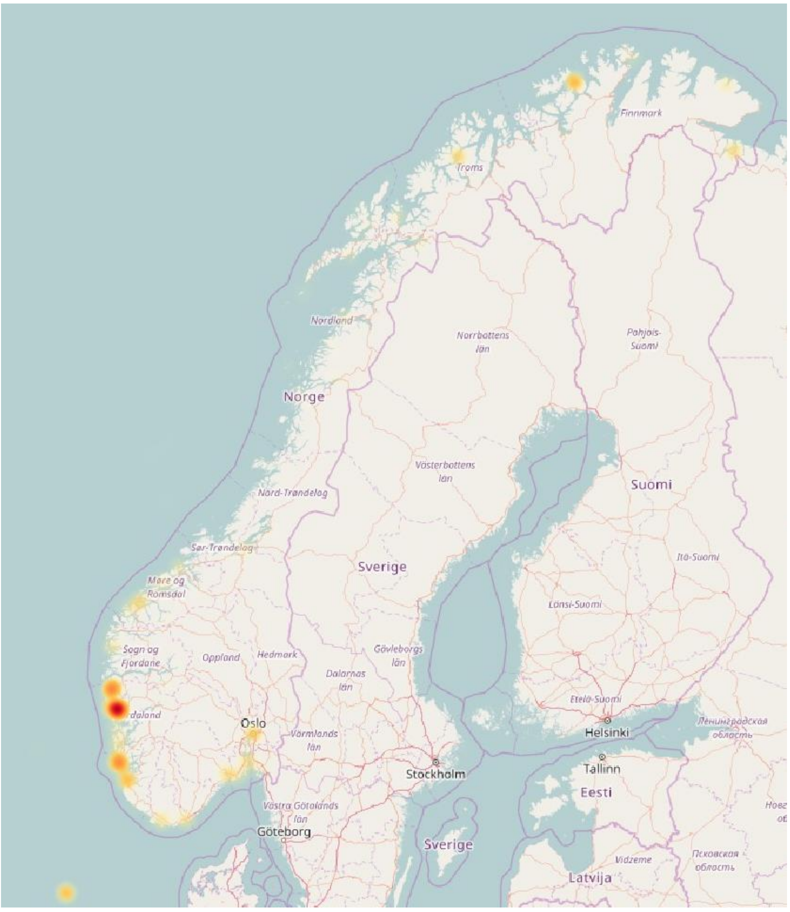
ANALYSIS OF CHARGING- AND SHORE POWER INFRASTRUCTURE IN NORWEGIAN PORTS

ReCharge

ENOVA SF

Report No.: 2017-0101, Rev. 0
Customer Ref.: 15/815
Date: 31.01.2017



Project name:	Analysis of charging- and shore power infrastructure in Norwegian ports	DNV GL Group Technology and Research Tel: + 47 95927110
Report title:	ReCharge	
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Date of issue:	31.01.2017	
Project No.:	911A0348	
Organisation unit:	GGRNO911	
Report No.:	2017-0101, Rev. 0	
Customer Ref:	15/815	

Applicable contract(s) governing the provision of this Report:

Objective: The main objective of the project is to analyse the emission reduction potential of developing charging- and shore power infrastructure for a number of Norwegian ports. The project will also seek to highlight the investment costs of the proposed infrastructure, and hence give different stakeholders access to potential business models and barriers for implementation.

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Keywords:
Shore power, Charging power, Big data analytics, AIS

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
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1 SUMMARY AND CONCLUSIONS

Ships move more than 80% of world trade by volume, and are by far the most energy efficient mode of transport. In fact, there is a large potential for coastal shipping to replace less efficient, but rapidly growing road transport. To make this prospect even more attractive, the maritime sector and its partners must pay attention to emissions and air quality – an area also likely to attract a lot more public scrutiny in the future. When a ship is docked, its energy requirement is typically met by on-board diesel-powered generators. This is not only an inefficient use of energy, but also results in emissions of greenhouse gases, local pollutants and noise. Utilization of power from shore can eliminate these negative consequences, and shore power facilities are likely to become more widespread, as ports and local authorities respond to the anticipated demand for charging on board batteries for propulsion of battery-hybrid ships and for fully electric ships, which are predicted to represent an increasing proportion of ships in the future.

