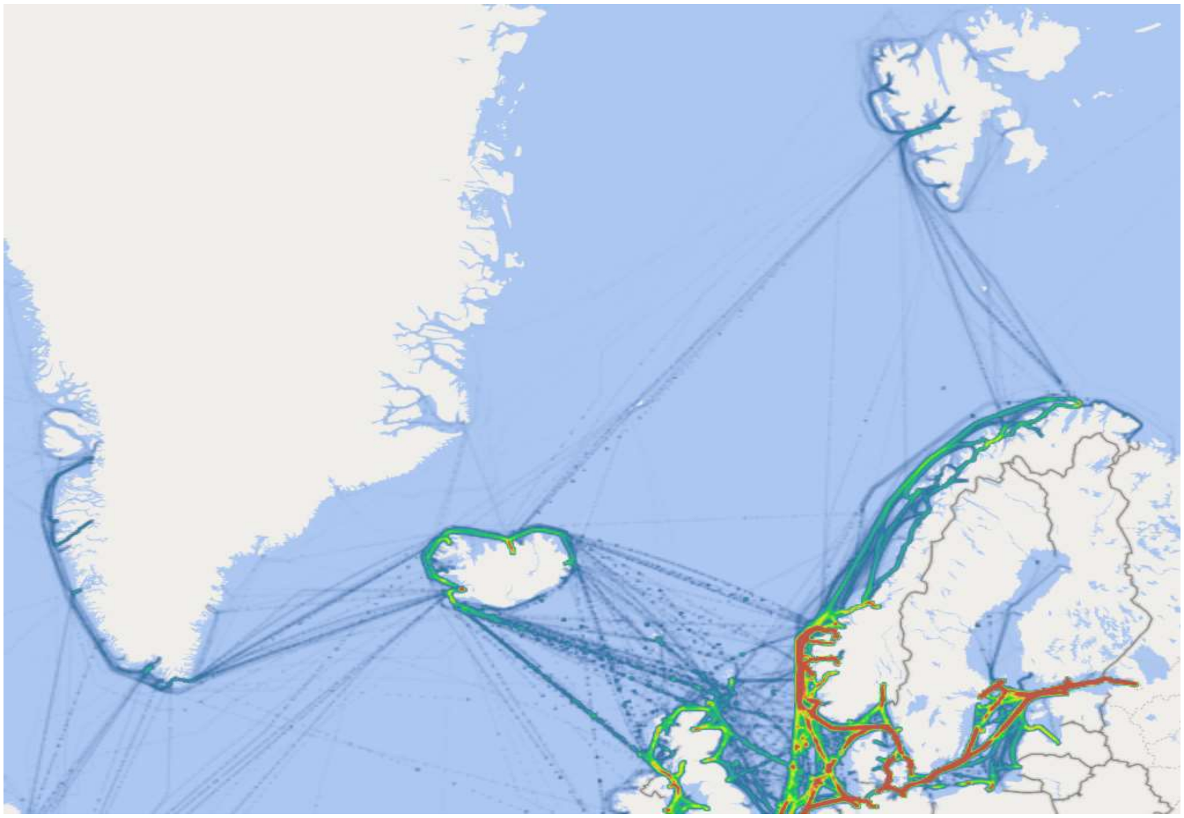

Figure 3-7. Traffic patterns for all cruise vessels – 2019. Colouring indicates fuel consumption density at the given geographical location.

3.2.3 Cargo vessels

An overview of the ship traffic patterns for all cargo vessels are shown in Figure 3-8. The figure shows that the cargo traffic is concentrated in the southern part of Norway, into the Baltic and along the coast of Sweden and Finland with several clearly defined port destinations. Along the Norwegian coast the shipping routes follow the coastline with multiple port locations. Identifiable cargo shipping routes to Faro Islands, Island, and distinguishable routes to and within Greenland are also observed. The fuel consumption for all cargo vessels operating in Nordic ship traffic represents about 28 % of the totals, as presented in Table 3-1. The fuel consumption distributed by size is 25% (<5000 GT), 21% (5000-10000 GT), 31% (10000-25000 GT), 20% (25000-50000 GT), 1% (50000-100000) and 2% (>100000 GT).

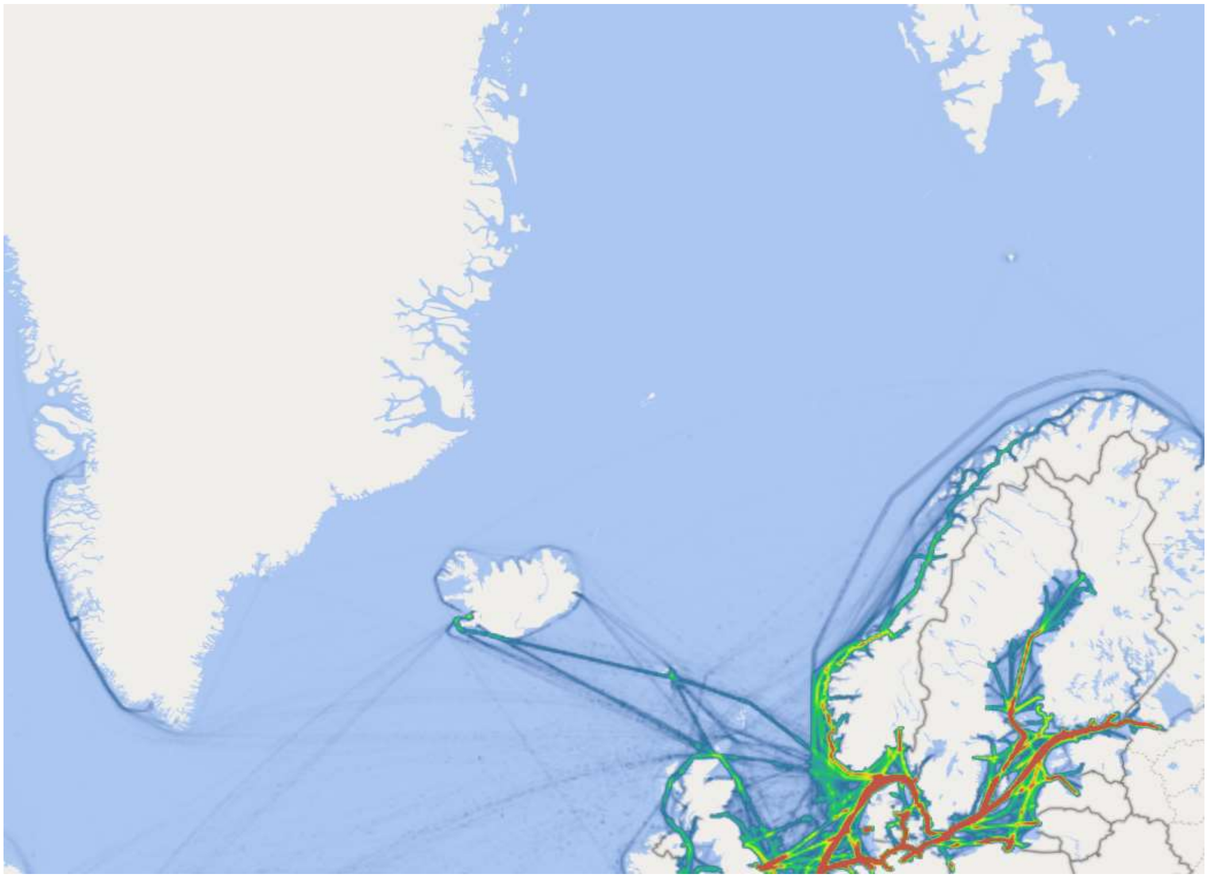

Figure 3-8. Traffic patterns for all cargo vessels – 2019. Colouring indicates fuel consumption density at the given geographical location.

3.2.4 Wet and dry bulk vessels

An overview of the ship traffic patterns for all dry and wet bulk vessels is shown in Figure 3-9. The figure shows that the bulk vessels traffic is concentrated in the southern part of Norway, around Denmark into the Baltic and along the coast of Sweden and Finland with several clearly defined port destinations. The fuel consumption for all dry and wet bulk vessels operating in Nordic ship traffic represents about 26 % of the totals, as presented in Table 3-1. The fuel consumption distributed by size is 11% (<5000 GT), 11% (5000-10000 GT), 26% (10000-25000 GT), 20% (25000-50000 GT), 26% (50000-100000) and 6% (>100000 GT).

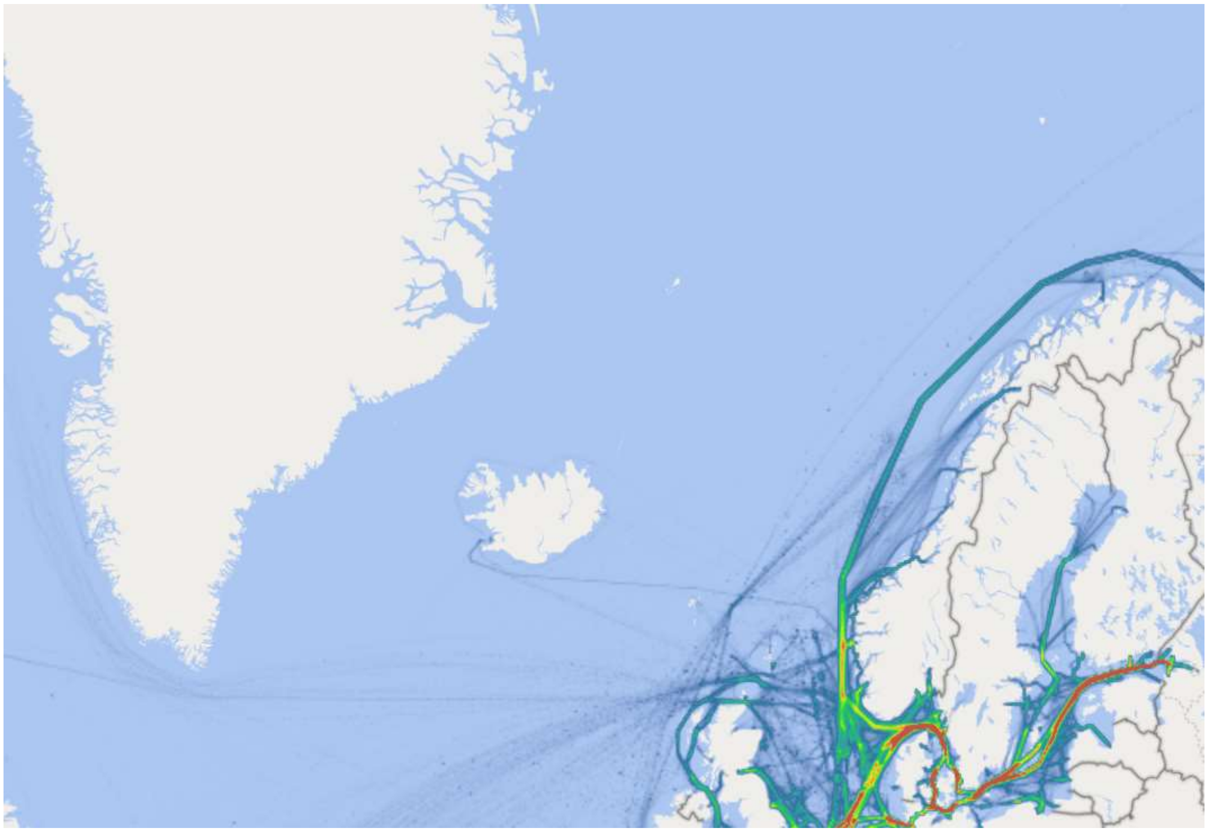

Figure 3-9. Traffic patterns for all wet and dry bulk vessels – 2019. Colouring indicates fuel consumption density at the given geographical location.

3.2.5 Work and service vessels

An overview of the ship traffic patterns for all work and service vessels is shown in Figure 3-10. The figure shows that the ship traffic for work and service vessels is concentrated in the southern part of Norway, the North Sea and along the Norwegian coast. Offshore vessels being a significant contributor to fuel consumption in this segment operates from a few central port locations. The fuel consumption for all work and service vessels operating in Nordic ship traffic represents about 15% of the totals, as presented in Table 3-1. The fuel consumption distributed by size is 47% (<5000 GT), 29% (5000-10000 GT), 13% (10000-25000 GT), 6% (25000-50000 GT), 2% (50000-100000) and 3% (>100000 GT).

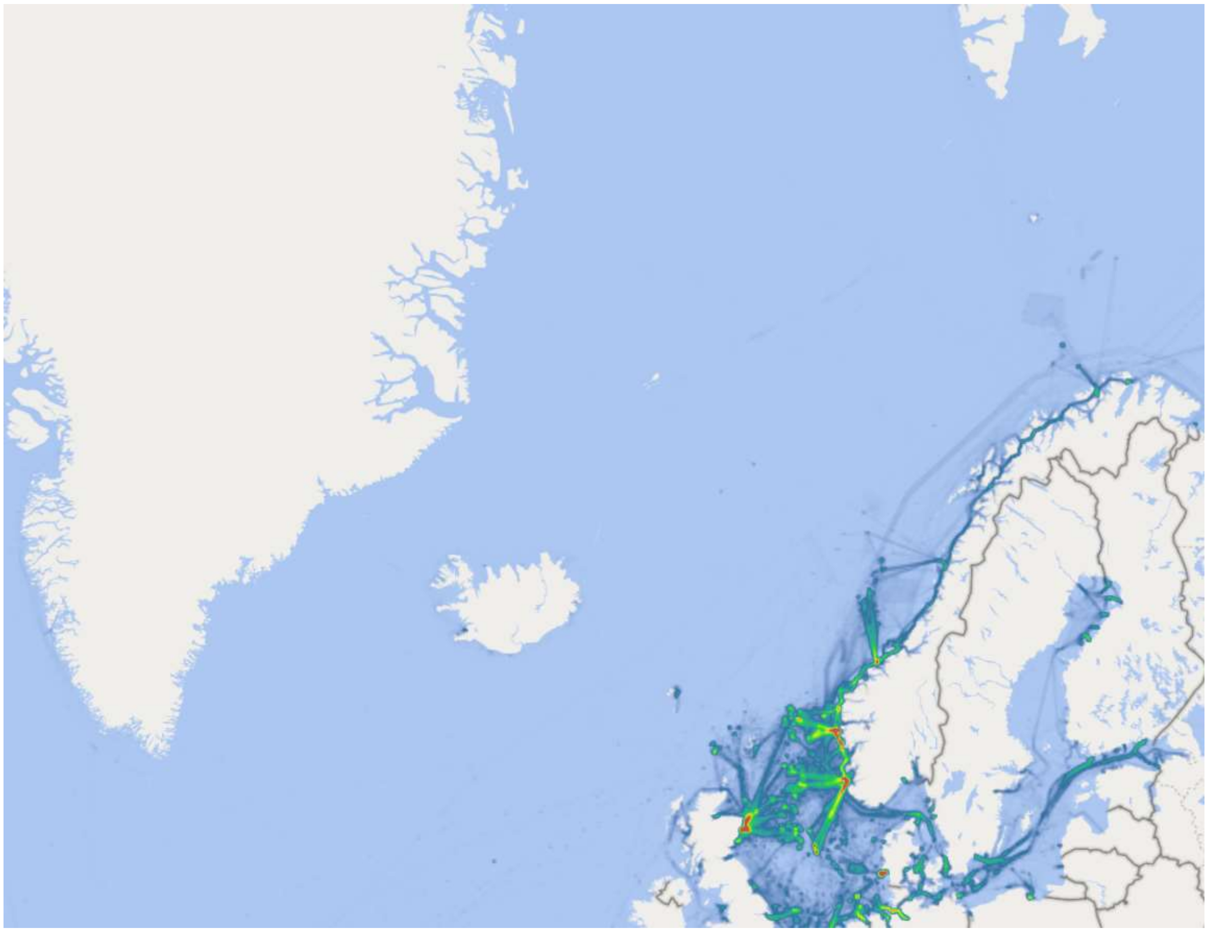

Figure 3-10. Traffic patterns for all work and service vessels – 2019. Colouring indicates fuel consumption density at the given geographical location.

3.2.6 Fishing vessels

An overview of the ship traffic patterns for all fishing vessels are shown in Figure 3-11. Most fishing activities are identified as Nordic domestic ship traffic (83%). The fuel consumption for all identified fishing vessels operating in Nordic ship traffic represents about 15 % of the totals as presented in sub-chapter 3.1. The fuel consumption distributed by size is 30% (<1000 GT), 69% (1000-5000 GT) and 1% (5000-10000 GT).

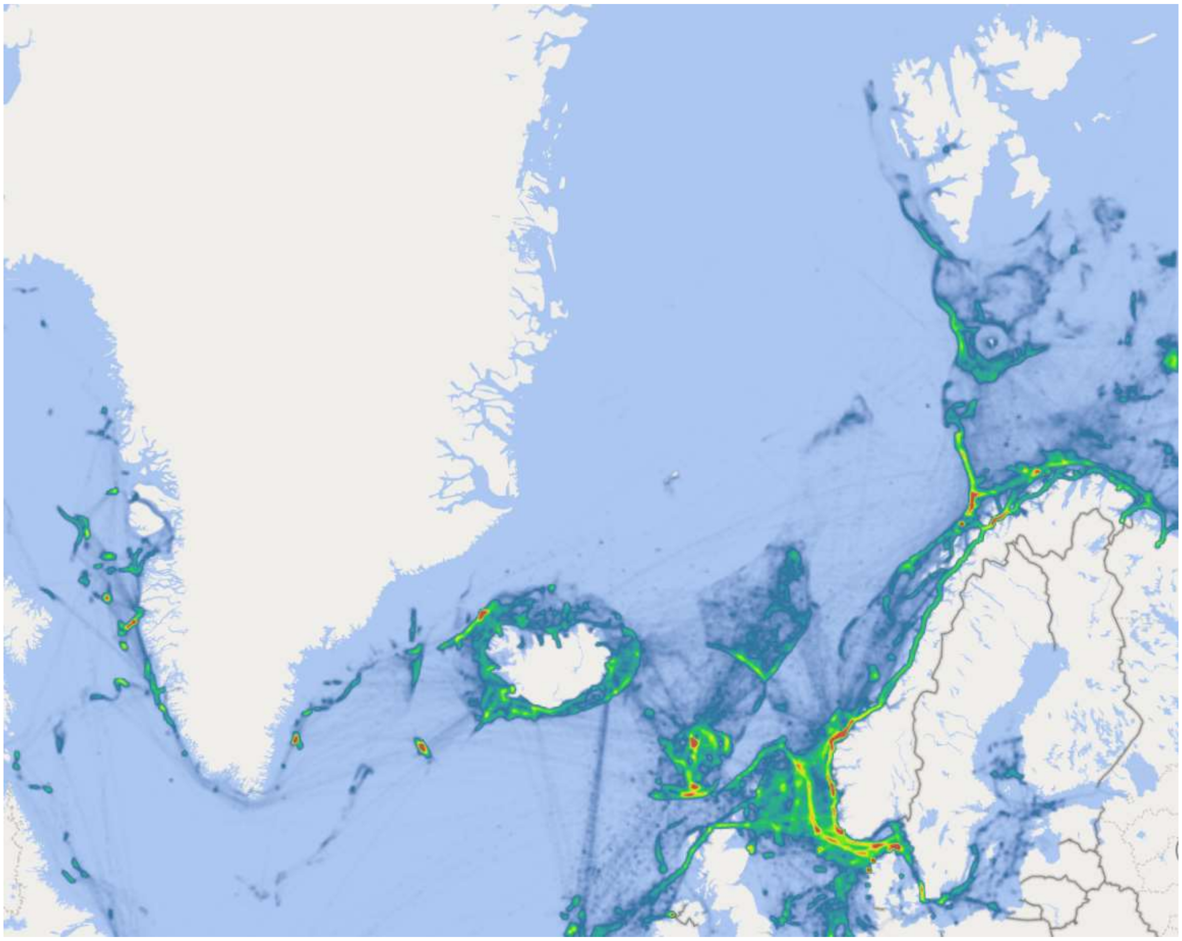

Figure 3-11. Traffic patterns for all fishing vessels – 2019. Colouring indicates fuel consumption density at the given geographical location.

4 DETAILED ANALYSIS OF NORDIC SHIP TRAFFIC

With year 2019 as reference year, this chapter prevents a high-level analysis of the geographic distribution of Nordic ship traffic and energy demand. The analysis provides results from AIS-based modelling for some 8900 vessels that have been active Nordic ship traffic,[44] dividing into *domestic*, *intra Nordic*, and *Nordic International* traffic. For each traffic type, results are provided with breakdown on 6 superior ship categories[45], 17 specific ship types and 7 ship size segments based on gross tonnage (as described in chapter 2).

Sub-chapter 4.1 provides an overview of the distribution between the three traffic types and discusses the energy demand from the various ship types. Sub-chapter 4.2 presents the feasibility assessment of sustainable zero-emissions fuels for the three traffic types. Based on the findings within each traffic type in sub-chapter 4.1, selected ship segments evaluated as suitable for initial green corridors is further investigated in sub-chapter 4.3. The investigation focusses on intra Nordic ship traffic types, but also addresses key trends within domestic and Nordic international ship traffic. Additional information can be found in Appendix A and Appendix B.

4.1 Three traffic types

In chapter 3 we estimated the overall fuel consumption for Nordic ship traffic to 8.6 mill. tonnes. A breakdown of the overall fuel consumption for Nordic shipping by the defined traffic types is shown in Figure 4-1. The figure shows that the voyages belonging to Nordic international ship traffic dominates representing 58% of the totals for Nordic shipping activities, followed by Domestic Nordic (32%) and Intra Nordic (10%). Some of the reason for the high share on international ship traffic is that this includes relatively large vessels involved in long haul international voyages. As addressed in sub-chapter 2.1.3, the calculated fuel consumption for Nordic ship traffic is based the *entire voyage* to, from or in-between Nordic ports. However, most of the Nordic International traffic and energy demand is for trips to Northern Europe, as will be shown in sub-chapter 4.1.3.

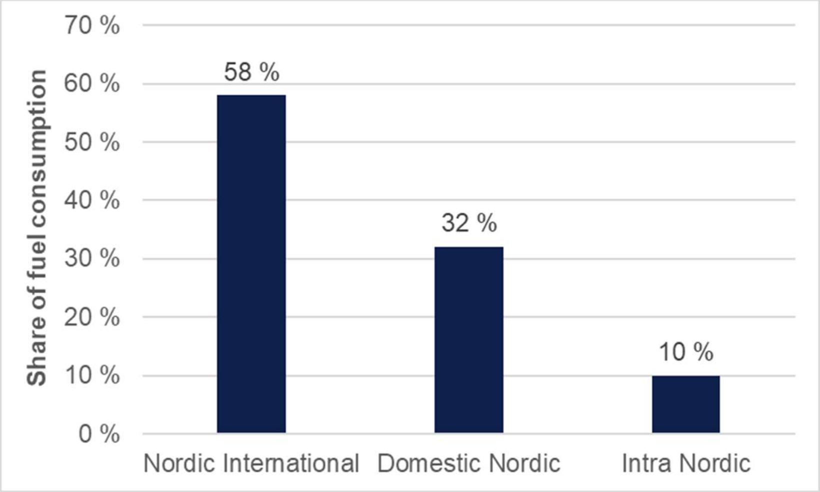

Figure 4-1. Distribution of fuel consumption between Nordic ship traffic types.

The breakdown on fuel consumption per ship traffic type, distributed on the six ship categories as illustrated in Figure 4-2 (left). Cargo and wet and dry bulk vessels are responsible for approximately 50% of the total Nordic fuel consumption. The figure shows that the cargo carrying ships dominates for the international Nordic ship traffic, followed

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[44] *Nordic ship traffic* is all ship voyages (trips between two ports) involving at least one Nordic port

[45] Passenger vessels, Cruise vessels, Cargo vessels, Wet and dry bulk vessels, Work and service vessels, and Fishing vessels

by wet and dry bulk. The Intra Nordic ship traffic are dominated by passenger vessels followed by cargo carrying vessels. The domestic ship traffic is dominated by work/service vessels followed by passenger vessels.

Considering the fuel consumption by the defined size categories in Figure 4-2 (right), we find that the smallest size categories dominate by domestic Nordic, while international Nordic gradually dominates for the increasing ships size categories.

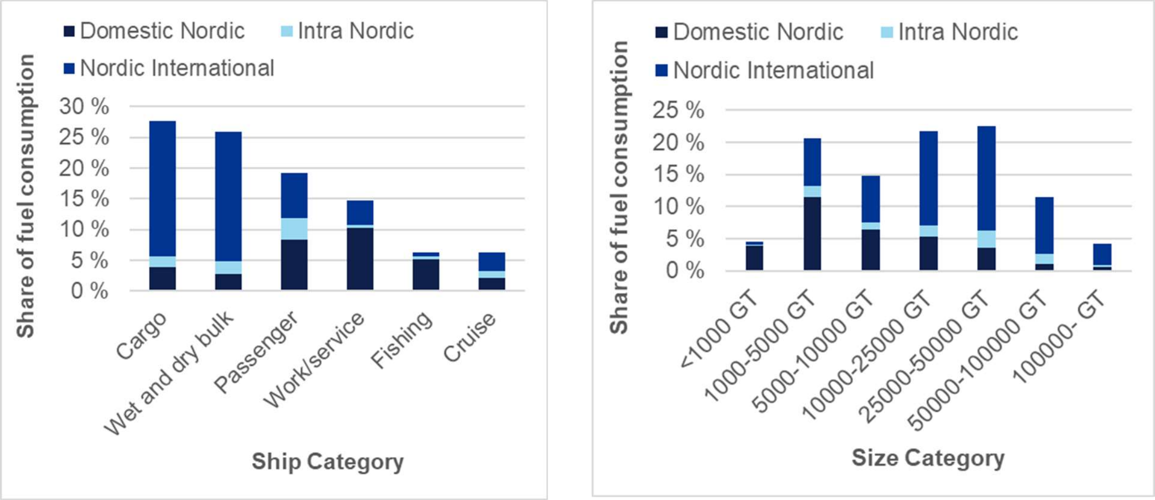
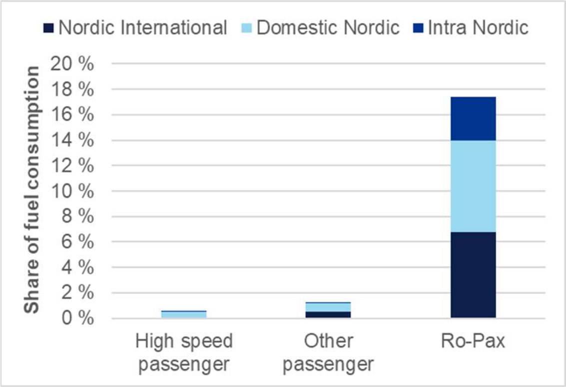


Figure 4-2. Fuel consumption share per traffic type, distributed among ship categories (left) and size categories (right).