Throughout the project, the use of AIS (Automatic Identification System) data in combination with ship technical data and engine characteristics, has been used to pinpoint where in a port emissions take place, where the reduction potential is highest and what kind of infrastructure needs to be developed to mitigate these emissions.

This methodology has identified Bergen as the port in Norway which stands to reduce consumption the most by developing shore power infrastructure. To showcase the importance of geographical location of the emission and their potential adverse health effect on the public, the NO_x emission for the different ports have been multiplied with number of inhabitants in the municipality in which the ports are located. Doing so, Bergen still comes out on top with Oslo, Stavanger and Tromsø following. For each port, the aggregated fuel consumption and related emissions for different ship types and sized have been identified.

Further a methodology for identifying which cargo ships that are eligible for pure battery propulsion, and their corresponding routes, have been established. This methodology identified that in 2016, 64 different vessels had an operational profile that would allow for pure battery propulsion. The ship types are; fishing vessels, tugs and smaller work boats, offshore supply vessels and general cargo vessels. Charging infrastructure for 97 different routes would have to be developed to facilitate battery propulsion for the before mentioned 64 ships. The emission reduction potential was found to be: 12517mt of CO_2 and 149133 kg of NO_x. Although the project has not calculated the investment cost on the ship side and port side, the estimated cost of facilitating such an infrastructure would be too high to defend the emission reduction potential. The ports are also spread out along the coast and are geographically fragmented, further increasing grid investment costs. On this basis, the project has concluded that a more suitable way of identifying charging infrastructure candidates is by focusing on the ports in Norway that handles the most freight. By developing charging infrastructure in key ports in southern Norway, the ports handling 76% of the freight from dry cargo ships could be covered by small feeder vessels with low power requirements running on battery power, like the ReVolt. A standard LV shore connection system would satisfy the charging need. Developing charging infrastructure in these ports could catalyst the uptake and building of new battery powered ships serving these ports as part of a new nationally integrated logistics chain.

As most ship types, from an energy efficiency point of view, would benefit from hybridization to various extents, developing charging infrastructure to serve plug-in hybrid ships could yield environmental and cost benefits. The degree of hybridization, intended operational use and power requirement would, however, vary from case to case. The project has therefore not been able to develop a generic methodology for identifying ships and routes that are applicable for plug-in hybridization. Instead, the project has chosen to focus on developing a methodology for evaluating the applicability of hybridization on a case by case basis.

To determine the cost effectiveness of the potential charging and shore power infrastructure projects, the ReCharge project has developed a cost calculator, based on cost figures from existing and completed projects, to give users a rough estimation on cost and emission reduction potential. The cost calculator is set up to be in compliance with the LV and HV shore connection standards.

Several case studies from the port of Oslo has been presented in the report;

Sjursøya container terminal:

- 45 ships called the berth in 2016, whereas 5 contributed to 50% of the consumption
- A power output of 946kW is needed to serve existing traffic
- A LV shore connection system is needed
- Average lay time is 12,5 hours per ship
- Total yearly emission reduction potential is; 1 129mt fuel, 3 579mt CO_2 and 49 680kg NO_x
- Total cost of connecting 5 ships is estimated to 4,2 million USD, 77 USD/ CO_2-tonne and 5,5 USD/NO_x-kg

Vippetangen ferry terminal:

- 3 ships called the berth
- A power output of 1 194kW is needed to serve existing traffic
- A HV shore connection system is needed
- Average lay time is 4,4 hours per ship
- Total yearly emission reduction potential is; 1 022mt fuel, 3 241mt CO_2 and 15 272kg NO_x
- Total cost of connecting 3 ships is estimated to 2,2 million USD, 23 USD/CO_2-tonne and 4,8 USD/NO_x-kg