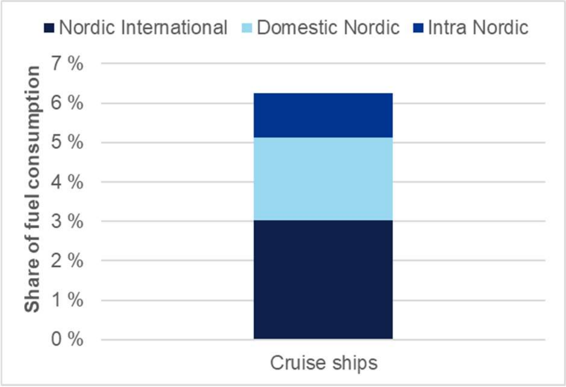
The breakdown on fuel consumption per ship traffic type, distributed on the 17 ship types, is illustrated in Figure 4-3. The results show large variations in the fuel consumption for the 17 ship types, where the highest share of fuel consumption is for Ro-Pax vessels, followed by general cargo ships and chemical tankers. The Ro-Pax vessels have a significant share of the fuel consumption linked to Nordic domestic and Intra Nordic ship traffic.

We can analyse how “Nordic” a ship’s overall operation is by looking at how much of the ship’s total fuel consumption is related to Nordic traffic, i.e. how “bound” the ship is to Nordic traffic. This can be useful information to assess the potential of “Nordic-specific” actions for decarbonization, and in what ship categories such actions may have the most effect. Nordic specific actions will have less of an impact for ships that have much of their trade in non-Nordic waters. Passenger ships is the category which to the highest degree is bound to Nordic trade; almost all energy consumption for passenger ships is for ships that spend close to all their time in the Nordics. Also, for work/service ships and fishing vessels, a dominating share of energy consumption are for location-bound ships. For cargo and especially wet and dry bulk and cruise, the situation is the opposite: Most of the energy consumption for these ship categories is related to ships having a lower share of their total activity in Nordic traffic. More details can be found in Appendix B5.

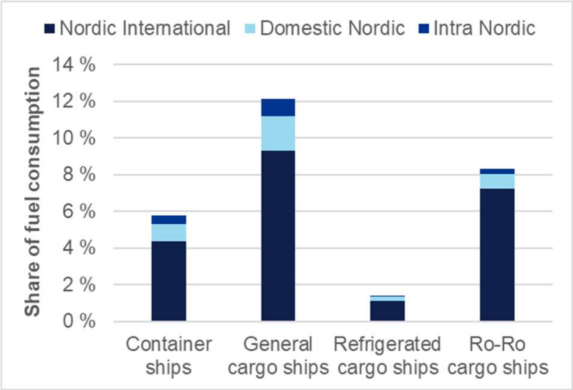
Passenger



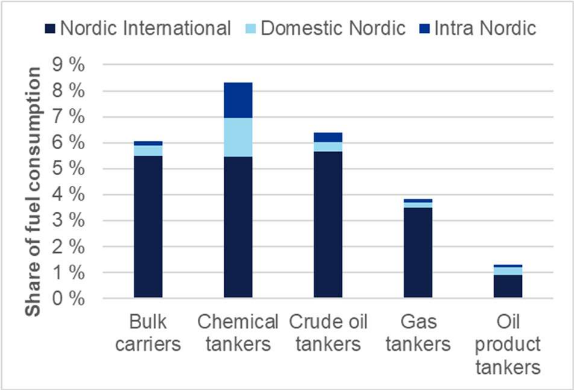
Cruise



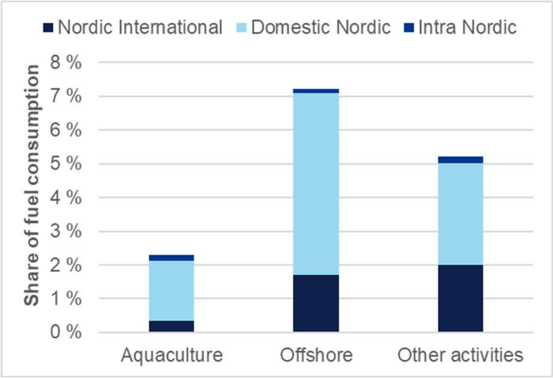
Cargo



Wet and dry bulk



Work/service



Fishing

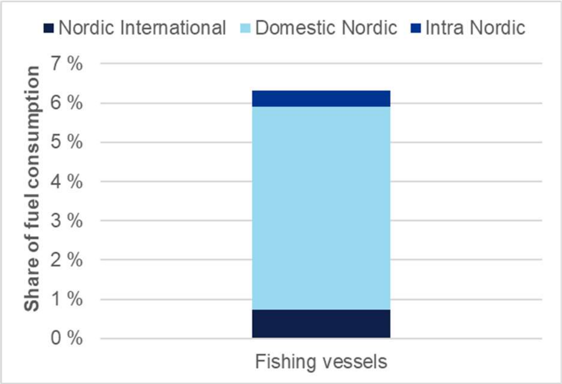


Figure 4-3. Share of Nordic ship traffic total fuel consumption for each traffic type and ship type (note different scales on the vertical axes).

4.1.1 Intra Nordic ship traffic

This sub-chapter presents a deep dive into the intra Nordic ship traffic. Table 4-1 presents an overview of intra Nordic ship traffic in 2019. Intra Nordic voyages accounts for 10% of the total fuel consumption in the Nordic ship traffic. A total of 2648 vessels sailed intra Nordic in 2019, where of 45% of the vessels belonged to the cargo segment. However, the

75 passenger vessels operating intra Nordic accounts for the largest share (38%) of fuel consumption and CO_2 emissions, followed by wet and dry bulk vessels (23%) and cargo vessels (18%). 121 cruise ships with a total of 1449 voyages sailed in the Nordic in 2019, accounting for 12% of intra Nordic CO_2 emissions. However, the cruise traffic is unregular and AIS data from one year only may give misleading information. Some work/service and fishing vessels operates intra Nordic, responsible for 5% and 4% of the intra Nordic CO_2 emissions from fuel consumption, respectively.

Table 4-1. Overview of intra Nordic ship traffic (2019) with number of ships involved, number of voyages identified, fuel consumption and share of CO2 emissions split on the main ship categories.

Ship category	No of vessels	No. of voyages	Fuel consumption (Mtoe)	Share of CO_2 emissions (%)
Cargo vessels	1196 (45%)	9857	0.15	18 %
Wet and dry bulk vessels	600 (23%)	5643	0.19	23 %
Passenger vessels	75 (3%)	15553	0.31	38 %
Cruise ships	121 (5%)	1449	0.10	12 %
Work / service vessels	367 (14%)	2077	0.04	5 %
Fishing vessels	281 (11%)	1527	0.035	4 %
Totals	**2648 (100%)**	**36109**	**0.82**	**100 %**

Figure 4-4 shows the distribution of fuel consumption by ship category and size segment for intra Nordic ship traffic. Passenger vessels in the size range of 10 000 – 50 000 GT dominates, followed by cargo vessels and wet and dry bulk vessels of 1000 – 25 000 GT. Passenger vessels, cargo vessels and wet and dry bulk vessels stand out as the most interesting ship types for intra Nordic voyages, representing close to 80% of the intra Nordic fuel consumption. Voyages and routes for these ship types will be further investigated in sub-chapter 4.2 and sub-chapter 4.3.

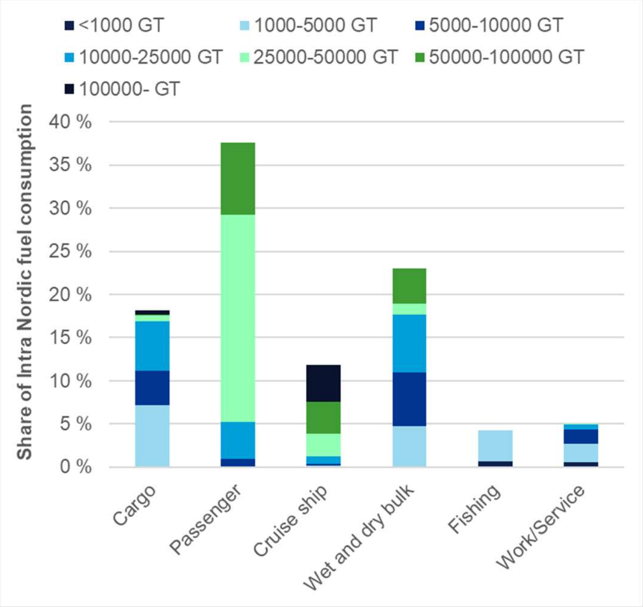


Figure 4-4. Distribution of intra Nordic energy consumption by skip category and size segments.

The detailed voyage connections of intra Nordic traffic are analyzed in order to assess the dominating voyages between regions and ports. Figure 4-5 presents the overall regional flow of intra Nordic ship traffic (all ship categories), based on fuel consumption. Denmark east, Finland south, and Sweden east are the regions with highest fuel consumption, which each account for 16-19% of the total intra Nordic fuel consumption. From Denmark west, the high fuel consumption is mainly due to voyages to Norway east-south, Norway west, and Sweden west-south. However, the voyages between Sweden east and Finland south is the regional connection with the highest fuel consumption, corresponding to 104 000 tonnes of fuel in 2019. Further details on the distribution of energy consumption for all voyages from and to countries and regions can be found in Appendix B3.

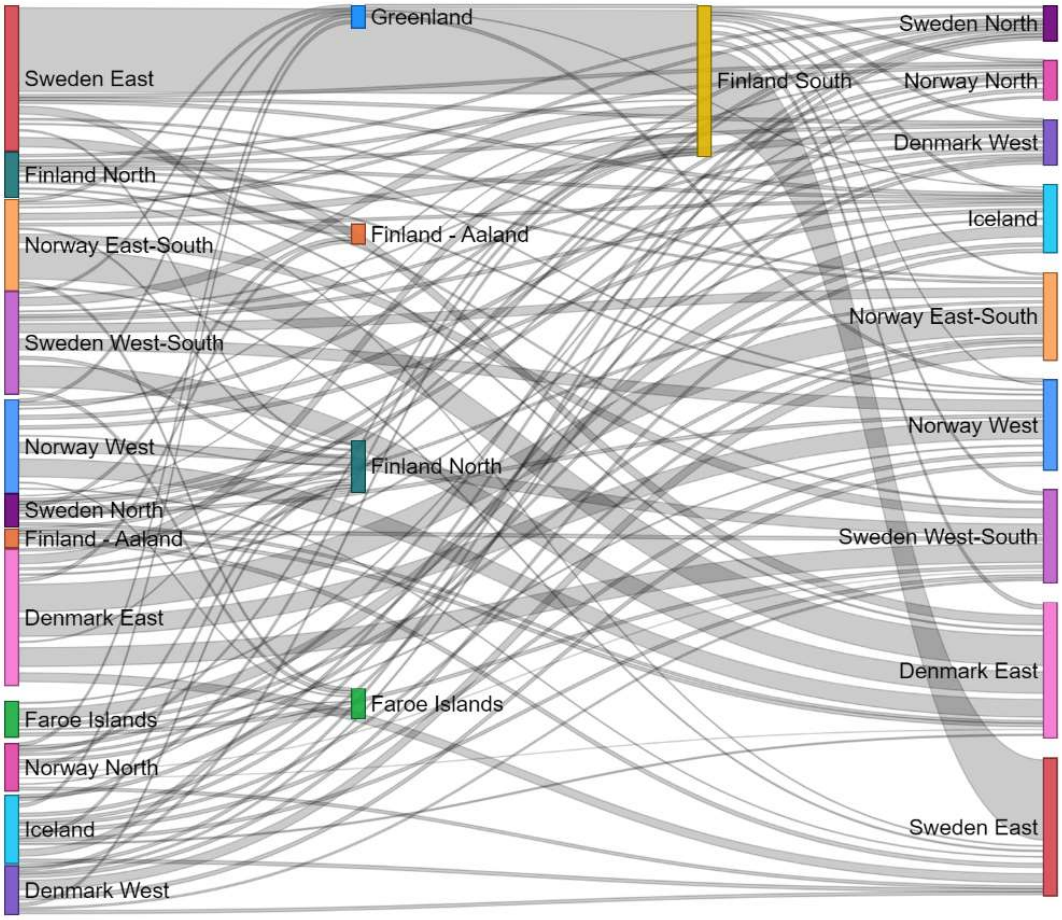


Figure 4-5. Illustration of regional intra Nordic ship traffic. The width of lines represents the relative weight of fuel consumption in region connected voyages, and the width of the coloured boxes represents the weight of fuel consumption of all voyages from (left) and to (right) the respective regions. Greenland, Finland – Aaland, Finland North, Finland South and the Faroe Island are placed in the middle, showing flow of fuel consumption both in (from left) and out (right) of the region.

4.1.2 Domestic Nordic traffic

A total of 6216 vessels are included in the Nordic domestic traffic from 2019, and domestic traffic accounts for 32% of fuel consumption related to Nordic ship traffic (total of 8.6 Mt). Most domestic traffic goes in and out from the same port. This is especially due to the high fraction of fishing and work/service ships in the domestic traffic. Table 4-2 show an overview of Nordic domestic ship traffic. There is approximately the same number of cargo and work/service vessels operating in domestic ship traffic. However, the work/service vessels account for 32 % of the CO_2 emissions from domestic traffic, twice the amount compared to cargo vessels (12 %). This can be explained by the operational pattern of work/service vessels (aquaculture, offshore or other activities), that often are related to energy-requiring operations with high fuel consumption. The number of passenger vessels operating domestic are less than half of the number of cargo vessel, but still accounts for 24 % of the total fuel consumption from domestic ship traffic.

Table 4-2. Overview of Domestic Nordic ship traffic (2019) with number of ships involved, number of voyages identified, fuel consumption and share of CO2 emissions split on the main ship categories.

Ship category	No of vessels	No. of voyages	Fuel consumption (Mtoe)	Share of CO_2 emissions (%)
Cargo vessels	1684 (27%)	68374	0.33	12 %
Wet and dry bulk vessels	741 (12%)	19349	0.24	8 %
Passenger vessels	775 (13%)	258518	0.72	24 %
Cruise ships	145 (2%)	5910	0.18	7 %
Work / service vessels	1666 (27%)	117299	0.88	32 %
Fishing vessels	1128 (18%)	55342	0.45	17 %
Totals	**6216**	**528375**	**2.80**	**(100 %)**

Illustration of domestic traffic between regions in Nordic countries is shown in Figure 4-6. The width of each line scales with the fuel consumption for voyages between the different regions. Domestic traffic in Norway is dominating and particular at the west coast (“Norway West”), with a share of around 37% of the total domestic Nordic fuel consumption. This is followed by Norway north and Denmark west with approximately 17% and 10%, respectively. We also find that the other Nordic countries, including Greenland, has contributions, but they all have significantly lower share than Norway. Further details on the distribution of energy consumption for all voyages from and to countries and regions can be found in Appendix B6.

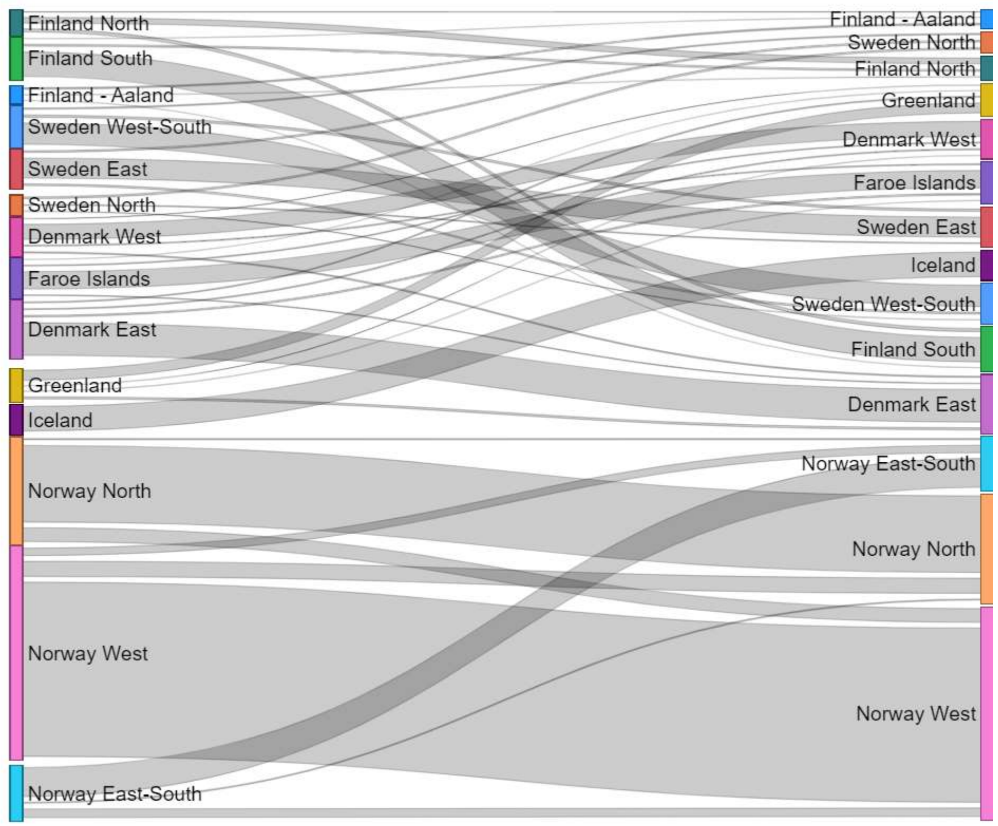


Figure 4-6. Illustration of domestic traffic between regions in Nordic countries. The width of each line scales with the fuel consumption for voyages between the different regions.

A breakdown on ship categories of domestic fuel consumption on voyages from regions is found in Figure 4-7Figure 4-7. The figure shows that the fuel consumption from domestic ship traffic is dominated by work/service (aquaculture, offshore and other activities), fishing and passenger vessels. Norway, both in the north and west, has it largest contribution from fishing, passenger vessels (ferries) and offshore vessels. In Denmark, passenger vessel voyages constitute the highest energy consumption in the east, and work/service vessels in the west. Passenger vessels do also dominate in Sweden (both east and west south). Iceland has a major share of fishing vessels. Fishing do also dominate in the Faroe Islands, which also have some work/service activities.

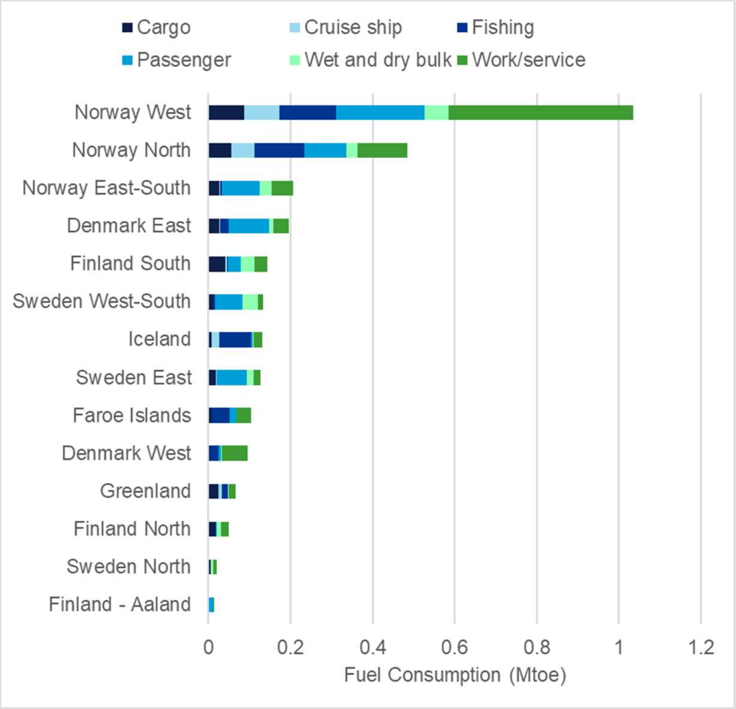


Figure 4-7. Total fuel consumption for domestic voyages sailing from regions, distributed by ship categories.

4.1.3 Nordic International ship traffic

A total of 7462 vessels had registered voyages between Nordic and non-Nordic countries in 2019. The dominating international traffic to and from the Nordic countries is short sea traffic to and from Europe, with a total share of 76 % of international voyage energy consumption. Voyages between Nordic regions and north-west Europe account for approximately 54% of the total fuel consumption, and voyages between Nordic countries and the Baltic countries account for 9%. Voyages between Nordic countries and countries outside of Europe – i.e., traffic that can be denoted as *deep-sea*[46] – are accountable for 24% of the total *Nordic international* traffic energy consumption.

Table 4-3. Overview of Nordic International ship traffic (2019) with number of ships involved, number of voyages identified, fuel consumption and share of CO2 emissions split on the main ship categories.

Ship category	No of vessels	No. of voyages	Fuel consumption (Mtoe/TWh)	Share of CO_2 emissions (%)
Cargo vessels	2509 (34%)	51980	1.90	38 %
Wet and dry bulk vessels	2138 (29%)	17347	1.82	36 %
Passenger vessels	393 (5%)	24569	0.63	12 %
Cruise ships	148 (2%)	2319	0.26	5 %
Work / service vessels	1510 (20%	5626	0.35	7 %
Fishing vessels	713 (10%)	2399	0.06	1 %
Totals	**7462 (100%)**	**104394**	**5.02**	**100 %**

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[46] Deep sea shipping refers to the maritime transport of goods on intercontinental routes, crossing oceans.

Figure 4-8 shows the regional distribution of fuel consumption for Nordic International ship traffic. The largest share of traffic is between north-west Europe and Nordic regions, mainly west-south Sweden, south Finland and west Norway. The distribution of energy consumption of Nordic international voyages energy consumption per region and ship category is shown in Figure 4-9. Voyages to/from the Nordic to/from the north-west Europe is dominated by cargo vessels (including cargo and wet and dry bulk), in addition to some passenger and cruise ships. Finland south is the Nordic region with highest fuel consumption for Nordic International ship traffic. The region is dominated by cargo vessels, as well as some passenger and wet and dry bulk vessels. Norway west has the second highest fuel consumption in this traffic category, dominated by wet and dry bulk vessels, in addition to some cargo and work/service vessels (mainly offshore). Sweden west-south has contributions from both cargo, wet and dry bulk, and passenger vessels. There are also some international traffic connections from the Nordic to the Baltics, mainly by passenger vessels and some cargo vessels. In addition, there are some cargo and wet and dry bulk connections to North America, Russia, Asia and South America. Further details on the distribution of energy consumption for all voyages from and to countries and regions can be found in Appendix B.

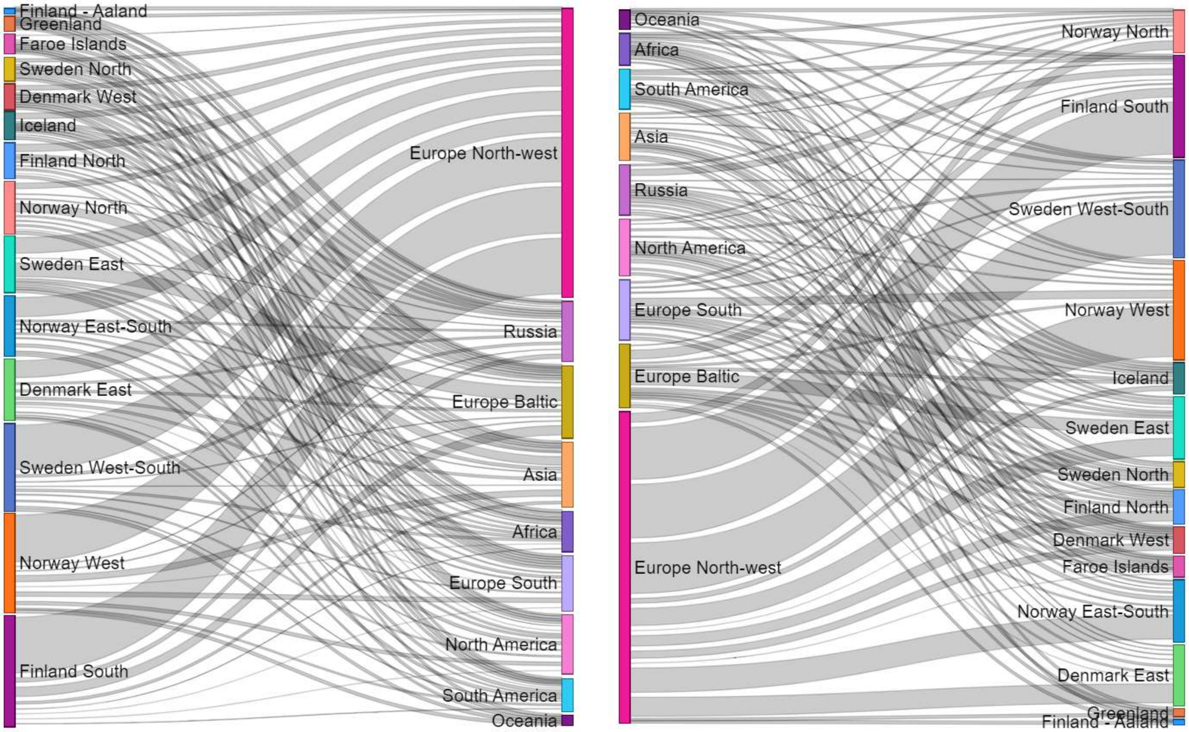

Figure 4-8. Illustration of domestic traffic between Nordic regions and non-Nordic regions (Nordic international traffic). The width of each line scales with the fuel consumption for voyages between the different regions. Left: voyages starting in the Nordics, right: voyages ending in the Nordics.

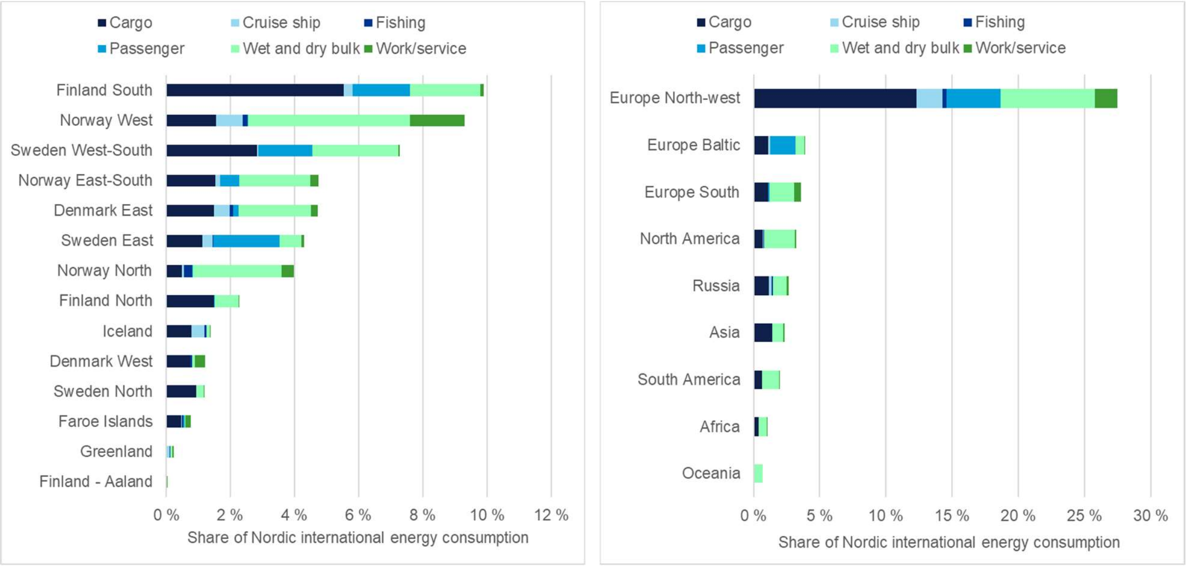

Figure 4-9. Total fuel consumption by voyage start region and ship category, Nordic international ship traffic (left: starts in Nordic; right: ends in Nordic).

4.2 Feasibility of sustainable zero-carbon fuels

The energy density of zero-emission fuels is lower compared to conventional fuels, hence more frequent bunkering is required. This chapter presents the feasibility assessment of sustainable zero-emissions fuels for the three traffic types.

Our method for feasibility screening described in sub-chapter 2.3 depends on estimated energy consumption per dimensioning voyage for single ships in the current fleet. This relies on sailing distance, speed and power need of the various voyages, compared to ship size and tonnage. Figure 4-10 shows distribution of sailing distances of voyages within each traffic type. For reference, some straight-line distances are showed on the map of the Nordic and north European region in Figure 4-11. This should not be confused with sailing distances, which are considerably longer. Although domestic traffic overall has the shortest sailing distances, almost 20 % of domestic fuel consumption are from voyages longer than 1000 nm. 25 % are 100-250 nm. Many intra Nordic routes are relatively short, and 25 % of intra Nordic fuel consumption are for voyages of distances 100-250 nm. For Nordic international traffic, around 45 % of fuel consumption is for distances above 1000 nm, while also a fair share are relatively short voyages below 500 nm. Many Nordic locations have relatively short distance to North Europe, which is the destination for most of the traffic.

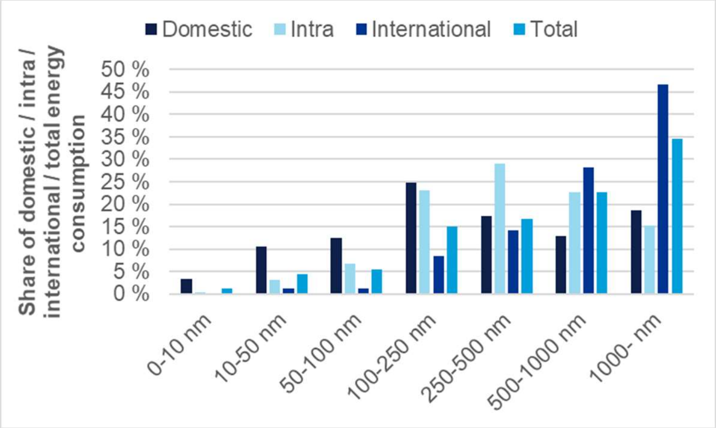

Figure 4-10. Share of fuel consumption within domestic, intra and Nordic international voyages, distributed by voyage distance.

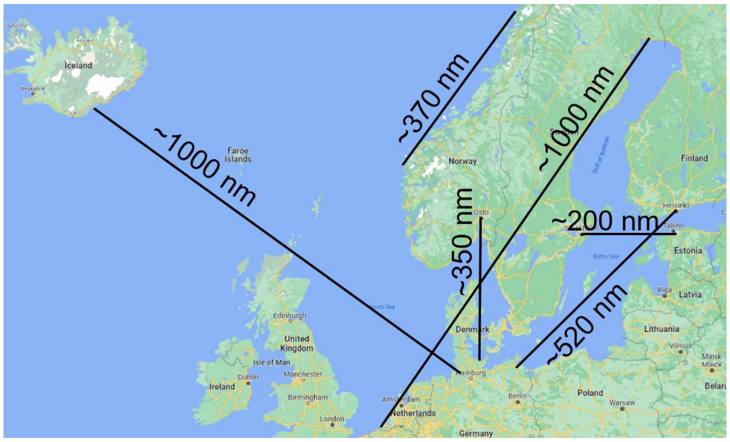

Figure 4-11. Examples of straight-line distances in the Nordic region (not to be confused with travel distance of ship routes).

We do screening for *fully electric battery* operation, *compressed hydrogen gas* and *methanol*, denoting three levels of energy density of the fuel and fuel storage systems (low, medium and long range respectively). These represent three feasibility “levels”, ordered by increasing energy storage density and thus increasing degree of feasibility. They are also significantly different in terms of the fueling rate, represented by charging power, hydrogen filling or container swapping rate and methanol (liquid fuel) bunkering rate, although bunkering aspects are not evaluated as a feasibility criteria. The energy density of ammonia is lower than but close to that of methanol, and ammonia feasibility would hence be similar to that of methanol, from an energy density point of view. Furthermore, liquefied methane (LNG) (fossil, bio or synthetic) has an energy density similar to methanol and hence similar feasibility from an energy density point of view. Methanol, ammonia and liquefied methane are considered typical “long range” fuels, relevant also for deep sea routes. Liquid biofuel (e.g. hydrotreated vegetable oil) is equivalent to conventional diesel/fuel oil in terms of energy density, and compatible with conventional onboard fuel tanks and supply systems.

Figure 4-12 shows the results of the feasibility analysis, as percentages of energy consumption of the ships within each ship category found feasible at the three feasibility levels. The total for the overall fleet is given in Table 4-4.

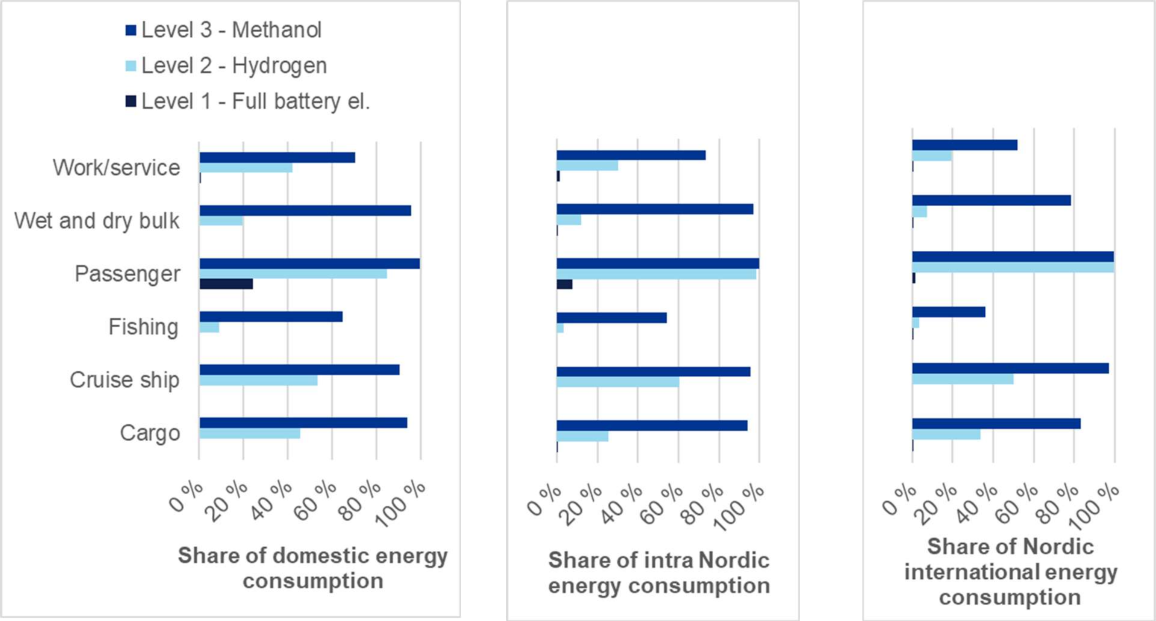

Figure 4-12. Percentages of energy consumption of the ships within each ship category found feasible with the different alternatives.

Table 4-4. Percentage of traffic for which fuels are technically feasible per traffic type and total.

Traffic type	Battery electrification	Compressed hydrogen gas	Methanol
Domestic Nordic	7 %	47 %	83 %
Intra Nordic	3 %	53 %	94 %
Nordic International	~0 %	32 %	82 %
Total	**3 %**	**39 %**	**83 %**

Battery electrification (level 1) is found to be feasible primarily for domestic passenger ship traffic, but also to some degree for intra Nordic passenger routes. The feasibility within other ship categories is very limited. Future improvements in e.g. energy density of batteries may increase the feasibility potential of battery-electric ships. It should be noted that this refers to full battery electrification, not hybrid solutions which are feasible and relevant to reduce energy consumption and emissions for most ships and while operating in port.

The feasibility of compressed hydrogen (Level 2) is quite substantial for several ship categories, in particular passenger vessels. Feasibility is most limited for bulk and fishing. Although the energy density of hydrogen is low, there is potential also for intra Nordic and Nordic international routes, which are short sea routes to North Europe.

The long-range fuels (level 3) are to a large extent applicable for all categories. However, the limitation of feasibility for methanol (level 3) is especially clear for fishing vessels, dominated by smaller ships with limited carrying capacity, sometimes irregular sailing distances and typically long time at sea. In this segment, there presently exists few vessels with alternative fuel technology. A few LNG trawlers have been built, and this has been solved by building the ships larger than if they were conventional.[47]

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[47] https://www.fiskeribladet.no/bater/sigurd-teiges-gassbat-sunny-lady-narmer-seg-ferdig-se-video-av-baten-pa-provetur/2-1-1275580

The screening analysis is a very high-level analysis meant to illustrate a theoretical maximum potential of alternative fuel technology based on current trade and ship activity pattern (sailing speed and distances as identified from AIS data) and current ship sizes. The finding that the feasibility of Level 3 does not reach an overall 100 % reflects the fact that there may be a need for change in sailing patterns, ship sizes, operational speed, energy efficiency etc. to accommodate for the use of alternative low energy density fuels in certain parts of the fleet.

Other approaches to assess feasibility or technical potential may be used. In an analysis of US ship traffic (UMAS, 2022), it was for example assessed that 19 % of US ship traffic energy demand could be covered by battery electric ships. This was based on assuming that small vessels with mean voyage less than 100 nautical miles can be battery electric. Ship types with such characteristics were in this analysis among others found to be Ro-Ro ships up to 5000 DWT, as well as all offshore and fishing vessels. This contradicts our analysis for the Nordic ship traffic. In a Nordic context, for example the two latter types, are ships with too high energy consumption and long voyage ranges to be found feasible for battery electric operation. If all Nordic voyages below 100 nm were to be battery electric in our analysis, this would add up to 11 % of the total energy consumption. As another approach, a study by VTI (2021) rather applies 100 km as a distance limit for electrification, assumed representative for current battery technology. By using the energy consumption per dimensioning voyage, our approach takes both distance and speed into account.

Furthermore, the effect on potential of future cost reduction and increasing energy density for maritime batteries has also been analysed in a recent paper (Kersey, 2022), where it was assessed that even interregional *container* shipping of sailing distances of thousands of kilometres could be battery electric and cost competitive to fossil fuels, in a pathway where 40 % of global containership traffic is electrified within this decade. This relies on significantly lower battery investment costs than today and increasing energy density.[48] Such scenarios might be quite specific for container ships, where a share of the cargo containers is replaced by battery containers.[49] The battery size of such large battery electric containerships – up to 1000s of MWh – are considerably larger than today's largest maritime battery systems of around 10 MWh. Challenges related also to build up necessary charging capacity in port. Today, not all ports are able to provide shore-based power, enabling vessels to plug in to the onshore electricity grid when in port.[50]

At last, Table 4-5 shows the feasibility screening results, distributed by the Nordic regions defined in sub-chapter 2.1.3. We find that battery electrification is to the highest degree feasible in regions where a relatively high share is coastal traffic. The same applies to a certain degree for compressed hydrogen.

Table 4-5. Share of energy consumption at different ship fuel feasibility levels, for ship traffic from the defined Nordic regions.

Region	Level 1 - Battery electrification feasible	Level 2 - Compressed hydrogen feasible	Level 3 - Methanol feasible
Denmark East	4 %	36 %	88 %
Denmark West	1 %	40 %	76 %
Faroe Islands	1 %	16 %	73 %
Finland - Aaland	34 %	95 %	100 %
Finland North	1 %	10 %	80 %
Finland South	2 %	51 %	91 %
Greenland	2 %	16 %	63 %
Iceland	2 %	17 %	81 %
Norway East-South	1 %	48 %	82 %
Norway North	6 %	34 %	73 %
Norway West	6 %	40 %	84 %

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[48] In general, maritime batteries have a significantly higher investment cost per kWh than electric vehicle batteries, among other factors due to additional safety and control systems. When it comes to energy density (battery energy per mass and volume), our values are based on stated values of large battery systems today https://corvusenergy.com/products/energy-storage-solutions/corvus-blue-whale/

[49] COSCO Shipping will for example build two 700 TEU container ships to trade on the Yangtze, each with 50 MWh battery containers.

[50] DNV's *Alternative Fuels Insight* portal includes an overview of shore power installations shown in map.

It should be noted that the feasibility results do not tell if ship owners will actually prefer e.g. compressed hydrogen over ammonia or methanol, which depends on other aspects such as availability, safety aspects, design and cost considerations and allowed bunkering time. There exist plans for ships on compressed hydrogen sailing e.g. between Norway and Northern continental Europe, as well as ammonia or methanol ships travelling similar routes.

4.3 Candidates for potential green shipping corridors

In this sub-chapter, we further analyse parts of Nordic ship traffic that are relevant as *potential Nordic green shipping corridors*. As was seen in Figure 4-2, the major contributors to energy consumption in Nordic ship traffic *apart from domestic traffic*, are

- *Intra Nordic passenger* ship traffic
- *Nordic international passenger* ship traffic
- *Nordic international and intra Nordic cargo* ship traffic
- *Nordic international and intra Nordic bulk* ship traffic

Here, we therefore dig further into these four. The results will be used as a baseline for the identification of potential intra Nordic and Nordic International green shipping corridors in chapter 5. Domestic traffic is not investigated further, as this is less of a focus point in the Nordic roadmap. However, the realization of such corridors may have spin-off effects for the domestic traffic as well, as discussed in chapter 5.

4.3.1 Intra Nordic passenger traffic

Passenger vessels are the ship type with highest contribution to CO_2 emissions for intra Nordic ship traffic. Ro-Pax vessels in the size of 25 000 – 100 000 GT are responsible for the large share, as seen in Figure 4-13. *High speed passenger* is a ship type solely trading on domestic routes, not having any intra Nordic voyages.[51] The ship type *Other passenger* has only a small contribution to intra Nordic, and do not sail on regular routes. We therefore focus on Ro-Pax ship traffic in the further. Figure 4-14 shows the flow of energy consumption for intra Nordic Ro-Pax vessels, which illustrates that the highest consumption of these vessels is in voyages between Sweden east and Finland south. There are also some voyage connections from Norway east-south to Denmark east with high fuel consumption. A longlist of potential intra Nordic Ro-Pax corridors is included in chapter 5.

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[51] *High speed passenger* in this respect is a ship with service speed above 25 knots, *carrying passengers only*. Some Ro-Pax ships also have a service speed above 25 knots, but these also carries cars/vehicles.

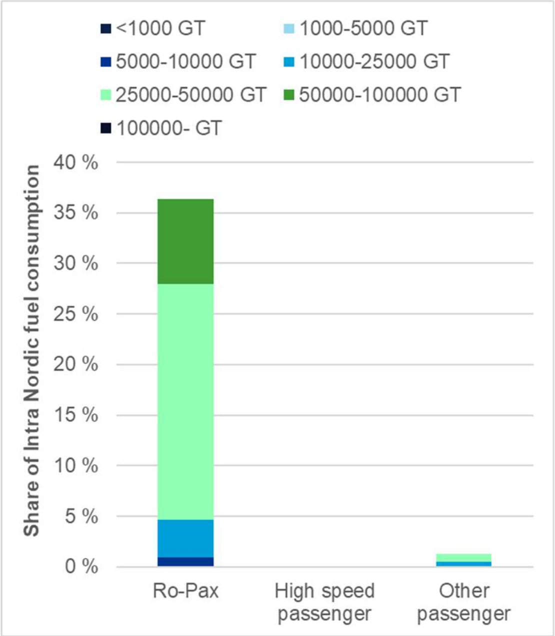


Figure 4-13. Distribution of energy demand/fuel consumption and size segments for intra Nordic voyages for passenger vessels.

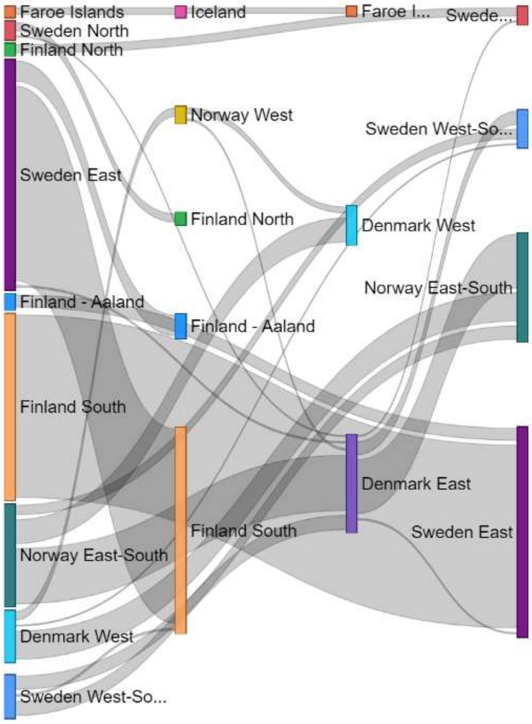


Figure 4-14. Illustration of intra Nordic traffic for Ro-Pax vessels. The width of each line scales with the fuel consumption for voyages between the different regions.

4.3.2 Nordic International passenger traffic

As seen in sub-chapter 4.1.3, passenger vessels were the ones that dominated the direct voyages with highest fuel consumption (also seen in the list of top 20 Nordic International voyage connections in Appendix B4). Ro-Pax vessels in the size of 10 000 – 100 000 GT are responsible for close to 12% of the total fuel consumption in Nordic International ship traffic, as seen in Figure 4-15. Figure 4-16 shows the flow of energy consumption for Nordic International Ro-Pax vessels, which illustrates that the highest fuel consumption is due to voyages between Nordic regions and North-West Europe or the Baltic. A longlist of potential Nordic international Ro-Pax corridors is included in chapter 5.

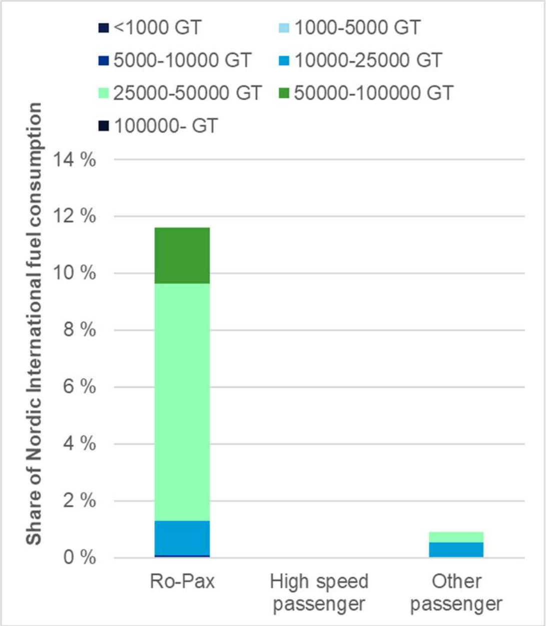


Figure 4-15. Share of fuel consumption per size segment for Nordic international voyages for passenger vessels.

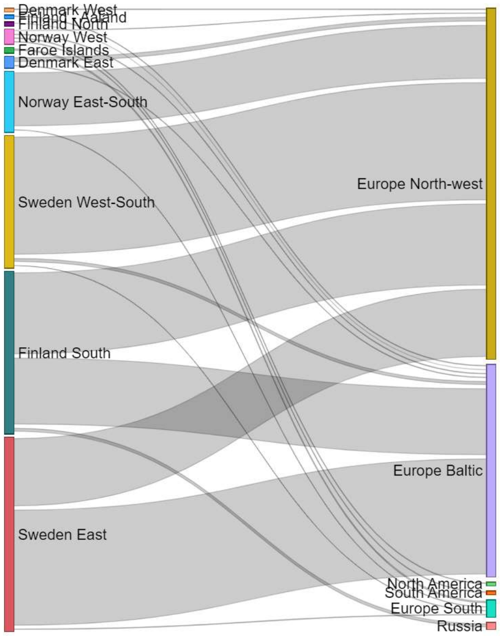


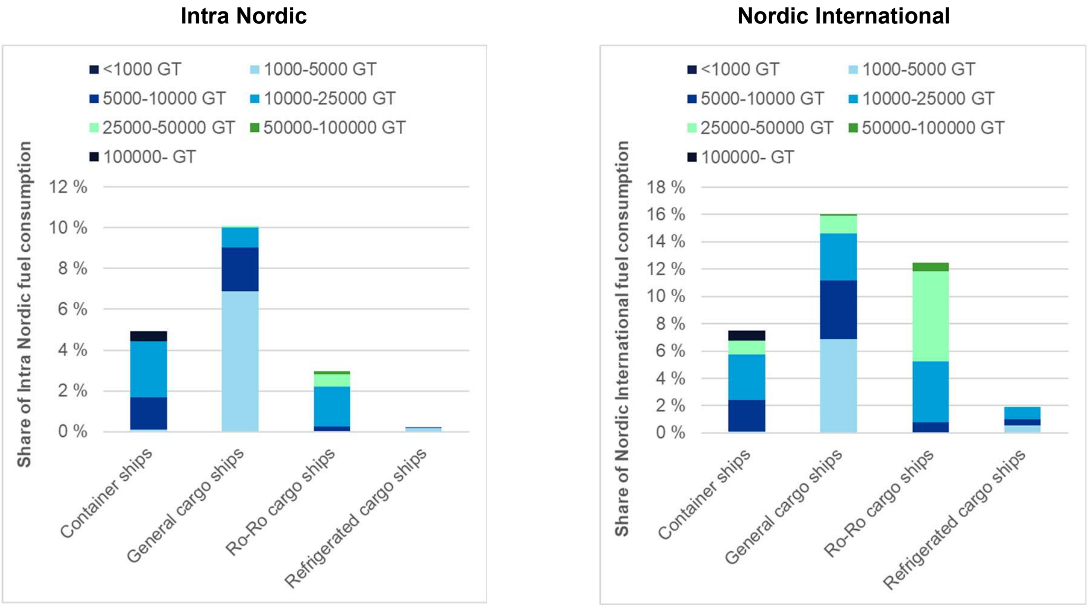
Figure 4-16. Illustration of Nordic international Ro-Pax vessel voyages, with start region in the Nordic. The width of each line scales with the fuel consumption for voyages between the different regions.

4.3.3 Intra Nordic and Nordic International cargo traffic

Figure 4-17 shows that the cargo segment in intra Nordic and Nordic International ship traffic includes both container ships, general cargo ships and Ro-Ro cargo ships. The intra Nordic traffic is dominated by general cargo ships in the range of 1000-10 000 GT, while general cargo of 1000-50 000 GT and Ro-Ro cargo of 10 000-25 000 GT dominates the Nordic international ship traffic.

Figure 4-18 illustrates the regional intra Nordic and Nordic international voyage connections for cargo vessels. Intra Nordic cargo has a large share of fuel consumed from vessels operating out of Denmark East and Sweden West-south, as well as Iceland, Finland South and Norway East-South. For Nordic International traffic, most cargo voyages go to the North-West Europe and the Baltics. Finland South and Sweden West-South have the largest contribution of fuel consumption for Nordic international cargo connections.

A longlist of potential cargo corridors is included in chapter 5.


Intra Nordic

Nordic International

Figure 4-17. Share of fuel consumption per size segment for intra Nordic voyages (left) and Nordic international voyages (right) for cargo vessel types (note different vertical axes).

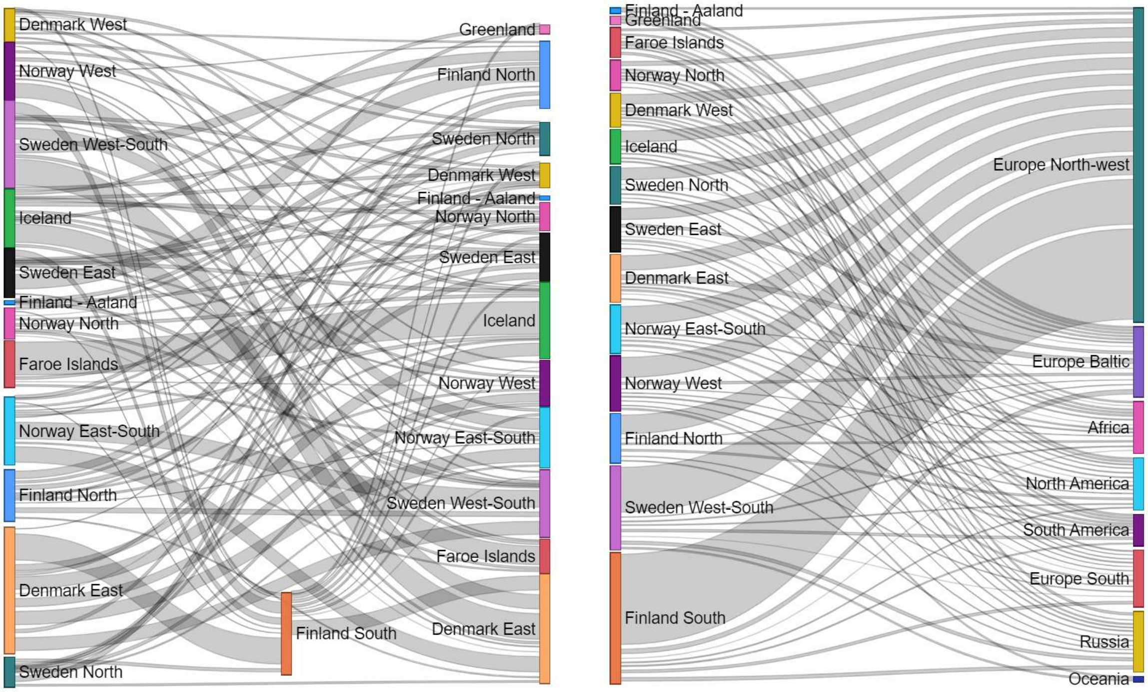


Figure 4-18. Illustration of intra Nordic (left) and Nordic international (right) traffic for cargo vessels. The width of each line scales with the fuel consumption for voyages between the different regions. The figure shows flow from start region to end region. Finland South is placed in the middle, showing flow of fuel consumption both in (from left) and out (right) of the region.

4.3.4 Intra Nordic and Nordic International wet and dry bulk traffic

Wet and dry bulk is the ship category with second highest fuel consumption, and hence CO_2 emissions, from intra Nordic ship traffic, after passenger. The segment is dominated by chemical tankers in the range of 5000 – 25 000 GT, in addition to crude oil tankers of 50 000-100 0000 GT, as shown in Figure 4-19. Wet and dry bulk is also the second highest contribution to Nordic international ship traffic, after cargo vessels. For international voyage connections, wet and dry bulk are dominated by crude oil tankers of 50 000-100 000 GT, closely followed by bulk carriers (mostly in the range of 10 000-100 000 GT) and chemical tankers (from 1000-50 000 GT).

Figure 4-20 illustrates the regional intra Nordic and Nordic international voyage connections for wet and dry bulk vessels. For intra Nordic traffic do Sweden West-South, Denmark East and Norway West account for the largest share of fuel consumption for wet and dry bulk. Nordic West do also have the largest contribution for Nordic international wet and dry bulk connections, followed by Sweden East-South and Finland South. Most of the international connections go to North-West Europe, but there is also significant amount of fuel consumed for voyages to North America, South Europe and Russia.

A longlist of potential bulk corridors is included in chapter 5.

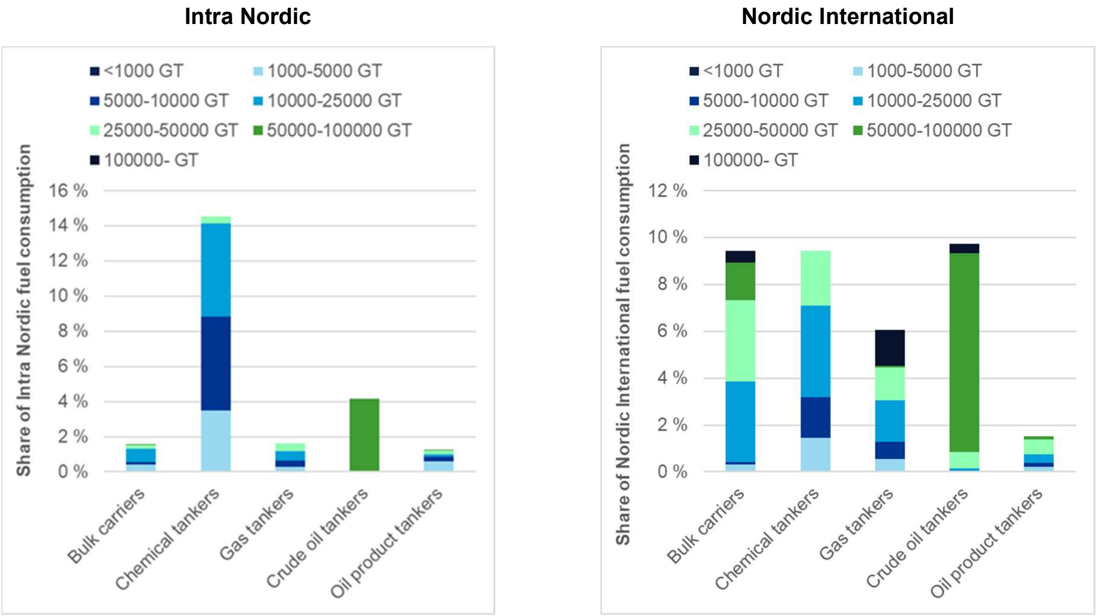


Figure 4-19. Share of fuel consumption per size segment for intra Nordic voyages (left) and Nordic international voyages (right) for wet and dry bulk vessel types (note different vertical axes).

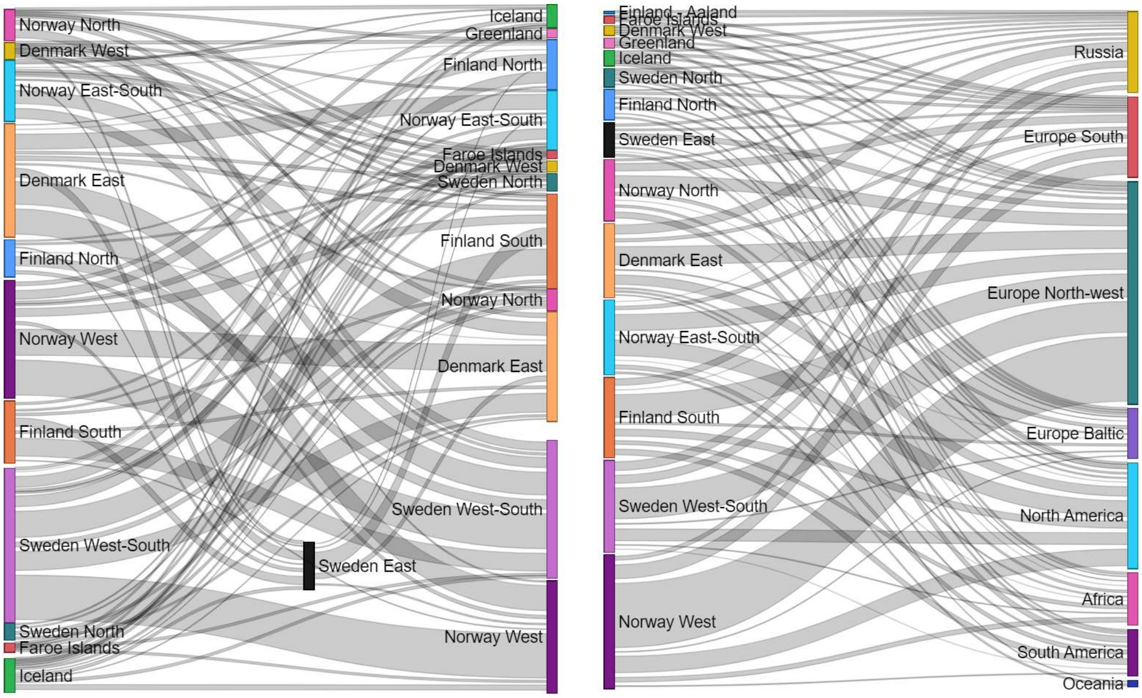


Figure 4-20. Illustration of intra Nordic (left) and Nordic international (right) traffic for wet and dry bulk vessels. The width of each line scales with the fuel consumption for voyages between the different regions. The figure shows flow from start region to end region. Sweden East is placed in the middle, showing flow of fuel consumption both in (from left) and out (right) of the region.

5 LONGLISTS OF POTENTIAL GREEN CORRIDORS FOR RO-PAX, CARGO AND BULK SHIPS

The establishment of green shipping corridors is a vital step in the decarbonisation process for the entire shipping industry. Selecting initial and feasible green shipping corridors is essential to accelerate the uptake of zero-carbon fuels and for generation of sustainable operations that can be transferred to other routes.

This chapter presents an overview of in total 81 potential green corridors for Nordic ship traffic; four longlists identified for vessels operating in intra Nordic Ro-Pax traffic (sub-chapter 5.1), Nordic international Ro-Pax traffic (sub-chapter 5.2) and cargo ships (sub-chapter 5.3) and wet and dry bulk ships (sub-chapter 5.4) operating in relatively regular round trips between a limited number of port locations. The four longlists include route specific information, i.e. corridor name (from port - to port), voyage distance between ports and estimated energy demand per trip. In addition, the longlists present AIS based results for our four pre-defined KPI's as described in sub-chapter 2.2: annual energy consumption, regularity (number of voyages and unique ships per route), fuel feasibility and spin-off potential. Fuel feasibility is assessed with the method described in sub-chapter 2.1.4. As described in sub-chapter 2.2, the spin-off potential indicates to which degree ports involved with each corridor also serves other ship traffic. There could be more corridor candidates not identified, and this should be analysed further in upcoming studies.

Each longlist is sorted by annual fuel consumption, but this in combination with the other three KPI's should be used when establishing a shortlist and selecting potential fist movers for initial green corridors. The shortlist will be made in task 2B, where infrastructure and onshore bunkering challenges are incorporated.

The routes are summarized in Table 5-1. Altogether, they constitute an energy consumption of 17% of the total energy consumption of Nordic ship traffic, and the Nordic international Ro-Pax routes dominate.

Table 5-1. Summary of routes selected as potential green shipping corridors.

Route type	Number of routes	Potential annual energy demand	
		Mtoe	% of Nordic ship traffic
Intra Nordic Ro-Pax routes	18	0.38	4.4%
Nordic international Ro-Pax routes	23	0.70	8.1%
Intra/international cargo routes	20	0.31	3.6%
Intra/international bulk routes	20	0.07	0.8%
Total	**81**	**1.46**	**17%**

The result of the feasibility screening for each route is indicated as *Level 1, Level 2* or *Level 3* for each route. As explained in sub-chapter 4.2, *Level 1* indicates all options are feasible, including battery electrification, *Level 2* indicates the potential is limited to compressed hydrogen or higher energy density technologies and *Level 3* denotes only high energy density option (e.g., methanol or ammonia) is feasible. In total the fuel feasibility screening identifies 12 corridors with score *Level 1*, 47 corridors with score *Level 2*, and 22 corridors with score *Level 3*. These results, of the high-level feasibility analyses, indicates that some shorter routes/corridors (Ro-Pax) are found to be battery feasible, but most of the identified corridors will need to supply of zero-carbon fuels such as hydrogen, methanol or ammonia.

It should be noted that the feasibility check exercise is just an overall screening taking only the energy density of fuel storage system compared to ship size and weight into account. In many cases both batteries and hydrogen tanks will be huge. Ship designs need to accommodate for this. Furthermore, there may be aspects that lead to other conclusions than what is concluded in the feasibility screening when detailed feasibility studies for the routes are carried out.

5.1 Intra Nordic Ro-Pax

As described in sub-chapter 4.3.1, intra Nordic Ro-Pax traffic constitutes an important part of Nordic ship traffic. From the voyage analysis, we identify 49 unique intra Nordic connections for Ro-Pax ships. However, most of these have just a few annual trips, and cannot be regarded a fixed route. We identify 18 routes with an annual number of trips above 50 and examine these further as potential green shipping corridors, as listed in Table 5-2.

For the intra Nordic Ro-Pax routes, there are some short routes which are found to be battery feasible. The route Gothenburg - Frederikshavn is for instance planned to become battery electric before 2030.[52] It should be noted that all the routes screened as battery feasible (apart from Helsingborg-Helsingør, which is already operated battery-electric) require larger batteries and higher charging capacities than any battery powered ship/route today. To realize such projects, batteries of 50-100 MWh or more are needed, as well as development of charging infrastructure of several 10s of MW. As such, battery electrification of such routes will push the limits of electrification, and they cannot necessarily be denoted as low hanging fruits even though battery technology is mature today. Furthermore, the feasibility of retrofitting of existing vessels to battery propulsion or other technologies instead of newbuilds has not been evaluated. On a general note, realizing these fuel technologies may require too large design changes for retrofit of existing vessels to be practically possible.

Table 5-2. Longlist of potential intra Nordic green corridors, Ro-Pax.

Route data				**Green Corridor KPIs**				
	Name	**Voyage distance (nm)**	**Energy demand per trip (MWh)**	**Total fuel consumption (tonnes)**	**Number of ships**	**Annual number of trips[53]**	**Fuel feasibility**	**Spin-off potential**
1	ABO (TURKU)->STOCKHOLM	160	100-500	21 %	4	2768	Level 2	High
2	HELSINKI (HELSINGFORS)->STOCKHOLM	260	100-500	20 %	5	1462	Level 2	High
3	KOBENHAVN->OSLO	270	100-500	12 %	2	692	Level 2	Medium
4	HIRTSHALS->KRISTIANSAND	70	50-100	7 %	3	775	Level 2	High
5	HIRTSHALS->LARVIK	90	100-500	6 %	2	343	Level 2	High
6	SANDEFJORD->STROMSTAD	40	10-50	5 %	4	1648	Level 1	Low
7	KAPELLSKAR->NAANTALI (NADENDAL)	110	50-100	4 %	2	1331	Level 2	Low
8	BERGEN/STAVANGER<->HIRTSHALS	290	100-500	4 %	2	520	Level 2	High
9	RØNNE<->YSTAD	70	50-100	4 %	4	2105	Level 2	Low
10	FREDERIKSHAVN->GOTEBORG	50	10-50	3 %	2	1141	Level 1	High
11	HELSINGOR->HELSINGBORG	10	10-50	3 %	3	10000	Level 1	Medium
12	KAPELLSKAR->MAARIANHAMINA (MARIEHAMN)	40	10-50	2 %	1	409	Level 1	Low
13	GRENAA->NYGARD	60	10-50	2 %	1	350	Level 1	Low
14	ECKERO->GRISSLEHAMN	70	50-100	2 %	1	406	Level 1	Low
15	HOLMSUND->VAASA /VASKLOT (VASKILUOTO)	50	10-50	2 %	1	765	Level 1	Low
16	MAARIANHAMINA (MARIEHAMN)->STOCKHOLM	80	10-50	2 %	3	653	Level 1	High
17	MJOEYRARHOFN->TORSHAVN	290	100-500	1 %	1	90	Level 2	Medium
18	HIRTSHALS<->LANGESUND	90	50-100	1 %	2	149	Level 2	High
	All longlisted intra Nordic Ro-Pax routes			100 %				

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[52] https://energiogklima.no/nyhet/gronn-skipsfart/gronnskipsfart-elektrisk-danskebat-i-2030-batteriteknologien-er-klar-i-dag/

[53] Number of identified trips is inaccurate for some passenger routes, due to not all port calls being identified because of data resolution

5.2 Nordic International Ro-Pax

We identify 23 unique Nordic international connections for Ro-Pax ships with an annual number of voyages higher than 50. The longlist of these potential green corridors and their attributes is provided in Table 5-3.

Similar to intra Nordic Ro-Pax routes, there are some shorter routes with battery electric potential (Level 1), although this involves very large batteries and charging powers. Although the Nordic International Ro-Pax routes are on average longer than the Intra Nordic, the geographical proximity of North Europe and the Baltics makes quite a few relatively short routes.

Table 5-3. Longlist of potential Nordic International green corridors, Ro-Pax.

Route data				Green Corridor KPIs				
	Name	**Voyage distance (nm)**	**Energy demand per trip (MWh)**	**Total fuel consumption (tonnes)**	**Number of ships**	**Annual number of trips**	**Fuel feasibility**	**Spin-off potential**
1	HELSINKI (HELSINGFORS)<->TRAVEMUNDE	620	>500	16 %	4	595	Level 2	High
2	HELSINKI (HELSINGFORS)<->TALLINN	40	50-100	11 %	10	4523	Level 2	High
3	KIEL<->OSLO	360	100-500	9 %	2	703	Level 2	Medium
4	MALMO<->TRAVEMUNDE	130	100-500	8 %	4	1501	Level 2	Medium
5	GDYNIA<->KARLSKRONA	170	100-500	7 %	3	1832	Level 2	Low
6	ROSTOCK<->TRELLEBORG	80	10-50	6 %	7	896	Level 2	Medium
7	TRAVEMUNDE<->TRELLEBORG	120	100-500	5 %	7	1398	Level 2	Medium
8	STOCKHOLM<->TALLINN	250	100-500	4 %	4	704	Level 2	High
9	GDANSK<->NYNASHAMN	280	100-500	4 %	2	596	Level 2	Medium
10	KARLSHAMN<->KLAIPEDA	220	100-500	4 %	6	886	Level 2	Low
11	SWINOUJSCIE<->TRELLEBORG	100	50-100	4 %	9	572	Level 1	Medium
12	GOTEBORG<->KIEL	230	100-500	4 %	2	706	Level 2	High
13	RIGA<->STOCKHOLM	260	100-500	4 %	3	716	Level 2	High
14	NYNASHAMN<->VENTSPILS	150	50-100	3 %	3	1190	Level 2	Medium
15	SWINOUJSCIE<->YSTAD	90	50-100	3 %	4	623	Level 1	Low
16	KAPELLSKAR<->PALDISKI	160	50-100	2 %	4	1125	Level 2	Low
17	PUTTGARTEN<->RØDBY	10	10-50	2 %	4	14600	Level 1	Low
18	ROSTOCK<->VAGGERLOSE	90	50-100	1 %	2	165	Level 2	Low
19	HELSINKI (HELSINGFORS)<->MUUGA	50	<10	1 %	1	535	Level 2	High
20	PALDISKI<->TVARMINNE	40	10-50	1 %	2	856	Level 1	High
21	KLAIPEDA<->TRELLEBORG	290	100-500	1 %	3	72	Level 2	Medium
22	HELSINKI (HELSINGFORS)<->SAINT PETERSBURG	180	100-500	1 %	1	151	Level 2	High
23	SASSNITZ<->RØNNE	50	10-50	0 %	2	67	Level 2	Low
	All longlisted Nordic International Ro-Pax routes			100 %				

5.3 Intra Nordic and Nordic International Cargo

Unlike Ro-Pax ships, which sail on regular routes typically between two ports, the majority of cargo traffic is less regular, and the routes often involve several ports. To be able to capture voyage patterns, we therefore assess *round trips* that are frequently carried out by cargo ships, starting and ending at the same Nordic port. There are hundreds of intra Nordic and Nordic international round trips identified; most of them have a low number of annual trips. Most round trips involve both intra Nordic and Nordic International voyages. As potential green cargo corridors we select the top 20 round trips, ranked by the total annual fuel consumption. Many of the identified corridors have several weekly, with a limited number of ships, indicating high regularity. This longlist of potential cargo corridors is given in Table 5-4.

Table 5-4. Longlist of 20 potential intra Nordic and Nordic international green corridors (round trips), cargo.

Route Data			Green Corridor KPIs				
	Name	**Energy demand per round trip (MWh)**	**Share of total fuel consumption (%)**	**Number of ships**	**Annual number of identified round trips**	**Fuel feasibility**	**Spin-off potential**
1	ESBJERG - IMMINGHAM – ESBJERG	>500	12 %	4	300	Level 2	High
2	HANKO - LUBECK – HANKO	>500	10 %	5	190	Level 2	Medium
3	HANKO - ROSTOCK – HANKO	>500	9 %	3	188	Level 2	Medium
4	GOTEBORG - ZEEBRUGGE – GOTEBORG	100-500	8 %	17	361	Level 2	High
5	GOTEBORG - IMMINGHAM – GOTEBORG	>500	7 %	8	173	Level 2	High
6	HANKO - GDYNIA – HANKO	>500	6 %	3	151	Level 2	Medium
7	NYSTAD (UUSIKAUPUNKI) - TRAVEMUNDE - NYSTAD (UUSIKAUPUNKI)	>500	5 %	2	76	Level 2	Low
8	GOTEBORG - TERNEUZEN - TERNEUZEN – GOTEBORG	>500	5 %	8	104	Level 2	High
9	REYKJAVIK - ROTTERDAM - BREMERHAVEN - HELSINGBORG - AARHUS - TORSHAVN – REYKJAVIK	>500	5 %	2	35	Level 3	Medium
10	HELSINKI - HULL - HELSINKI	>500	5 %	1	46	Level 3	High
11	OSLO - KIEL – OSLO	100-500	4 %	1	136	Level 2	High
12	STOKKSEYRI - ROTTERDAM - TORSHAVN – STOKKSEYRI	>500	3 %	1	42	Level 2	Medium
13	KOTKA - ANTWERPEN - BREMERHAVEN - BALTIYSK – KOTKA	>500	3 %	3	32	Level 3	High
14	ABO (TURKU) - BREMERHAVEN - HARWICH - CUXHAVEN - PALDISKI - ABO (TURKU)	>500	3 %	1	30	Level 2	Medium
15	HELSINKI - ZEEBRUGGE - TILBURY - SANTURCE - ZEEBRUGGE - ANTWERPEN - PALDISKI - HELSINKI	>500	3 %	2	13	Level 3	High
16	HANKO - ANTWERPEN - SUNILA - SAINT PETERSBURG - SUNILA – HANKO	>500	3 %	5	19	Level 3	Medium
17	HELSINKI - KOTKA - ANTWERPEN - ROTTERDAM - SAINT PETERSBURG – HELSINKI	>500	3 %	5	15	Level 3	High
18	REYKJAVIK - HULL - ROTTERDAM - HULL – REYKJAVIK	>500	3 %	2	40	Level 3	Medium
19	HOLMSUND - KIEL - KIEL - MALMO - HOLMSUND	>500	2 %	3	27	Level 3	Medium
20	MALMO - HANKO - SAINT PETERSBURG - SOUTHAMPTON - ZEEBRUGGE - BREMERHAVEN – MALMO	>500	2 %	2	23	Level 2	High
	All longlisted cargo round trips		*100 %*				

In addition to the longlist presented in Table 5-4, a special mention is also given to an Arctic green corridor potential for the round trip between Aalborg, Aarhus, Helsingborg, Torshavn, Reykjavik and Nuuk[54]. This round trip is responsible for most imports to Greenland in addition to having a clear intra-Nordic connection.

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[54] https://www.royalarcticline.com/media/1170381/atlantrute-royal-arctic-line.pdf

5.4 Intra Nordic and Nordic International Wet and Dry Bulk

The wet and dry bulk vessels operate in a similar way as cargo, sailing from port to port, often as a round trip. However, it is found that a higher share of bulk ships voyages goes to destinations outside of Europe, compared to cargo ships. When assessing round trips from Nordic ports, we find that the top 20 compared to cargo ships have a relatively low number of annual trips and fuel consumption, as shown in Table 5-5. This indicates significantly less regularity in the bulk ship operation in the Nordic, compared to cargo.

Table 5-5. Longlist of 20 potential intra Nordic and Nordic international green corridors (round trips), wet and dry bulk.

	Route Data		Green Corridor KPIs				
	Name	**Energy demand per round trip (MWh)**	**Total fuel consumption (tonnes)**	**Number of ships**	**Annual number of round trips**	**Fuel feasibility**	**Spin-off potential**
1	MELKOYA - KLAIPEDA - MELKOYA	>500	22 %	4	17	Level 2	Medium
2	JELSA - TILBURY - JELSA	>500	8 %	7	52	Level 2	Low
3	ELNESVAGEN - MOERDIJK - ELNESVAGEN	>500	6 %	4	41	Level 2	Low
4	KARSTO - ANTWERPEN - KARSTO	>500	6 %	16	27	Level 2	Medium
5	SLAGENTANGEN - ABENRA – SLAGENTANGEN	100-500	6 %	2	41	Level 2	Medium
6	ELNESVAGEN - OULU (ULEABORG) – ELNESVAGEN	>500	6 %	2	15	Level 1	Low
7	KARSTO - SVANESUND – KARSTO	100-500	5 %	7	42	Level 2	Medium
8	NARVIK - BREMEN – NARVIK	>500	4 %	3	12	Level 2	High
9	ELNESVAGEN - EMDEN – ELNESVAGEN	100-500	4 %	4	34	Level 2	Low
10	JELSA - OSTERMOOR – JELSA	100-500	4 %	5	29	Level 2	Low
11	KILPILAHTI (SKOLDVIK) - UST'-LUGA - KILPILAHTI (SKOLDVIK)	100-500	4 %	8	24	Level 1	High
12	RAFNES - ANTWERPEN – RAFNES	100-500	3 %	8	23	Level 1	Medium
13	JELSA - GDANSK – JELSA	>500	3 %	5	15	Level 2	Low
14	RAFNES - PORT CLARENCE – RAFNES	100-500	3 %	6	47	Level 2	Medium
15	MONGSTAD - ANTWERPEN – MONGSTAD	100-500	3 %	12	29	Level 2	High
16	GOTEBORG - FREDRIKSHAMN (HAMINA) – GOTEBORG	>500	3 %	5	13	Level 1	High
17	ABENRA - SLAGENTANGEN – ABENRA	100-500	3 %	2	19	Level 2	Medium
18	KILPILAHTI (SKOLDVIK) - RIGA - KILPILAHTI (SKOLDVIK)	100-500	3 %	6	25	Level 2	High
19	KILPILAHTI (SKOLDVIK) - STOCKHOLM - KILPILAHTI (SKOLDVIK)	100-500	2 %	7	28	Level 2	High
20	GOTEBORG - BJORNEBORG (PORI) – GOTEBORG	>500	2 %	5	12	Level 2	High
	All longlisted bulk round trips		*100%*				

6 POTENTIAL ENERGY HUBS

In this chapter, we illustrate the geographic distribution of *potential* energy demand at ports and regions. The location of potential energy hubs is vital information for further planning and development of infrastructure to supply the uptake of zero-emission fuels. The identification of potential energy hubs is linked to the investigation of infrastructure and bunkering challenges in Nordic roadmap task 2B and the roadmap development in task 2C.

6.1 Background

At the intersection of land and sea, ports can play a pivotal role in decarbonization of shipping. Ports are a natural hotspot for sector coupling and energy system integration as they host many industry sectors including maritime, oil and gas, cruise-tourism, heavy transport, bulk transfer, manufacturing industries, power generation, electricity grid operators and offshore wind (DNV, 2020). According to (Mjelde et. al., 2019), ports could play a key role in the maritime fuel transition by serving as energy hubs providing both shore-side electricity and infrastructure for storing and fueling ships with alternative fuels. They could also play a significant role through investing in digitalization and improving coordination and synchronization between ship and port to reduce ship energy consumption, emissions and stationary time.

The demand of future fuels by geography can potentially serve a significant part of the fleet with green energy. This can be multiple routes/corridors or a combination of intra Nordic corridors and domestic shipping/international shipping. The AIS analysis provides information on the energy demand from different ship segments and traffic types, which can be used to identify potential Nordic energy hubs. We can also assess how many ships are involved in routes to and from the ports, the traffic regularity, and how routes or ports may be clustered. However, voyage screening is only a first step, and many obstacles must be solved to realize the green shipping corridors.

The energy density of zero-emission fuels is lower compared to conventional fuels, hence more frequent bunkering is required. With a wide range of fuel options, ports are challenged to decide on which fuel infrastructure to invest in. However, a hub does not have to be a specific port but could also be an area or smaller region where the same fuel type could serve several vessels. Clustering ports into hubs could ease infrastructure development and a steady fuel supply. For the longlist presented in this report, potential energy hubs only refer to current ports. The energy hubs could take advantage of nearby wind parks or other installations that provide a steady supply of renewable energy. Another option for bunkering of ship fuels is bunker barges, which are mobile and can adapt its availability to the geographical demand from ship traffic. In this analysis, we have not lumped together ports in clusters, since the focus is the corridors between single ports.

A green shipping corridor may require supply of green energy in both end ports. Several vessels, for example, fishing vessels or offshore service vessels, mainly sail in and out of the same port and will primarily bunker at this location. This is an additional advantage for an energy hub, giving it the opportunity to serve both corridor routes and local ship operations. Another possibility is to serve more extensive routes for international shipping. In the identification of potential intra Nordic green corridors in chapter 5, this additional advantage is referred to as a “spin-off effect”.

Sub-chapter 6.2 presents a list of potential energy hubs in the Nordic based on the energy consumption from Nordic ship traffic as a whole, and sub-chapter 6.3 presents the dominating potential energy hubs for ships involved in the potential corridors listed in chapter 5. Task 2B will further investigate the current infrastructure and supply of fuel in the different ports and locations.

6.2 Overall picture of potential Nordic energy hubs

Through the AIS analysis, close to 1900 Nordic port locations are identified having ship traffic. In theory, all ports can be considered as a potential energy hub, where they as minimum provide shore power for the ships while at berth. The ports can also be central energy hubs, serving every vessel entering the port with sufficient energy to operate on next voyage or on several of coming voyages.

Figure 6-1 presents the top 20 Nordic ports with highest potential fuel demand[55] from all Nordic ship traffic in 2019, split on the six ship categories. The presented fuel demand includes all voyages out of the ports, covering Nordic domestic traffic, Intra Nordic traffic and Nordic international traffic. Voyages out of Helsinki had a total energy demand of 240k ton fuel in 2019, mainly due to passenger vessels. Goteborg had a demand of 210k ton fuel, mainly from cargo and wet and dry bulk vessels. Mongstad and Stockholm had a demand of 176k ton and 170k ton fuel, respectively. Mongstad is mainly serving wet and dry bulk vessels and some work/service vessels, while passenger vessels dominated the demand in Stockholm. It is further referred to Appendix B7 for maps of dominating ports, for overall traffic, domestic voyages, intra Nordic voyages and international voyages.

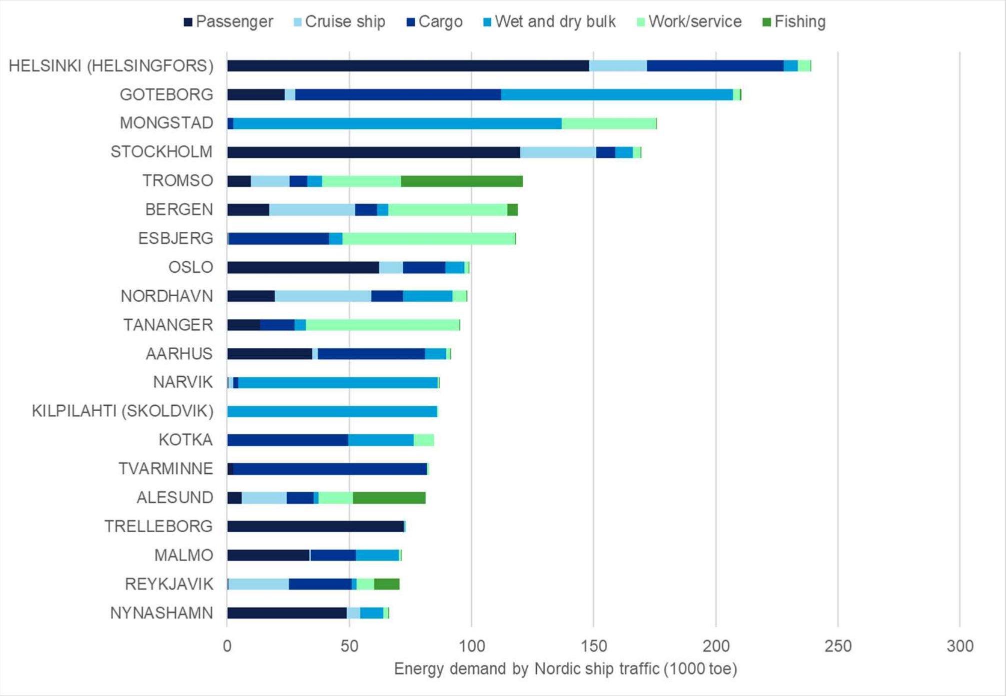

Figure 6-1. Top 20 potential energy hubs in Nordic based on energy demand from Nordic ship traffic, ranked by fuel consumption of all voyages departing from the port (2019).

There exists several projects and investments in development of land infrastructure and establishment of green energy hubs. The port of Gothenburg plans to establish Europe’s first green electro-methanol (e-fuels) hub, with the intent to launch in 2025[56]. In Norway, Norwegian Government has developed a hydrogen strategy[57] and Enova has announced to support hydrogen projects in the maritime sector with NOK 1.12 billion, which include the support of establishing five production plants for renewable hydrogen along the Norwegian cost[58]. The Nordic infrastructure and bunkering development for sustainable zero-carbon fuels and belonging challenges will be further mapped in the task 2B report. In addition, DNV’s Alternative Fuel Insight (AFI) platform provides updates on the uptake of alternative fuels and technologies[59].

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[55] Potential fuel demand here refers to the fuel consumption from all voyages going *out* of this port in 2019, estimated by use of AIS data

[56] https://www.liquidwind.se/news/industry-leaders-collaborate-europes-first-green-efuels-hub

[57] Regjeringens hydrogenstrategi - på vei mot lavutslippssamfunnet

[58] Enova supports hydrogen projects in the maritime sector with NOK 1.12 billion | Enova SF

[59] https://afi.dnv.com/

6.3 Potential energy hubs corresponding with longlists of green corridors

Several ports are involved in multiple potential corridors included in the longlists described in chapter 5. In Figure 6-2 we show the top 20 ports present in the longlists, ranked by share of total fuel consumption of the involved potential corridors. Here, half of the fuel consumption of Ro-Pax routes is allocated to each port involved, while for the cargo and bulk round trips, the total fuel consumption of the round trip is included. This can be used to see which ports actions can be targeted towards in order to have an impact beyond just each single route in the longlist.

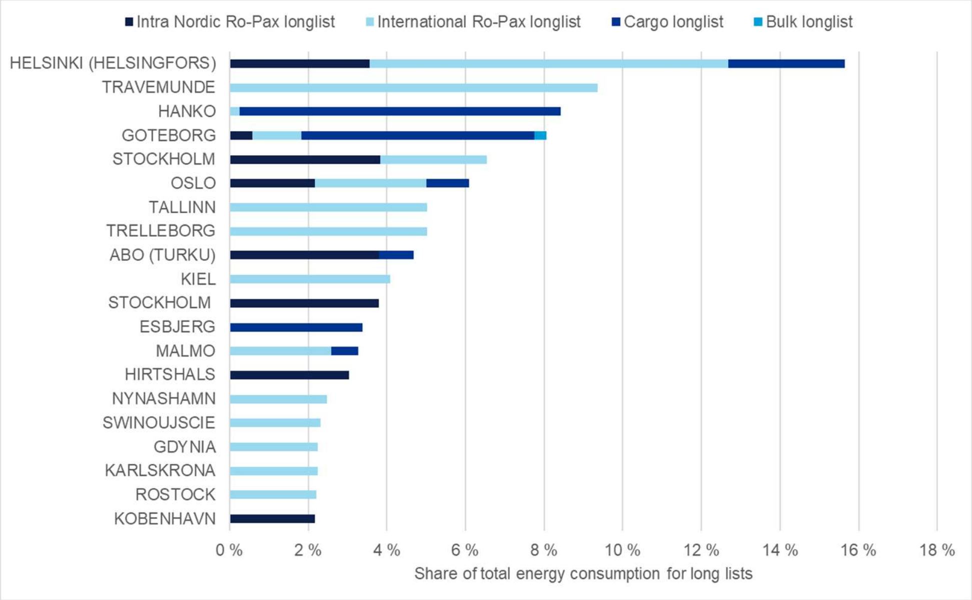

Figure 6-2. Share of total energy consumption, for top 20 ports present in longlists of potential green corridors.

7 DISCUSSION AND FURTHER WORK

The AIS analysis presented in the above sections provides a detailed fuel and emission inventory for Nordic ship traffic that will be an important cornerstone in the development of the Nordic roadmap (Task 2C), and provide input to various project tasks (e.g., Task 1A (Scorecard), 1C (LCA) and 2B (Infrastructure)). Having a breakdown on fuel consumption for domestic ship traffic, traffic between Nordic countries and Nordic international traffic will help dimensioning the future supply and infrastructure side, overall and for the individual Nordic countries. In addition, the voyage-based results of the AIS analysis will also provide information crucial for selecting segments and ports for initial green shipping corridors and green pilot projects. However, when going from a longlist of potential green shipping corridors to a *shortlist* of corridors (i.e., corridors that can be chosen as early movers), other data and parameters should also be considered, such as port and stakeholder readiness, fuel and infrastructure availability, bunkering and safety challenges.

This chapter first reflects on how we plan to develop the shortlist of potential green shipping corridors and energy hubs/ports. Such work is planned performed in Task 2B. Secondly, we indicate how the short and longlists are used in developing the Nordic roadmap (Task 2C). Finally, we discuss the challenges related to the realization of the first movers.

7.1 Developing the shortlists – finding potential first movers

Our AIS analysis in Chapter 5 provides a longlist of potential intra Nordic green shipping corridors based on four KPIs; i) annual energy consumption and CO_2 emission reduction potential, ii) regularity of voyages, iii) feasibility of fuels and iv) spin-off potential. The longlist presents potential green shipping corridors, referring to ship routes between two or more ports with highly regular ship traffic patterns and significant ship energy demand, favorable for establishing an initial market for ship transport using zero-carbon fuels. The shortlist of early movers does, however, depend on some additional aspects.

A green shipping corridor relies on sufficient production of renewable energy and steady supply of potential zero emission fuel. The bunkering infrastructure must be developed, and zero-emission must be available in start and end ports, or so-called energy hubs. The establishment of energy hubs in end-ports of a green corridor may also serve as fuel supply to smaller routes or vessels that operate in- and out of the same port, as discussed for the spin-off effects of the potential Nordic green shipping corridors. Bunkering infrastructure for ships consists of storage and bunkering through trucks, intermediate shore storage, or ships, to the receiving ship. Hub and spoke models of distribution can be used, with fuel transported from production facilities to a central hub for storage, and from there transported to ships for bunkering via trucks, pipes, or bunkering vessels. For some green fuels existing infrastructure will be reused, for some there can be blending in with fossil fuels in a transition. Bunkering liquids, such as oil, and methanol, has a relatively low cost, while compressed or liquefied hydrogen incurs a substantial cost for bunkering infrastructure. Liquified methane (LNG, bio-LNG, e-LNG) can use the existing LNG infrastructure, which is being developed. It is being investigated to what degree ammonia can use existing LNG infrastructure as well. Several projects for alternative fuel bunkering vessels are underway, also for ammonia[60]. Yara recently announced that they have ordered the construction of 15 floating bunkering terminals for ammonia, to be operated across Scandinavia within 2024[61]. There are currently about 120 ports globally which are involved in seaborne transport of ammonia and in port the commodity is usually stored in shore-side tanks.

Most potential zero-carbon fuels have properties posing different safety challenges from those of conventional fuel oils (see Task 1A/1B). This requires that the risks posed by e.g., toxicity of ammonia and high reactivity of hydrogen must be addressed along the bunkering logistic chains. Location of storage and bunkering facilities in relation to population densities, bunkering frequencies, topography, wind conditions etc are important boundary conditions in this regard. Safety studies have recently been carried out by for the ports of Oslo and Amsterdam (GSP, 2021; DNV, 2021c) and

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[60] MOL Acquires AIP for Ammonia Bunkering Vessel - Toward Realizing Ammonia Bunkering Business in Singapore - | Mitsui O.S.K. Lines

[61] Yara International and Azane Fuel Solutions to launch world's first carbon-free bunkering network, delivering green ammonia fuel to the shipping industry | Yara International

gaps have been reported related to «fuelling infrastructure» and «safety & operational risk management» aspects (Zero-Emission Shipping Mission, 2022). The safety regulations may be different in the various Nordic countries. The ban DSB (Norwegian Directorate for Civil Protection) previously had on bunkering LNG with passengers on board is an example. This resulted in LNG being transported by truck from Norway to Denmark for bunkering the Ro-Pax that runs between the two countries until the ban was lifted[62].

The location of potential feasible energy hubs in Nordic waters is vital information for further planning and development of infrastructure to supply the uptake of zero-emission fuels for green shipping corridors and other future demand. The longlist of energy hubs identified through our AIS analysis (Chapter 6), will be shorted by the infrastructure analysis to be performed in Task 2B. The infrastructure analyses will consider land-based barriers such as port and stakeholder readiness, fuel and infrastructure availability, bunkering and safety challenges. Having developed the shortlist of potential energy hubs in Task 2B, the related potential green shipping corridors can be identified, i.e. the shortlisted corridors.

The shortlisted potential corridors will be candidates for Nordic pilots (Task 3C, other initiatives) and important instruments to overcome bunkering and safety challenges identified in Task 1A/2B for the selected fuels. In the Nordic Roadmap (Task 2C), both short and longlisted green shipping corridors and energy hubs will be addressed, defining long term goals and major actions and milestones essential to reach these goals and to overcome barriers for supplying new zero-carbon fuels. As discussed below there are significant barriers to overcome for realization of initial green shipping corridors, including costs and bunkering challenges.

7.2 Realizing the first movers

The initial phase of establishing green shipping corridors is crucial, to ensure the specific routes are feasible to implement, and capable of generating sustainable operations that can be copied to other routes and used for "lessons to learn". The initial corridors will undoubtably reflect the importance of partnership among stakeholders and coalitions in the logistic ecosystem of a green shipping corridor. Motivated stakeholders are crucial for establishing an ecosystem for green shipping corridors and energy hubs. Commitment from all participants in the logistic chain would rise investment confidence and attract green financing. Financial support and incentives by public authorities are important for the realization of initial corridors.

Potential green shipping corridors can be categorized by feasibility and impact (Global Maritime Forum, McKinsey & Company, 2021). Routes with high feasibility and low impact can give "quick" wins, paving the way and providing learning effects. Other routes with high impact might have lower feasibility and will require more support for realization. Shipping routes with high feasibility and high impact can be a possible game changer and should be prioritized in the development of corridors.

There are several LNG fuelled vessels operating on Norwegian and Nordic ferry routes, that already have the reduced emissions and local pollution levels (ref. Figure 3-6). These routes could further be candidates for initial green shipping corridors with uptake of sustainable zero-emission fuels. The challenges and learnings from the decarbonization of Norwegian and intra Nordic ferry routes are relevant also for international shipping. The focus should also be put on the cargo vessels operating on relatively fixed routes, and routes that involve few individual ports on the round trips. The establishment of energy hubs in end ports of a green corridor may also provide spin-off effects and serve as fuel supply to smaller routes or vessels that operate on the same ports.

DNV's new Maritime forecast presents outlook on key barriers to, as well as opportunities to accelerate, the upcoming shore-side transition in fuel production and bunkering infrastructure to supply the future decarbonized world fleet and the potential initial green corridors (DNV, 2022). The forecast also provides an "Alternative fuel barrier dashboard", indicating that key onboard technologies and key fuel technologies needed will be available in 3-8 years (DNV, 2022). However, the fuel transition at sea hinges on developments on land and fuel availability becomes a key challenge.

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[62] https://www.offshore-energy.biz/skangass-bunkering-lng-ferries-with-passengers-on-board/

Given the immaturity of hydrogen and ammonia on board technologies, the Clydebank ambition of establishing at least six green shipping corridors between two (or more) ports by 2025 will have to consider ships fuelled by the more technically ready methanol and LNG (carbon neutral bio or synthetic).

However, key barrier to realizing initial green corridors towards 2025 is the competitiveness gap that exists between fossil fuels and zero-carbon emission fuels. The annualised end-to-end total cost of vessel ownership is forecasted by a recent study for vessel newbuilds in 2030, showing increases by 40-100% depending on ship type and fuel choice (Mærsk Mc-Kinney Møller Center, 2021). Actions to help support the first movers could contribute to reducing the cost gap. Example of supporting actions could be Contracts for Difference (CfD), supportive green procurement policies combined with long-term contracts, long-term financing to green ships, and risk-sharing mechanisms to reduce the risk for first movers between green shipping corridor stakeholders. Recently Oxford Smith School of Enterprise and the Environment (2021) analyzed the feasibility of applying a policy instrument known as a 'contract-for-difference' (CfD) as policy instrument to the decarbonization of shipping, which has previous shown success in driving down the costs of renewable technologies in the electricity sector. This is supported by the Global Maritime Forum (2022b) that suggested closing most of the cost gap for green corridors in EU by the use of CfD, in combination with the EU's Fit for 55 package for shipping (e.g. EU ETS, FuelEU Maritime). Among the corridors considered in the study was an EU CfD program target long-distance regional ferries in the Baltic.

One of the key success factors to scale up sustainable zero-emission fuels in a transport system, is that the different actors *actually dare to commit* with respect to demand and supply of immature and expensive fuels with uncertain future availability. Such commitment is impossible without common understanding and upfront agreement between the actors on "how to do things", including risk and cost sharing.

This is also at the core of the Green Shipping Corridor approach, as DNV sees it: to establish the required level of understanding and agreement among the actors for a specific transport system (i.e., ship route(s)), such that the risk level becomes acceptable and commitment to the delivery and use of zero-carbon emission fuels is possible. In this picture, mitigation of the practical, organizational, legal and financial barriers is as important as the technical challenges. The initial focus on tailormade commercial cases in a limited set of Green Corridors, allow for learning and later generalization on a regional and global scale.

In practical terms, planning for realization of an initial green shipping corridor will require structure process involving of a number of steps and a range of different criteria need to be fulfilled. There will be need for standardized framework for developing and operating future green shipping corridors. Already, the Global Maritime Forum/McKinsey (Global Maritime Forum, McKinsey & Company, 2021) have proposed criteria and assessed various sea routs. In addition, the US has suggested a Green Shipping Corridors Framework (U.S. Department of State, 2022).

DNV suggests that five key fundamental enablers should be assessed for identified corridors:

i) partnership and collaboration on supply and demand side to enable zero-carbon emission shipping,

ii) actions helping to ensure demand for zero-carbon emission fuels,

iii) increased availability of fuel and infrastructure to supply ships powered by zero-carbon emission fuels,

iv) mechanisms for closing cost caps between conventional and zero-carbon fuels, and

v) setting onshore and onboard safety standard to ensure a safe transfer to zero-emission shipping (see Figure 7-1).

Monitoring the developments will be crucial for the establishment of green corridors and for implementing corrective actions if found necessary. To monitor the gradual development of green shipping corridors, DNV's CO2 and technology transition barometer could be applied (DNV GL, 2019; DNV GL, 2020b). The transition barometer, in combination with

Alternative Fuel Insight (AFI) platform,[63] will provide the industry and policy makers with insight on speed and progress of the energy transition and allow for execution of corrective actions.

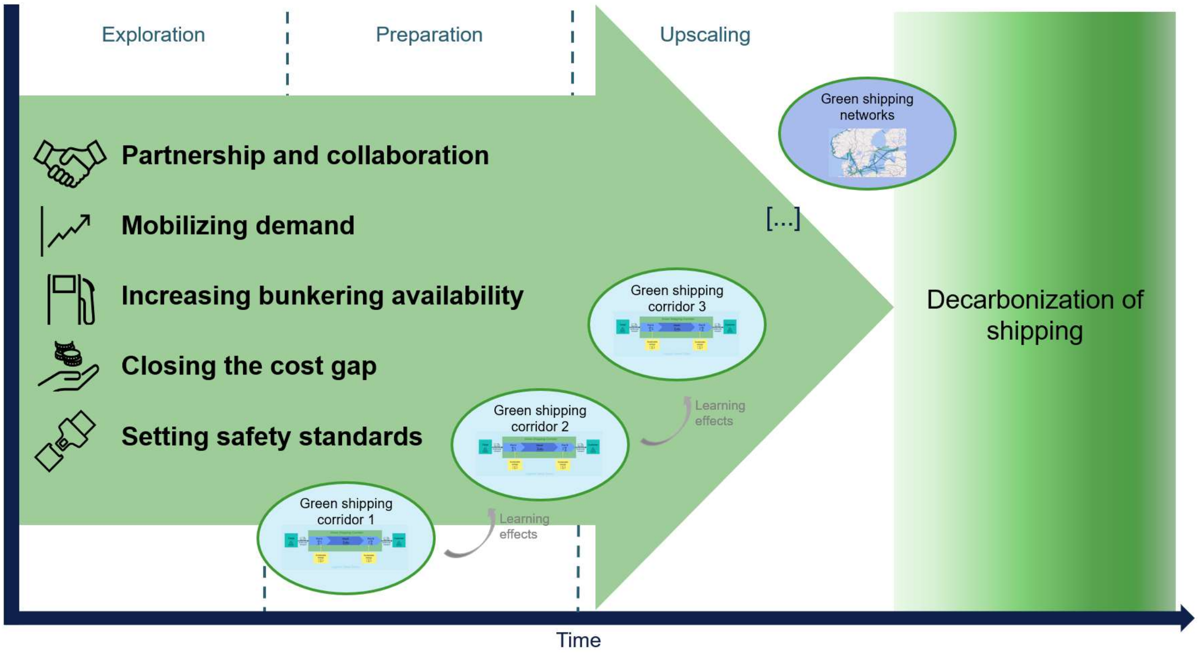

Figure 7-1. Five key fundamentals are driving ship decarbonization via green corridors (Source: DNV, 2022).

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[63] https://afi.dnv.com/

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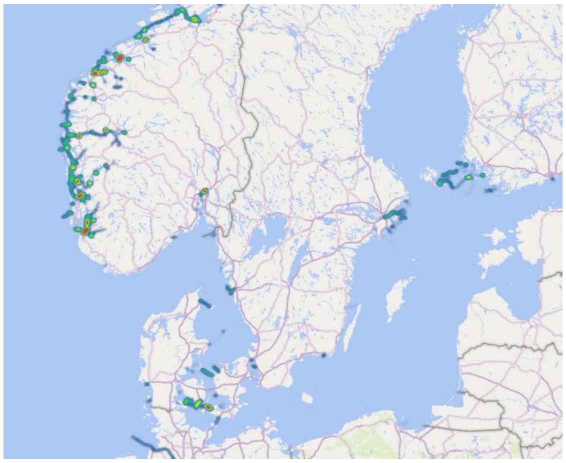
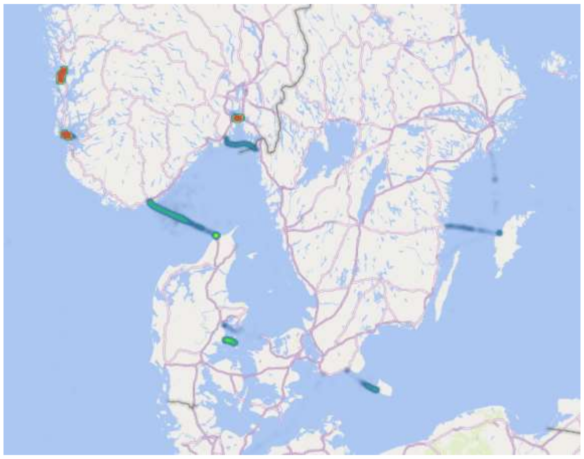
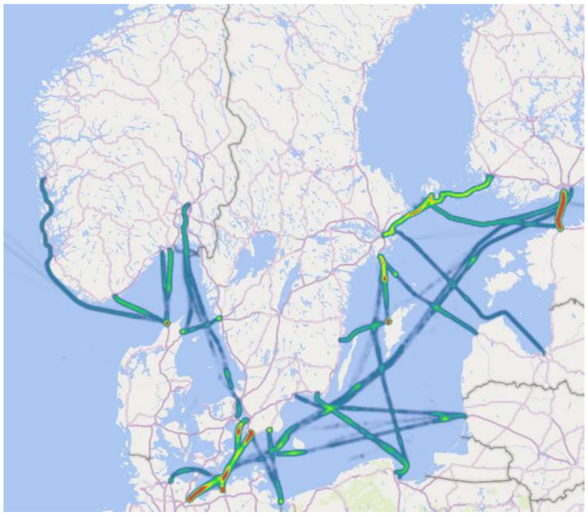
APPENDIX A – SHIP FUEL CONSUMPTION DENSITY MAPS FOR SHIP CATEGORIES AND SIZE SEGMENTS

Appendix A provides further maps of fuel consumption, one for each size segment within the six ship categories.

A1 Passenger vessels

The operating areas and major shipping routes by ship size segments for passenger vessels are illustrated in the figure below. The operational patterns for individual ship size segments show well defined shipping routes for Nordic domestic, intra Nordic, and Nordic International traffic. The smaller passenger vessels, being below 10 000 GT, mainly operate in domestic traffic patterns while the larger vessels are dominated by intra Nordic shipping routes or in Nordic International traffic patterns. We also observe an increasing length of the route, as the size of the ship increases. This will have a large impact of technology options.

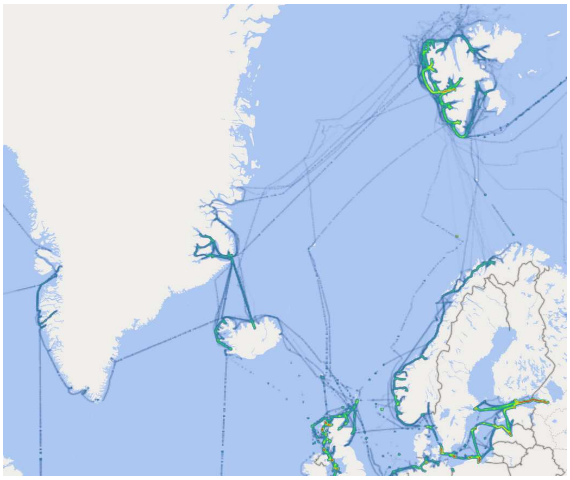
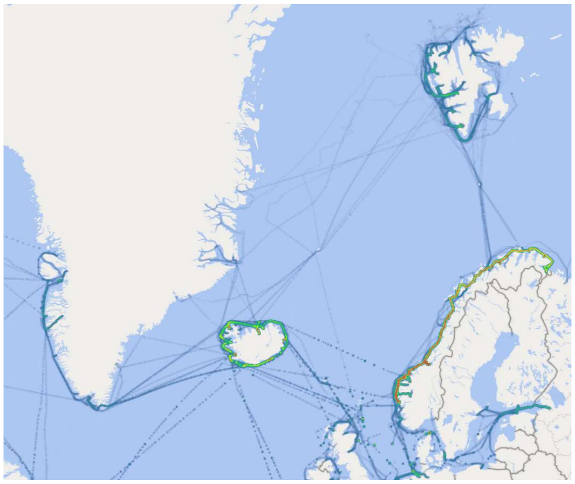
 5000 GT and below	 Between 5000 and 10 000 GT
 Between 10 000 and 25 000 GT	 Between 25 000 and 50 000 GT

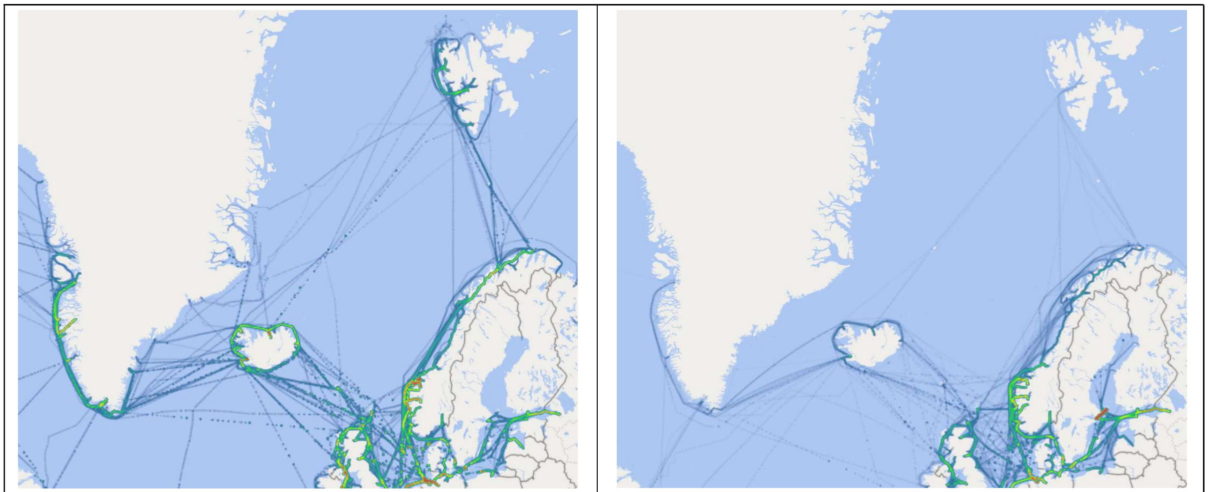
 Between 50 000 and 100 000 GT	No vessels in this size category - 100 000 GT and above

Traffic patterns for passenger vessels split on ship size categories – 2019. Colouring indicates fuel consumption density at the given geographical location.

A2 Cruise vessels

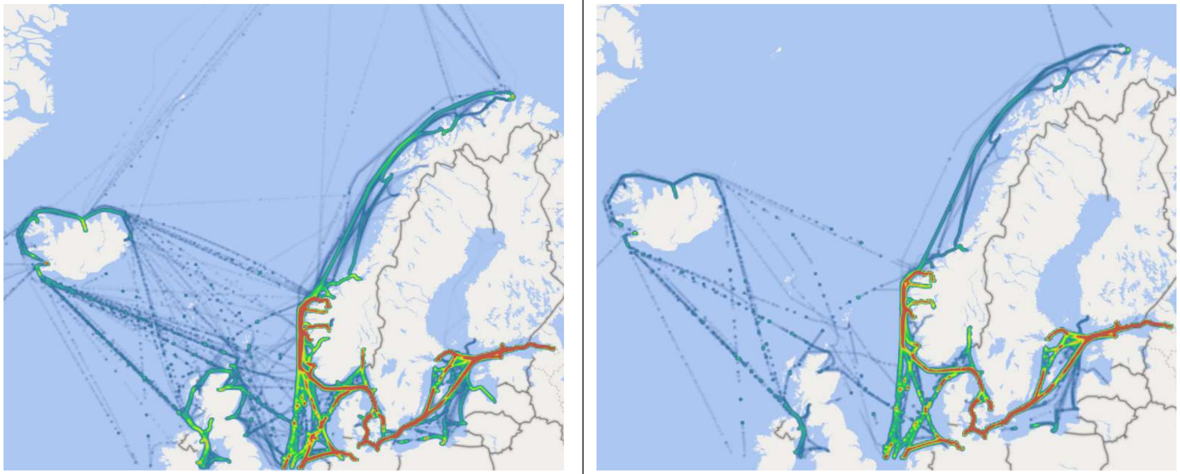
The operating areas and major shipping routes by ship size segments for cruise vessels are illustrated in the figure below. The operational patterns for the individual ship size segments show that the small cruise vessels, typically below 25 000 gross ton, have larger portions of their operations in the areas up north and on routes along the Norwegian coast, around Svalbard, Iceland, and Greenland. The cruise vessels being 25 000 gross ton and above are more concentrated on routes along the Norwegian coast, in the Baltic Sea, in Danish waters and to some extent around Iceland. Typical for the cruise vessels is that they operate on round trips (routes) for a specific period of the year, where the booking of port calls has been made years ahead.

 5000 GT and below	 Between 5000 and 10 000 GT



Between 10 000 and 25 000 GT

Between 25 000 and 50 000 GT



Between 50 000 and 100 000 GT

100 000 GT and above

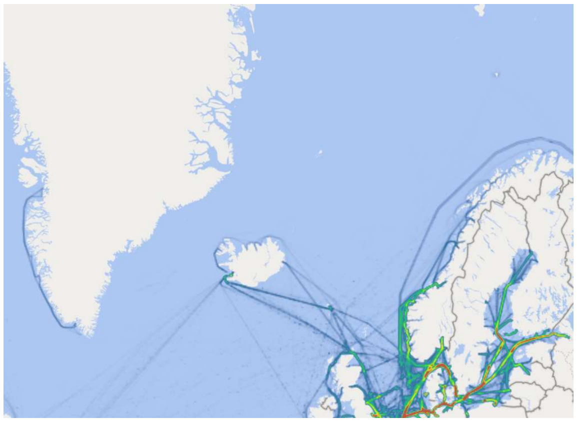
Traffic patterns for cruise vessels split on ship size categories – 2019. Colouring indicates fuel consumption density at the given geographical location.

A3 Cargo vessels

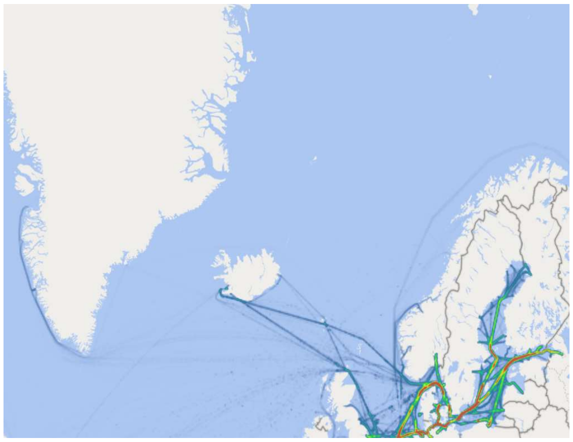
The operating areas and major shipping routes by ship size segments for cargo vessels are illustrated in the below figure. The operational patterns for the individual ship size segments show that the small cargo vessels, typically below 25 000 gross ton, have large portions of the operations on voyages within the Baltic Sea, along the Norwegian coastline, to Faroe Islands and Iceland, where multiple ports are involved. These relatively small vessels have a high share of the total fuel consumption for cargo vessels, 77%. The small general cargo vessels, below 5000 gross ton, dominates the fuel consumption estimates, followed by container vessels and Ro-ro cargo vessels.

For the cargo vessels being 25 000 gross ton and above, more concentrated traffic patterns are observed with some noticeable port destinations in Finland, Sweden, Denmark, and Norway. The Ro-Ro cargo vessels between 25 000 and 50 000 gross ton dominates the fuel consumption estimates followed by container vessels. Only container ships are found in the largest size segment > 100 000 gross ton with well-defined port destinations in Denmark and Sweden.

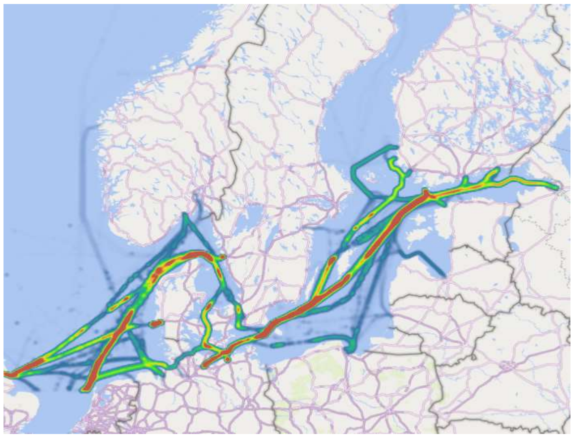
5000 GT and below



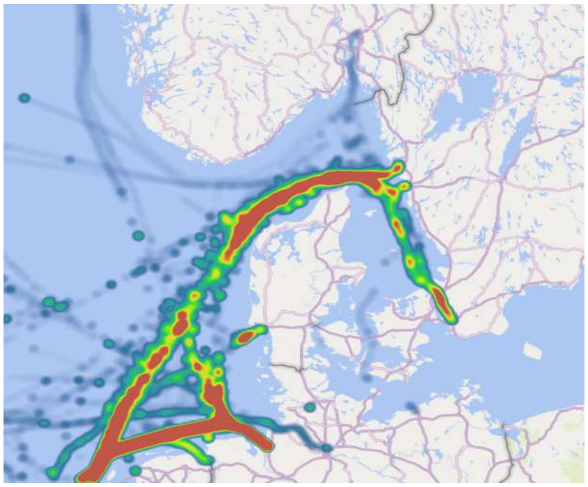
Between 5000 and 10 000 GT



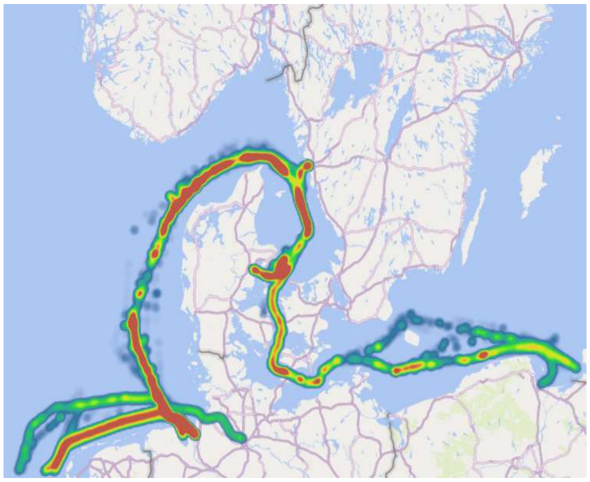
Between 10 000 and 25 000 GT



Between 25 000 and 50 000 GT



Between 50 000 and 100 000 GT



100 000 GT and above

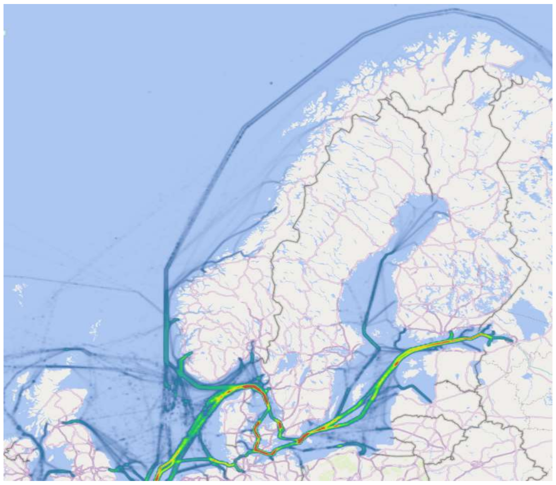
Traffic patterns for cargo vessels split on ship size categories – 2019. Colouring indicates fuel consumption density at the given geographical location.

A4 Wet and dry bulk vessels

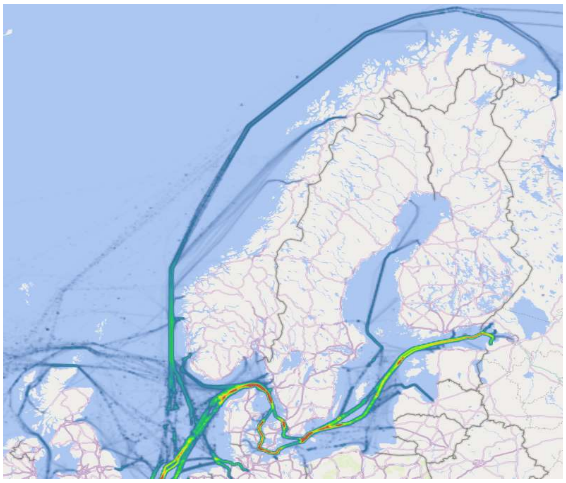
The operating areas and major shipping routes by ship size segments for wet and dry bulk vessels are illustrated in the below figure. The operational patterns for the individual ship size segments show that the small cargo vessels, typically below 10 000 gross ton, have widespread operational patterns in the Nordic waters where multiple ports are involved. For the larger vessels, 10 000 gross ton and above, more dedicated port locations are observed. The vessels above 100 000 gross ton is mainly LNG tankers and some bulk vessels operating out of Norwegian ports.

5000 GT and below

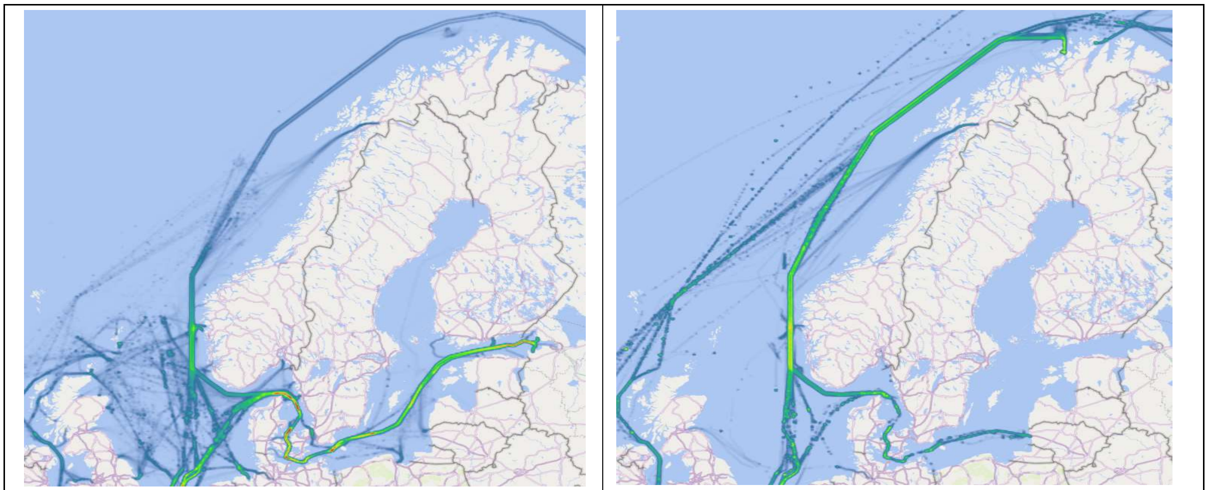
Between 5000 and 10 000 GT



Between 10 000 and 25 000 GT



Between 25 000 and 50 000 GT



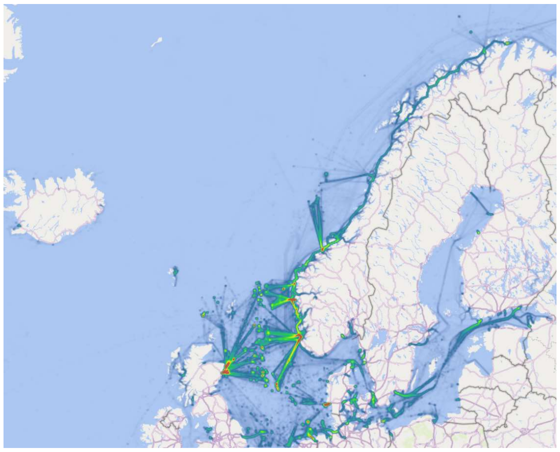
Between 50 000 and 100 000 GT

100 000 GT and above

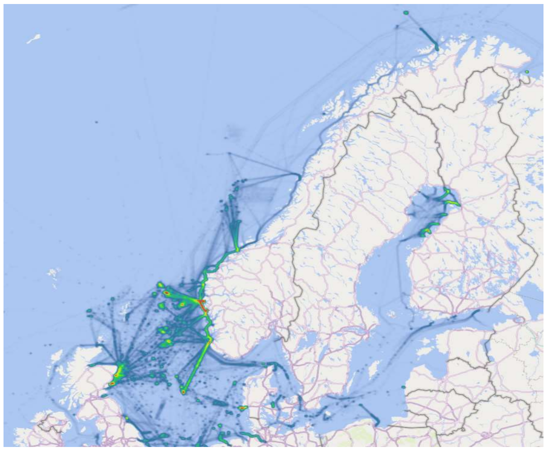
Traffic patterns for dry and wet bulk vessels split on ship size categories – 2019. Colouring indicates fuel consumption density at the given geographical location.

A5 Work and service vessels

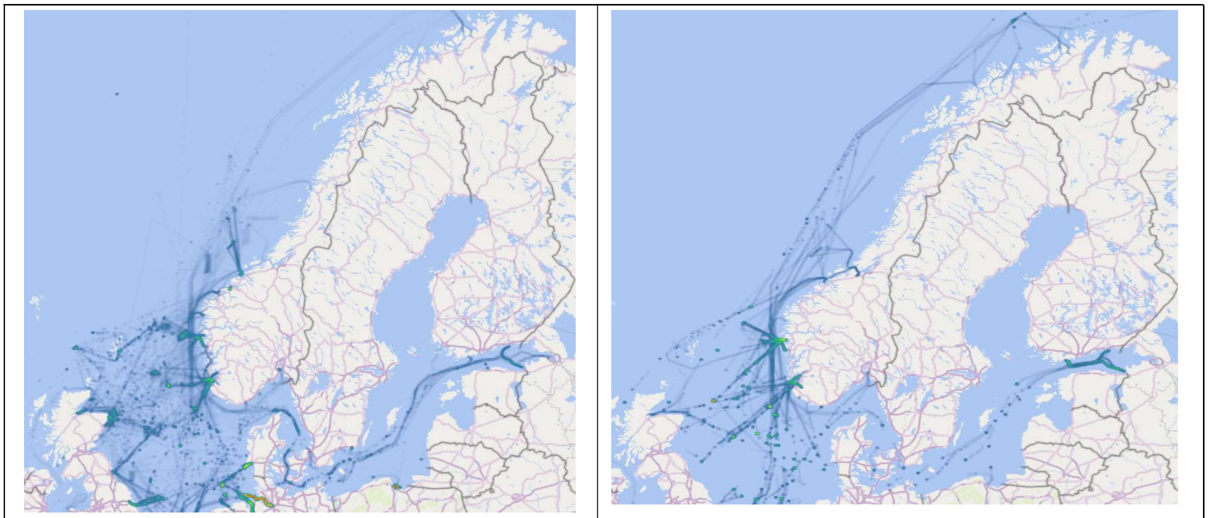
The operating areas and major shipping routes by ship size segments for work and service vessels are illustrated in the figure below. The operational patterns for the individual ship size segments show that the small work and service vessels, typically below 10 000 gross ton, operates in the North Sea (related to the offshore activity), as well as along the Norwegian coastline and in the Baltic Sea. The activity for work and service vessels decreases for increasing ship sizes, in line with the lower number of large vessels. Work and service vessels (including aquaculture, offshore and other activities) are mostly domestic ship traffic, often operating in and out of the same port.



5000 GT and below

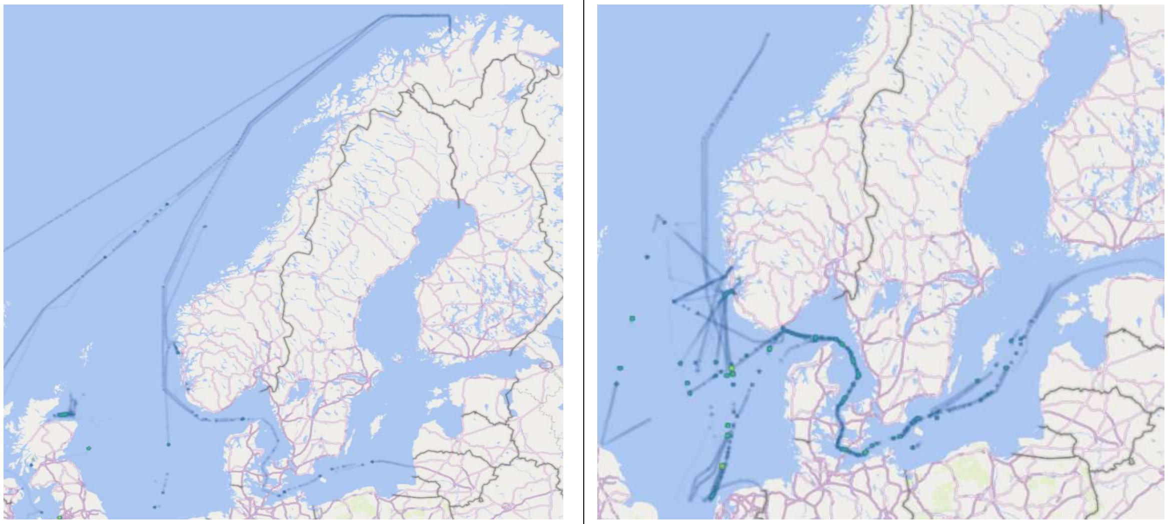


Between 5000 and 10 000 GT



Between 10 000 and 25 000 GT

Between 25 000 and 50 000 GT



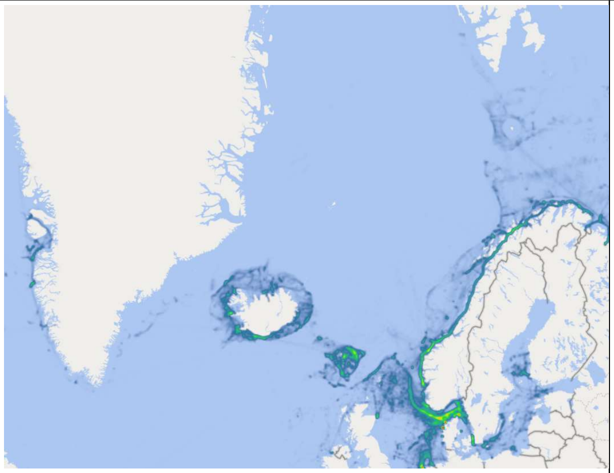
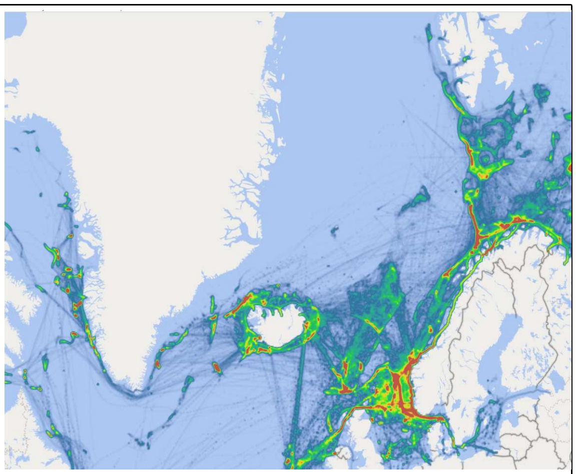
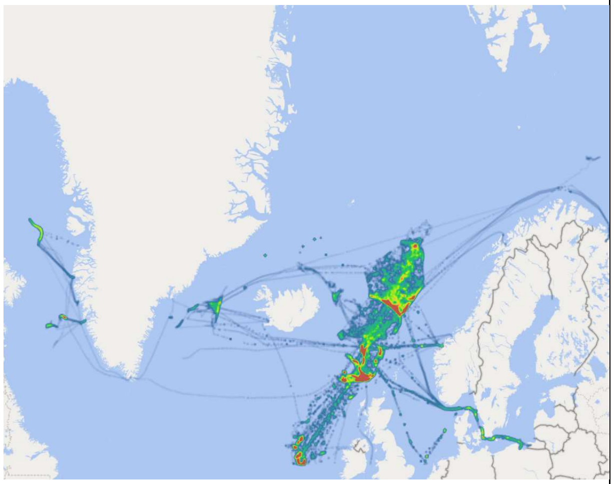
Between 50 000 and 100 000 GT

100 000 GT and above

Traffic patterns for work and service vessels split on ship size categories – 2019. Colouring indicates fuel consumption density at the given geographical location.

A6 Fishing vessels

The operating areas and major shipping routes by ship size segments for fishing vessels are illustrated below. The figure shows a clear distinction between the operation for the different size segments. Fishing vessels of 1000 GT or less operates along the Norwegian coastline, around Skagerrak, and in Fareo Islands and Iceland. 1000 and 5000 GT are the dominating size segment for fishing vessels, with high activity around Iceland, in the North Sea and in the Barents Sea. Fishing vessels between 5000 and 10 000 GT mainly operates in the Norwegian Sea. There are no fishing vessels above 10 000 GT.

 1000 GT and below	 Between 1000 and 5 000 GT
 Between 5 000 and 10 000 GT	No vessels in this size categories - 10 000 GT and above

Traffic patterns for fishing vessels split on ship size categories – 2019. Colouring indicates fuel consumption density at the given geographical location.

APPENDIX B – ADDITIONAL RESULTS

B1 Number of ships and fuel consumption per ship category and size segment

Number of ships in Nordic ship traffic, distributed by size categories per ship category.

Ship category	**<1000 GT**	**1000-5000 GT**	**5000-10000 GT**	**10000-25000 GT**	**25000-50000 GT**	**50000-100000 GT**	**100000-GT**	**Total**
Cargo vessels	4 %	50 %	20 %	16 %	4 %	5 %	1 %	**100 %**
Wet and dry bulk vessels	2 %	15 %	9 %	31 %	25 %	17 %	2 %	**100 %**
Passenger vessels	61 %	20 %	4 %	6 %	7 %	1 %	0 %	**100 %**
Cruise vessels	12 %	8 %	8 %	16 %	19 %	23 %	14 %	**100 %**
Work / service vessels	51 %	32 %	10 %	5 %	1 %	0 %	0 %	**100 %**
Fishing vessels	75 %	25 %	0 %	0 %	0 %	0 %	0 %	**100 %**
All	**29 %**	**31 %**	**11 %**	**14 %**	**9 %**	**6 %**	**1 %**	**100 %**

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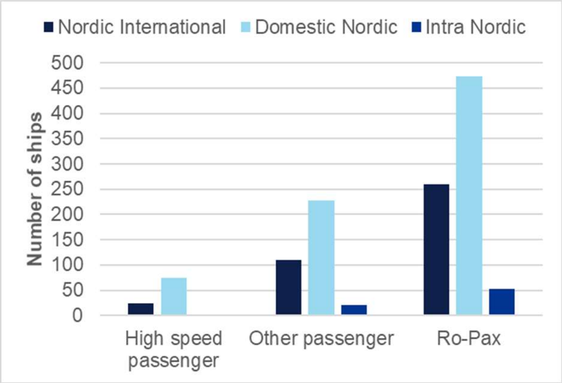
Total fuel consumption in Nordic ship traffic, distributed by size categories per ship category.

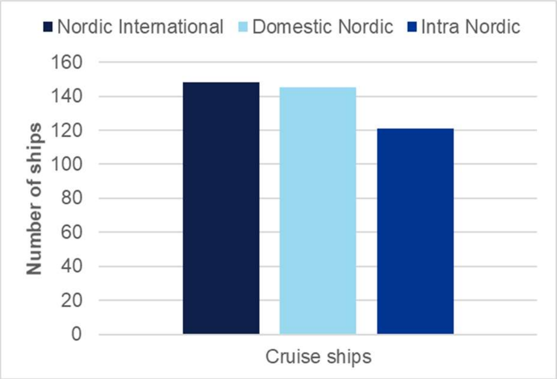
Ship category	**<1000 GT**	**1000-5000 GT**	**5000-10000 GT**	**10000-25000 GT**	**25000-50000 GT**	**50000-100000 GT**	**100000-GT**	**Total**
Cargo vessels	0 %	24 %	21 %	31 %	20 %	2 %	2 %	100 %
Wet and dry bulk vessels	0 %	10 %	11 %	26 %	20 %	26 %	6 %	100 %
Passenger vessels	5 %	8 %	8 %	19 %	50 %	10 %	0 %	100 %
Cruise vessels	0 %	1 %	4 %	13 %	18 %	35 %	29 %	100 %
Work / service vessels	9 %	37 %	29 %	13 %	7 %	2 %	3 %	100 %
Fishing vessels	31 %	68 %	1 %	0 %	0 %	0 %	0 %	100 %
All	5 %	21 %	15 %	22 %	22 %	12 %	4 %	100 %

B2 Number of ships involved in each traffic type

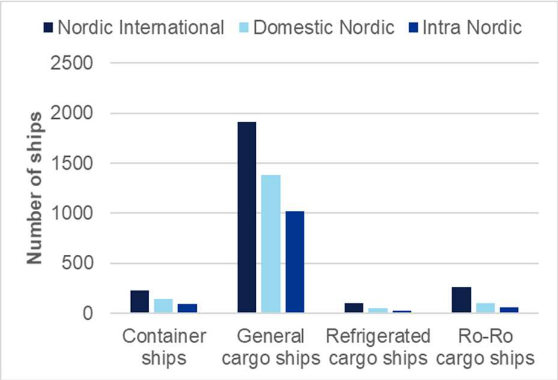
Passenger



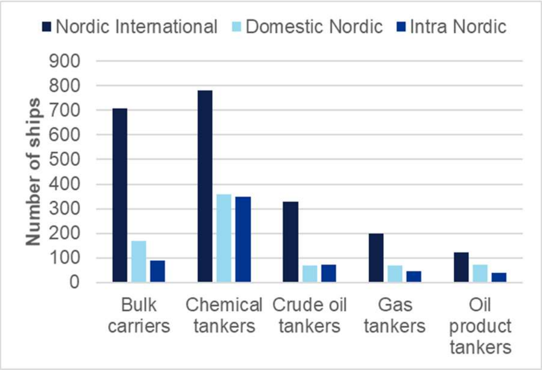
Cruise



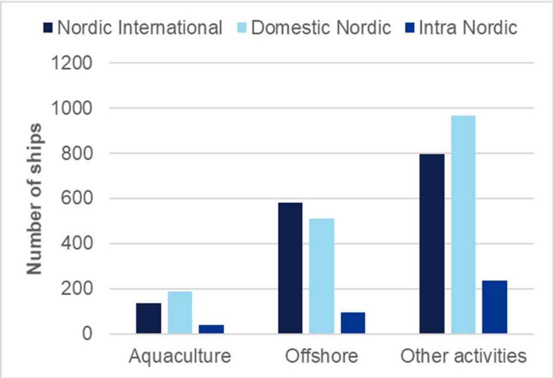
Cargo



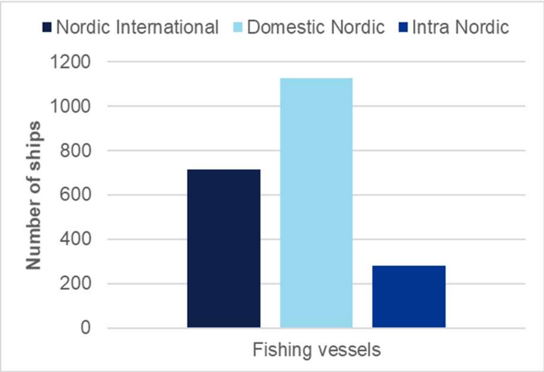
Wet and dry bulk



Work/service



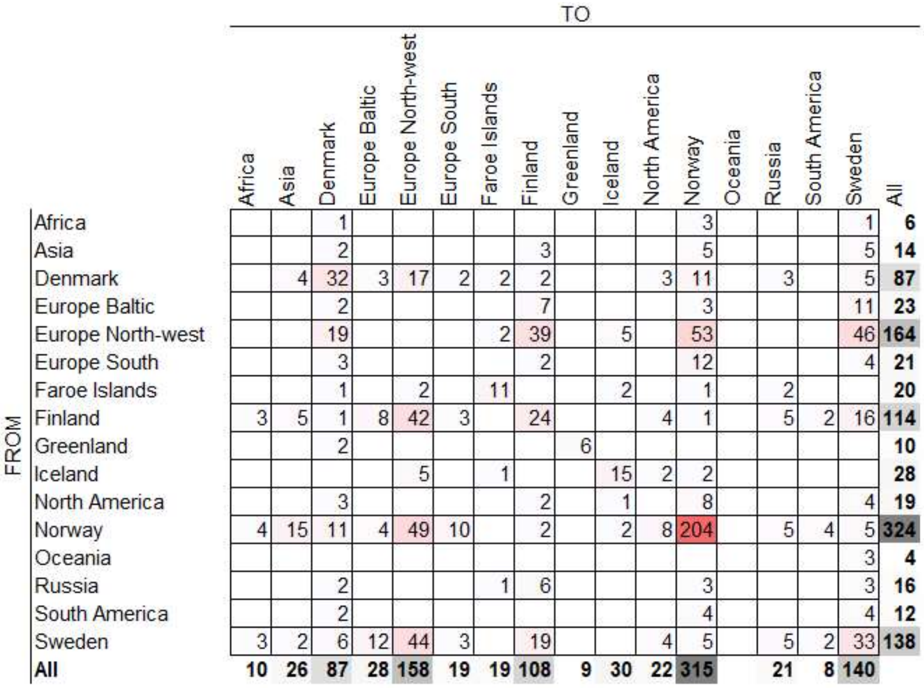
Fishing



Number of ships involved in each traffic type, divided by ship category.

B3 Geographic distribution of Nordic ship traffic and energy consumption

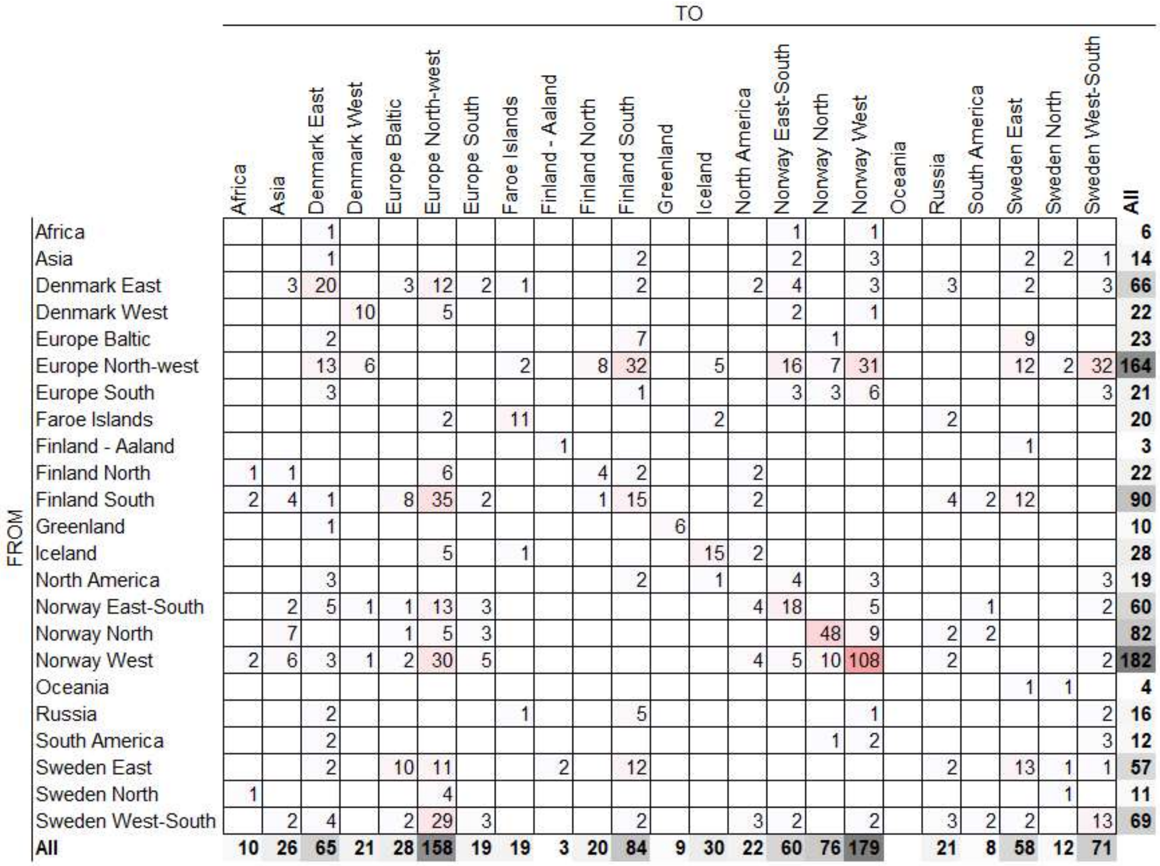
The tables below show the distribution of fuel consumption from and to Nordic countries and other regions outside the Nordic and the distribution of fuel consumption from and to Nordic regions and other regions.



TO

FROM	Africa	Asia	Denmark	Europe Baltic	Europe North-west	Europe South	Faroe Islands	Finland	Greenland	Iceland	North America	Norway	Oceania	Russia	South America	Sweden	All
Africa			1									3				1	**6**
Asia			2					3				5				5	**14**
Denmark		4	32	3	17	2	2	2			3	11		3		5	**87**
Europe Baltic			2					7				3				11	**23**
Europe North-west			19				2	39		5		53				46	**164**
Europe South			3					2				12				4	**21**
Faroe Islands			1		2		11			2		1		2			**20**
Finland	3	5	1	8	42	3		24			4	1		5	2	16	**114**
Greenland			2						6								**10**
Iceland					5		1			15	2	2					**28**
North America			3					2		1		8				4	**19**
Norway	4	15	11	4	49	10		2		2	8	204		5	4	5	**324**
Oceania																3	**4**
Russia			2				1	6				3				3	**16**
South America			2									4				4	**12**
Sweden	3	2	6	12	44	3		19			4	5		5	2	33	**138**
All	**10**	**26**	**87**	**28**	**158**	**19**	**19**	**108**	**9**	**30**	**22**	**315**		**21**	**8**	**140**	

Distribution of share of total Nordic ship traffic fuel consumption (per thousand - ‰) between *Nordic countries* and other regions. Values below 1 are left blank.

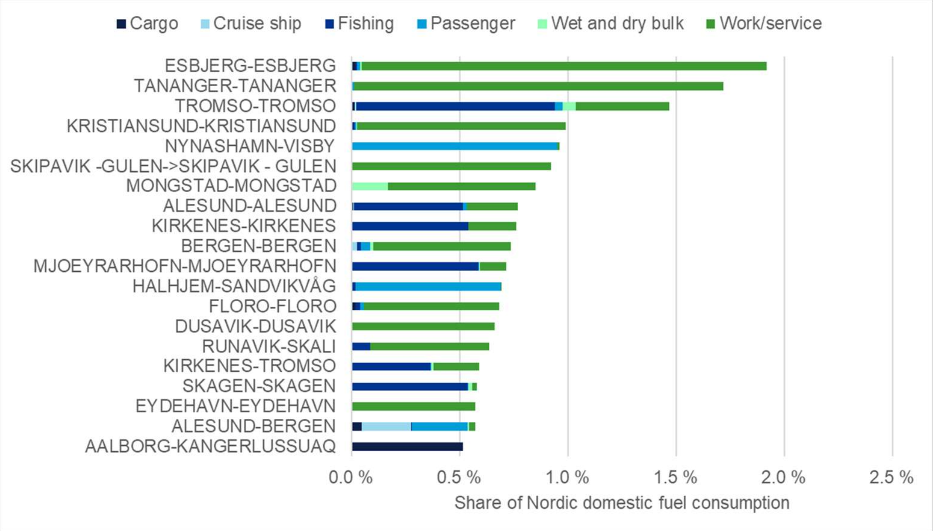


FROM \ TO	Africa	Asia	Denmark East	Denmark West	Europe Baltic	Europe North-west	Europe South	Faroe Islands	Finland - Aaland	Finland North	Finland South	Greenland	Iceland	North America	Norway East-South	Norway North	Norway West	Oceania	Russia	South America	Sweden East	Sweden North	Sweden West-South	All
Africa			1												1		1							**6**
Asia			1								2				2		3				2	2	1	**14**
Denmark East		3	20		3	12	2	1			2			2	4		3		3		2		3	**66**
Denmark West				10		5									2		1							**22**
Europe Baltic			2								7					1					9			**23**
Europe North-west			13	6				2		8	32		5		16	7	31				12	2	32	**164**
Europe South			3								1				3	3	6						3	**21**
Faroe Islands						2		11					2						2					**20**
Finland - Aaland									1												1			**3**
Finland North	1	1				6				4	2			2										**22**
Finland South	2	4	1		8	35	2			1	15			2					4	2	12			**90**
Greenland			1									6												**10**
Iceland						5		1					15	2										**28**
North America			3								2		1		4		3						3	**19**
Norway East-South		2	5	1	1	13	3							4	18		5			1			2	**60**
Norway North		7			1	5	3									48	9		2	2				**82**
Norway West	2	6	3	1	2	30	5							4	5	10	108		2				2	**182**
Oceania																					1	1		**4**
Russia			2					1			5						1						2	**16**
South America			2													1	2						3	**12**
Sweden East			2		10	11			2		12								2		13	1	1	**57**
Sweden North	1					4																1		**11**
Sweden West-South		2	4		2	29	3				2			3	2		2		3	2	2		13	**69**
All	**10**	**26**	**65**	**21**	**28**	**158**	**19**	**19**	**3**	**20**	**84**	**9**	**30**	**22**	**60**	**76**	**179**		**21**	**8**	**58**	**12**	**71**	

Distribution of share of total Nordic ship traffic fuel consumption (per thousand - ‰) between *Nordic regions* and other regions. Values below 1 are left blank.

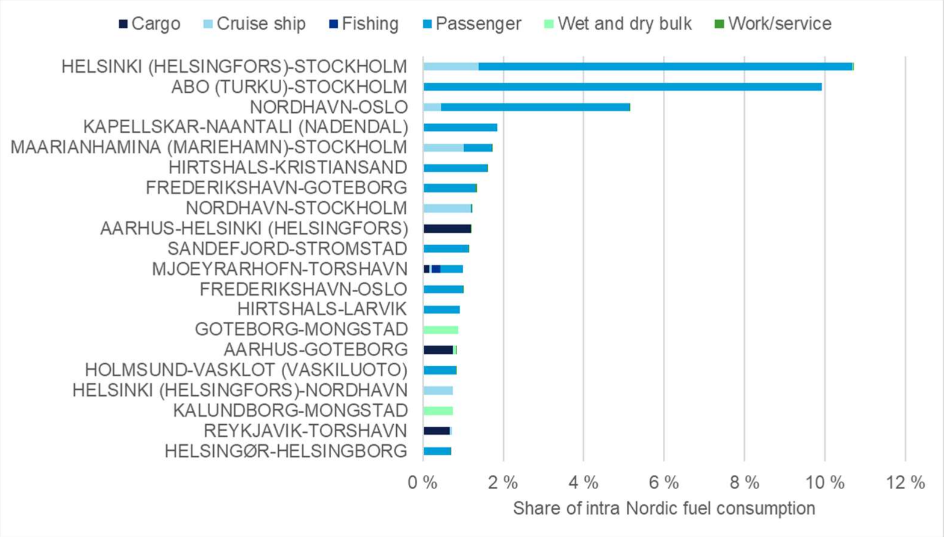
B4 Top 20 voyage connections – domestic, intra and international

The figure below shows the top 20 domestic Nordic voyage connections based on fuel consumption per ship category. Connections to and from the same port dominate (work/service and fishing vessels).



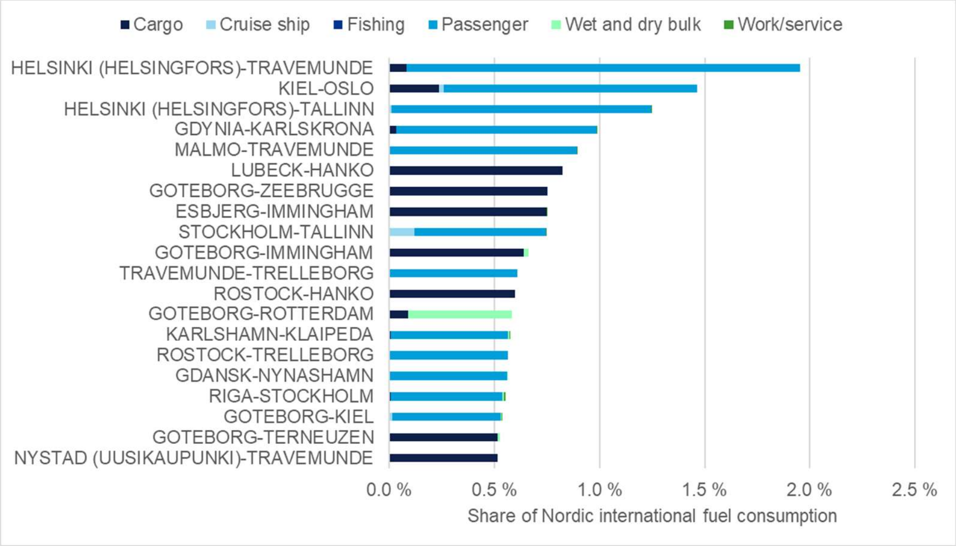
Top 20 domestic voyage connections.

The figure below shows the top 20 intra Nordic voyage connections based on fuel consumption per ship category.



Top 20 Intra Nordic voyage connections (fuel consumption per ship category).

The figure below presents the total fuel consumption of top 20 Nordic international voyage connections.



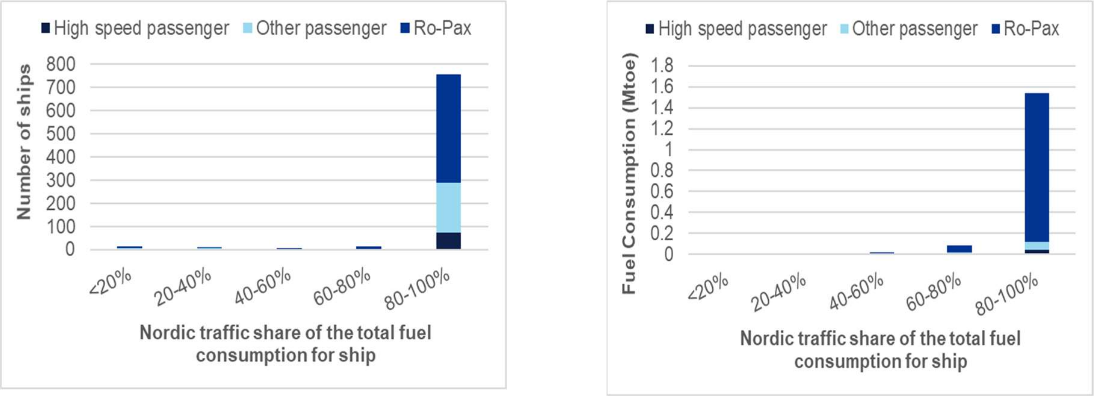
Top 20 Nordic International voyage connections.

B5 Statistics for time spent in Nordic waters per ship category

We can analyse how “Nordic” a ship’s overall operation is by looking at how much of the ship’s total fuel consumption is related to Nordic traffic. There are significant distinctions among the various ship categories and types. This can be useful information to assess the potential of “Nordic-specific” actions for decarbonization, and in what ship categories such actions may have the most effect. The following figures shows data for each of the six ship categories. The left plot in each figure shows how many ships within the given category have <20 %, 20-40%, 40-60%, 60-80% or 80-100% of their fuel consumption (and thus, operation) within Nordic ship traffic. We call these five percentage intervals the ship’s *Nordic operational share*. Furthermore, the right plot shows how the fuel consumption is distributed among the ships with different Nordic operational share.

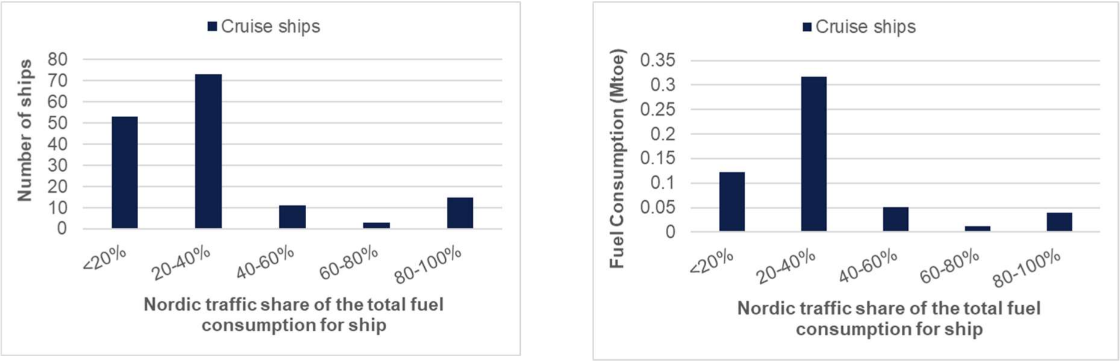
The figure below shows the case of passenger ships, where Ro-Pax stands for the majority of ships in number (left plot) and especially fuel consumption (right plot). Almost all ships have above 80 % of their annual fuel consumption within Nordic traffic, i.e. they are more or less constantly involved in Nordic ship traffic. The situation for cruise ships is as expected quite the opposite. Most of the fuel consumption is related to ships having 20-40% of their annual fuel consumption in Nordic traffic.

Passenger ships



Passenger ships - Number of vessels in each ship type (left), and fuel consumption (right) among the Nordic fuel share categories.

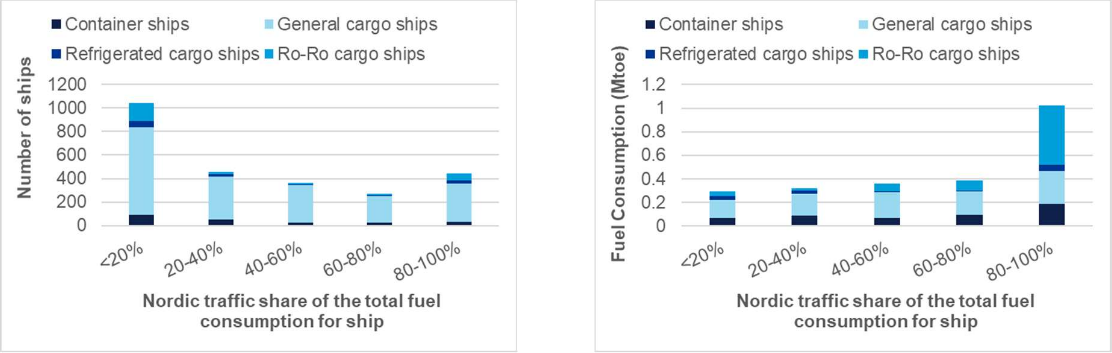
Cruise ships



Cruise ships - Number of vessels in each ship type (left), and fuel consumption (right) among the Nordic fuel share categories.

When it comes to cargo ships, most of ships are general cargo ships, and these stand for 12 % of fuel consumption in Nordic traffic (cf. Figure 4-3). These are however ships primarily operating to lesser degree in the Nordics. For Ro-Ro cargo ships, the situation is opposite: A relatively small number of vessels (65 vessels in 2019), stand for most of fuel consumption in the Nordic operational share category *80-100%*. This indicates that Ro-Ro is a ship type of which a substantial share can be said to be “Nordic” ships. These ships typically do round trips between Nordic countries and countries in North Europe.

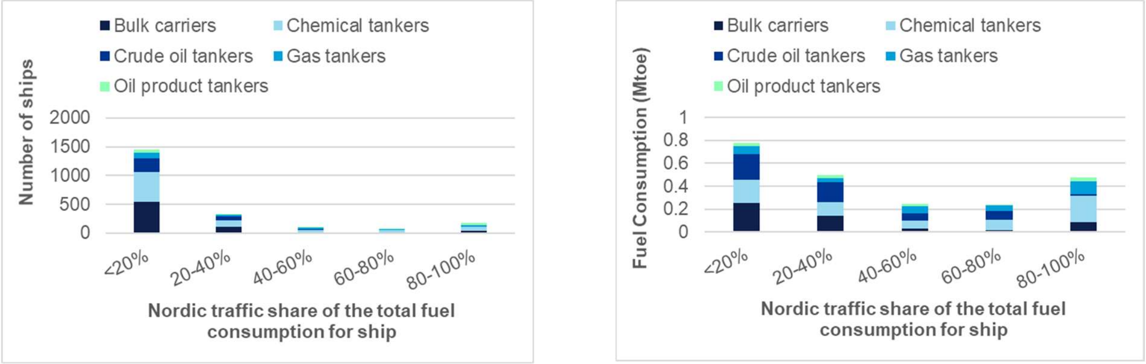
Cargo ships



Cargo ships - Number of vessels in each ship type (left), and fuel consumption (right) among the Nordic fuel share categories.

Looking at the wet and dry bulk ships (figure below), there are almost 1500 ships that have less than 20% of fuel consumption in Nordic traffic, dominated by bulk and chemical tankers. Chemical tankers however also stand out as the ship type having the most substantial share of ship with fuel consumption in the 80-100% category: Out of 786 chemical tankers, 74 have 80-100% Nordic fuel consumption, and these stand for one third of the Nordic fuel consumption for chemical tankers.

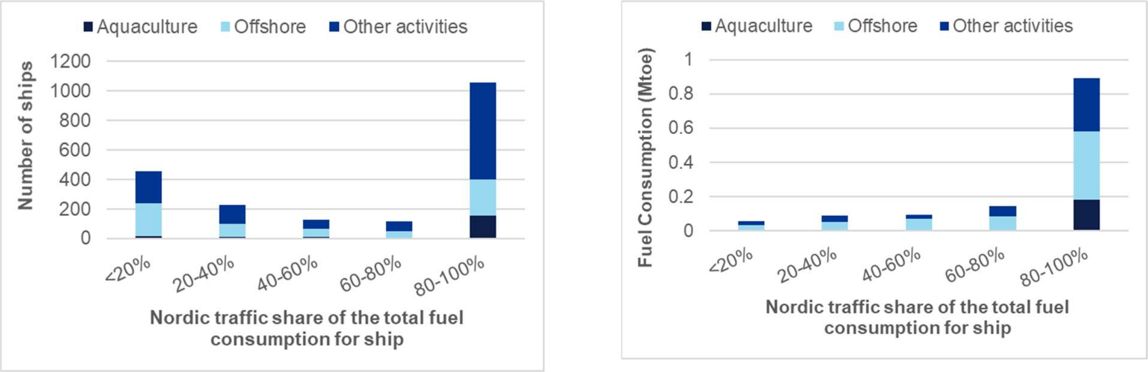
Wet and dry bulk



Wet and dry bulk ships - Number of vessels in each ship type (left), and fuel consumption (right) among the Nordic fuel share categories.

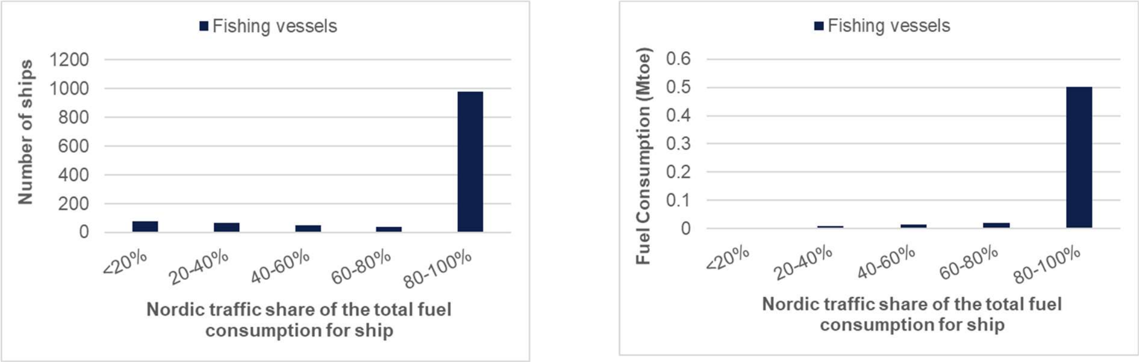
Turning to work/service ships and fishing vessels (figures below), these are category where most ships are “Nordic”, in the sense that they primarily operate in the Nordics. This is especially the case for fishing, where 80% of the ships have 80-100% of fuel consumption in the Nordics, standing for 92% of the fuel consumption within fishing. As seen in Figure 4-3, the most of work/service (including offshore, aquaculture and other activities) and fishing vessel traffic are domestic traffic.

Work/service ships



Work/service ships - Number of vessels in each ship type (left), and fuel consumption (right) among the Nordic fuel share categories.

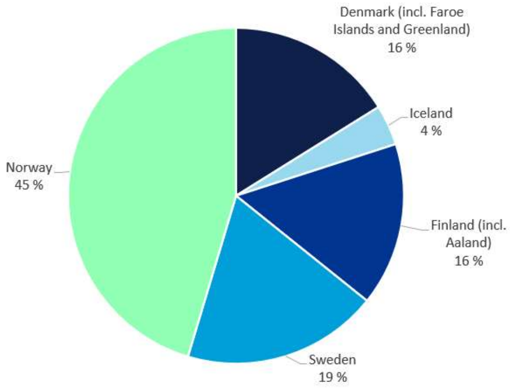
Fishing vessels



Fishing vessels - Number of vessels in each ship type (left), and fuel consumption (right) among the Nordic fuel share categories.

B6 Country by country traffic description

The figure below presents each Nordic country's share of the total fuel consumption from all Nordic ship traffic. Norway accounts for 45% of the total fuel consumption in Nordic ship traffic, followed by Sweden (19%), Denmark (16%), Finland (16%) and Iceland (4%).



Nordic countries share of total fuel consumption from all Nordic ship traffic

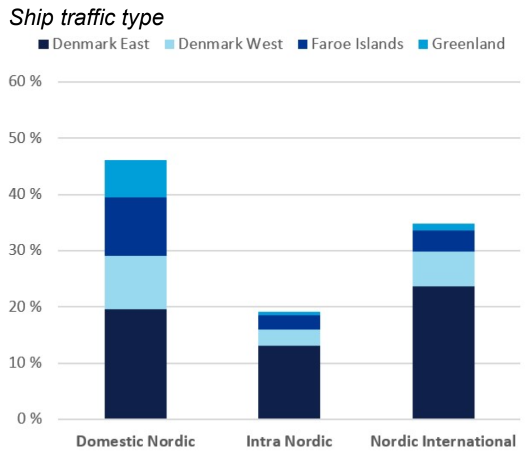
The plots on the next pages show a brief overview of the impact from each of the Nordic countries. All countries except Finland have its largest contribution to fuel consumption and hence CO_2 emissions from domestic ship traffic. For Denmark, the domestic traffic is mainly from the west of Denmark. All ship segments are represented in Danish ship traffic, but domestic passenger vessels and cargo vessels sailing from Denmark to a county outside the Nordic accounts for the highest share of the fuel consumption. Finland has mostly international voyages of cargo ships, mainly from the south of Finland. The total fuel consumption of Denmark and Finland is approximately the same and corresponds to around 1-million-ton fuel.

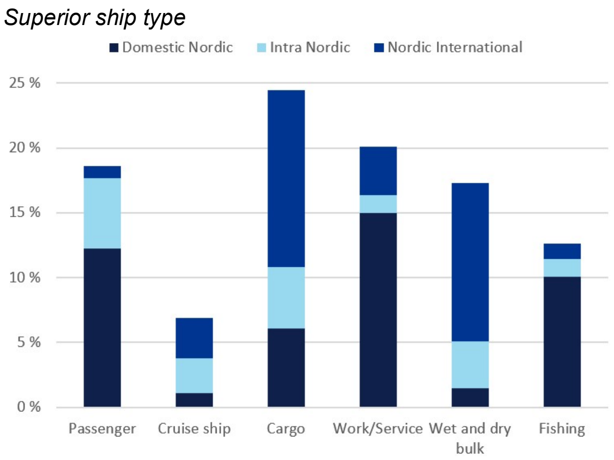
On the other hand, Iceland has a fuel consumption of approximately 240k tons. This fuel is mainly consumed by domestic fishing vessels. Norway has the highest fuel consumption of all Nordic countries, corresponding to 2,8million-ton fuel. This is mainly covered by domestic work/service (offshore) and passenger vessels, and international wet and dry bulk voyages. Sweden has the second-largest fuel consumption of approximately 1,2 million tons, where international sailing accounts for the largest share. Sweden has international voyages for both passenger, cargo, and wet/dry bulk vessels. In general, the passenger segment accounts for the largest energy demand in Sweden, including both domestic, intra Nordic, and international routes.

A brief overview of the impact from each of the Nordic countries. The total share in each bar chart is referring to the total fuel consumption for voyages with start port in the respective country.

DENMARK

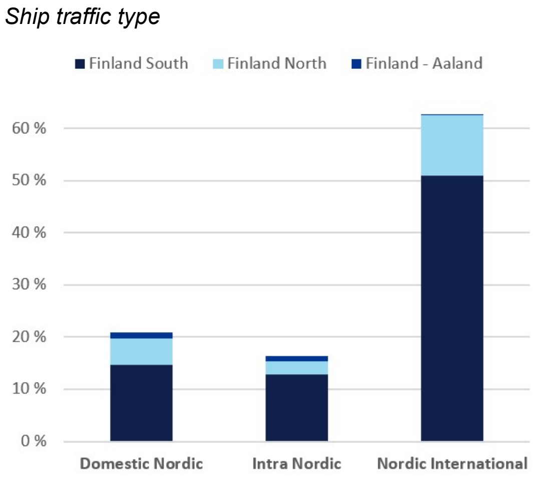
Total fuel consumption for voyages starting in Denmark: 998 827 ton (16.1% of total)

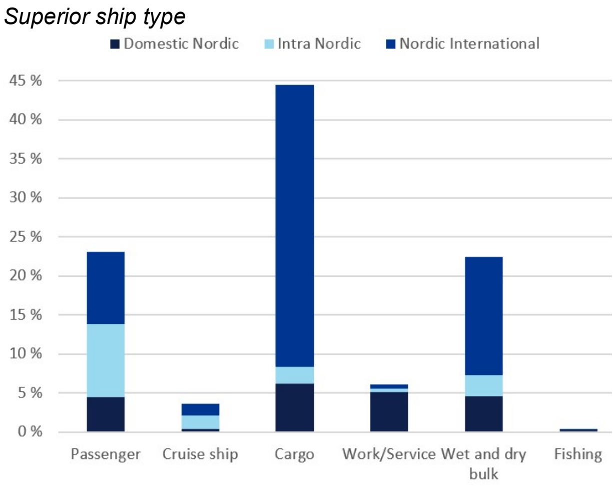




FINLAND

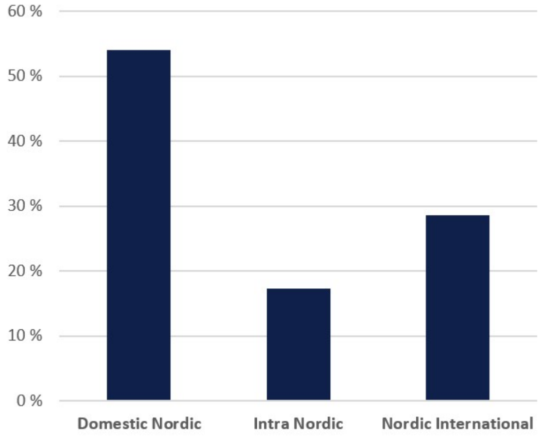
Total fuel consumption for voyages starting in Finland: 974 060 ton (15.7% of total)

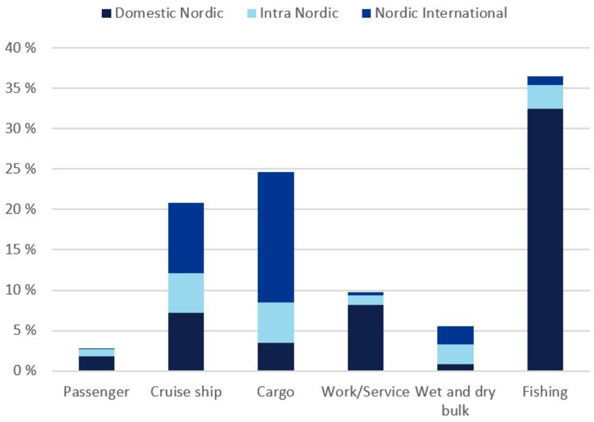




ICELAND

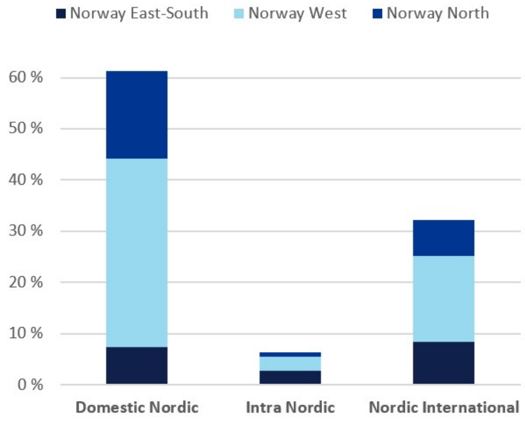
Total fuel consumption for voyages starting in Iceland: 240 542 ton (3.9% of total)

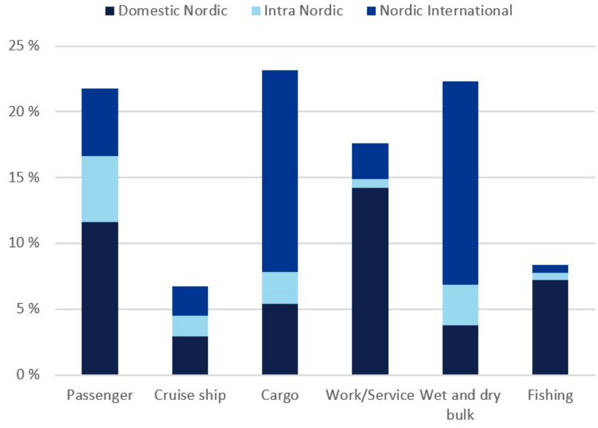

Ship traffic type


Superior ship type

NORWAY

Total fuel consumption for voyages starting in Norway: 2 808 497 ton (45.8% of total)

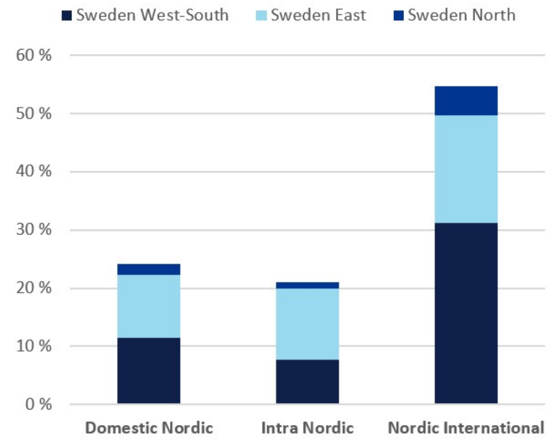

Ship traffic type


Superior ship type

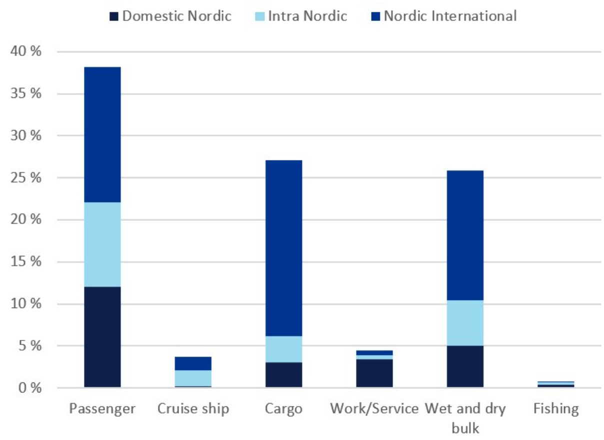
SWEDEN

Total fuel consumption for voyages starting in Sweden: 1 168 066 ton (18.9% of total)

Ship traffic type



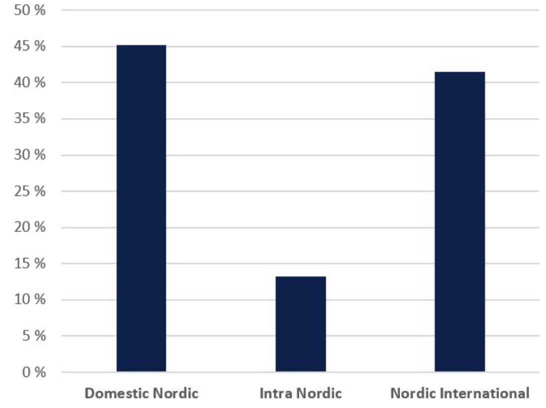
Superior ship type



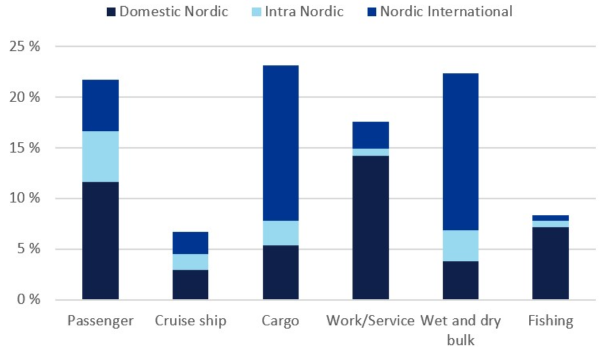
ALL NORDIC

Total fuel consumption for voyages starting in All Nordic: 6 189 993 ton (100% of total)

Ship traffic type



Superior ship type



B7 Maps showing dominating ports

The figure below shows Nordic ports each with energy demand[64] higher than 1 % of *total* Nordic traffic, i.e. all traffic from the Nordics is included. The five largest ones are Helsinki, Gothenburg, Stockholm, Mongstad and Tromsø. Among non-Nordic ports, Rotterdam, Kiel and Travemünde are top 3.

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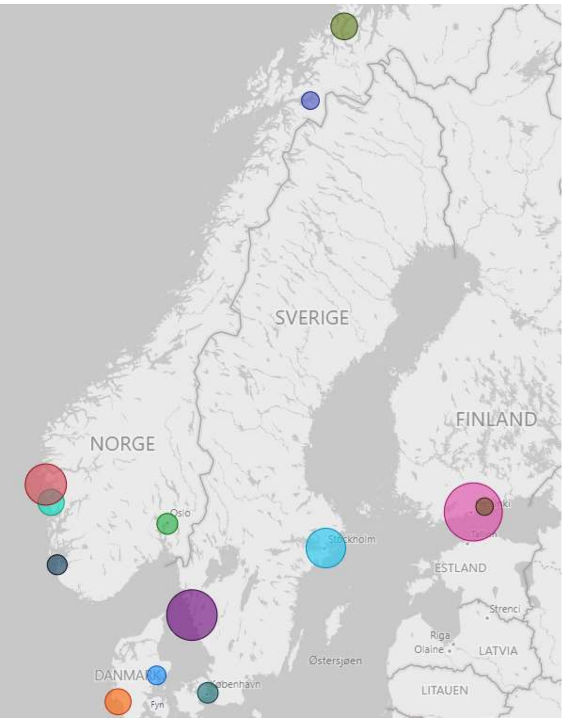
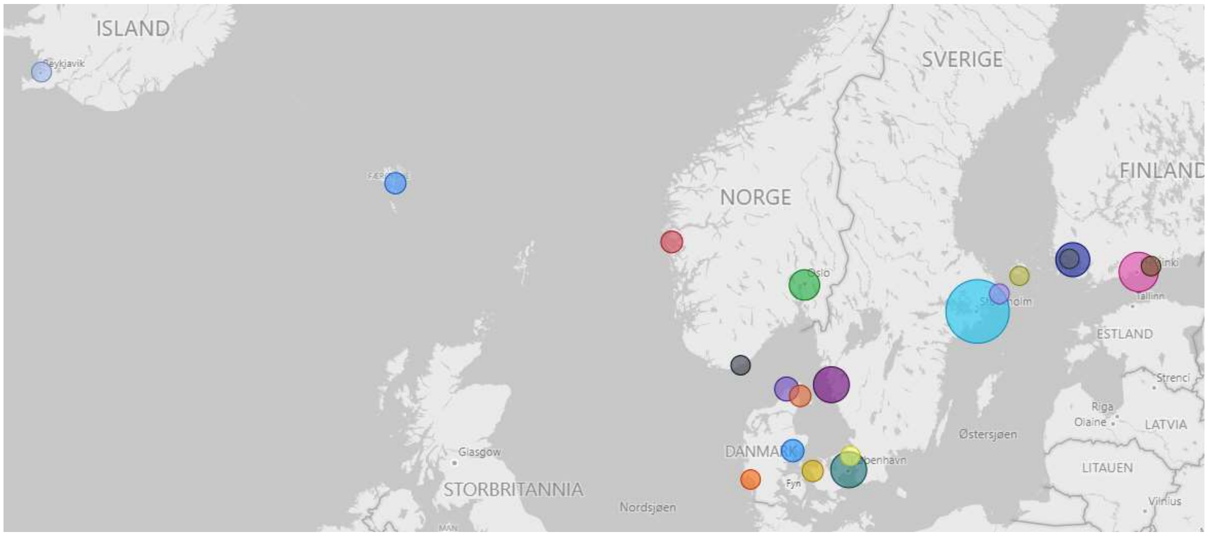
[64] By a port's *energy demand* we here mean the total consumption of all voyages departing from that port. This should not be confused with current bunkering locations.



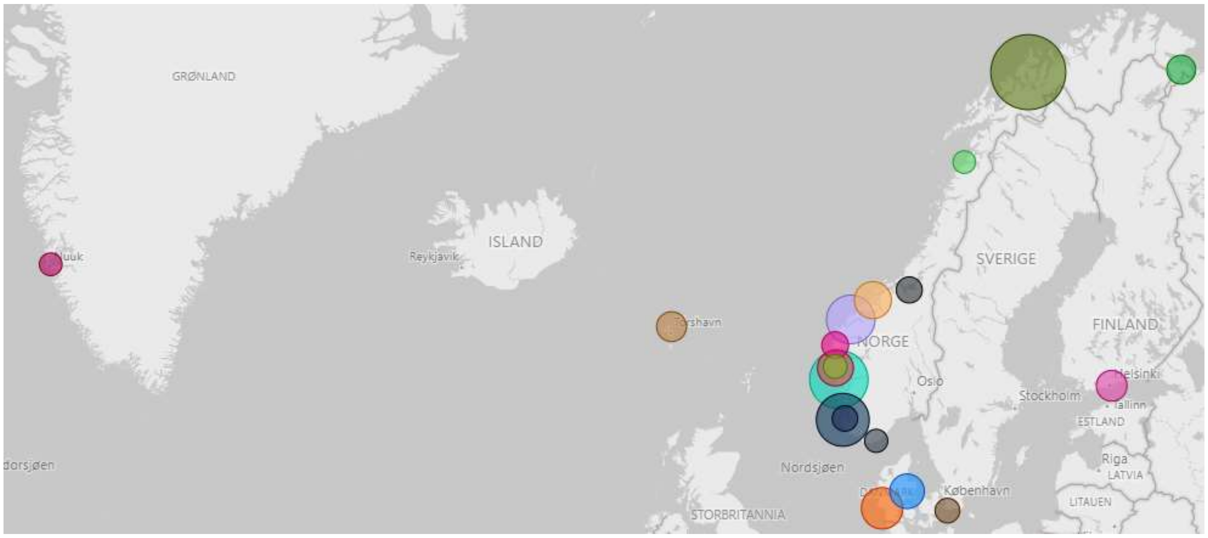
Ports with above 1 % of total Nordic traffic fuel consumption. Largest circle = 240 000 tonnes; smallest = 91 000 tonnes.

The figure below shows Nordic ports with energy demand higher than 1 % of *intra* Nordic traffic, i.e. fuel consumption for only intra Nordic voyages from the port is included. Stockholm is the port with highest potential energy demand from intra Nordic ship traffic, followed by Helsinki, Gothenburg, Copenhagen and Åbo (Turku).



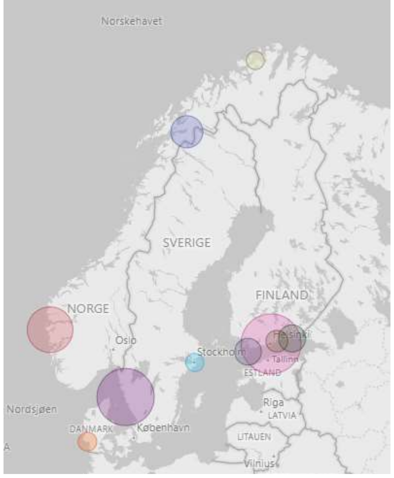
Ports where more than 1 % of total intra Nordic voyage fuel consumption. Largest circle = 105 000 tonnes; smallest = 8 000 tonnes.

The figure below shows Nordic ports with energy demand higher than 1 % of *domestic* Nordic traffic, i.e. fuel consumption for only domestic voyages from the port is included. The five largest ones are Tromsø, Bergen, Tananger, Ålesund and Esbjerg.



Ports with more than 1 % of total Nordic domestic voyage fuel consumption. Largest circle = 100 000 tonnes; smallest = 28 000 tonnes.

The figure below shows Nordic ports with energy demand higher than 1 % of *Nordic international* Nordic traffic, i.e. fuel consumption for only international voyages from the port is included. The five largest ones are Helsinki, Gothenborg, Mongstad, Narvik, and Kotka.



Ports with more than 1 % of total Nordic international voyages fuel consumption. Largest circle = 150 000 tonnes; smallest = 50 000 tonnes.

DNV

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.