Plug-in Ro-Pax

- Battery power between Port of Oslo and Filtvedt
- Power output of 3 631kW is needed
- A HV shore connection system is needed
- Average lay time is 4,4 hours
- Total yearly emission reduction potential is; 2 499mt fuel, 7 921mt CO_2 and 179 901kg NO_x
- Total cost of the project is estimated to 15,2 million USD, 64 USD/CO_2-tonne and 2,8 USD/NO_x-kg

The use of power from shore by ships is not new, and several projects worldwide have been realized over the past few years. Still, several barriers exist today that hampers a wide introduction of shore power. Barriers that needs to be addresses if shore power infrastructure is to be expanded to the point where it could scale commercially and deliver fleet- and nationwide environmental benefits. The project has addressed the different barriers and concerns voiced by the industry and tried to list measures needed to overcome these. The barriers have been grouped in technical, financial, regulatory, environmental and market barriers. The most important finding from the barrier study is that market mechanisms may in many cases not be enough to have a user initiated development of shore power infrastructure. Long term governmental funding is hence needed to maintain momentum in the development of the infrastructure.

The ReCharge project recommend that business models are adapted to reflect traffic type. Regular traffic, like ferry and fixed cargo routes, supports a business model which allows for a direct customer-supplier relationship between the ship owner and the grid provider. Irregular traffic, like cargo terminals, supports a business model where ports act as an intermediary between the ships and the grid provider. In the latter case; the ports have the possibility of exploring different revenue opportunities either related to selling electricity or increasing port dues.

2 ACKNOWLEDGEMENTS

This report is the product of a multi-disciplinary team effort, comprising different expertise from the involved project partners. The extended project team consists of:

Name	Responsibility
Hans Anton Tvete (DNV GL)	Project manager, AIS analyses, environmental assessment, financial assessment, barrier study, business models, film production
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Bjørn-Johan Vartdal (DNV GL)	Project Owner

The project management team wish to extend their gratitude towards the project members invaluable contribution to the project and its results.

3 INTRODUCTION

The shipping industry moves more than 80% of world trade by volume, making it an integral and vital part of the global economy. Seaborne trade is also expected to grow in line with, or possibly outpace, the global GDP growth. Although shipping has significantly lower CO_2 emissions per tonne-kilometre relative to road and air transport, the industry still accounts for a significant share of global emissions of CO_2, NO_x and SO_X, giving it a substantial environmental footprint /1/. Currently there is an increasing global focus on reducing greenhouse gas emissions to keep the temperature rise below 1.5 to 2°C, as decided in the COP21 meeting in Paris. Although shipping was left out of the agreement, it is expected that the maritime sector will experience increased scrutiny to lower its emissions and improve air quality in coastal areas in the future. This is exemplified by the Norwegian national transport plan/2/, which has the following ambitious goals:

- New ferries and fast ferries to operate on biofuel, low- or zero emission technology.
- Charging- and shore power infrastructure to be available in the biggest ports, and the ports with the highest emission reduction potential, of Norway within 2025.
- 40% of all ships in Norwegian short sea shipping shall use biofuel or be low- or zero emission.
- Norwegian transport shall be virtually emission free by 2050.

One way of improving energy efficiency and reducing local pollution and greenhouse gas emission is using electric power from shore. When a ship is moored, it no longer requires energy for propulsion. However, there are still consumers on board, including lighting, heating/cooling and auxiliaries etc., which needs energy. This energy requirement is largely met by on board diesel-powered generators running at part loads, which leads to emissions of greenhouse gases, local pollutants and noise. This also often occur in densely populated areas directly exposing people to pollutants that can give adverse effects on health /3/. As a mitigation alternative to using on board diesel-powered energy generation, electricity from shore power grids can be applied /4/. In addition, for plug-in battery-hybrid ships and for fully electric ships, shore power can be used for charging on board batteries for covering all or parts of the energy required for propulsion. These ships are expected to represent an increasing proportion of ships in the future, and the adoption of these types of propulsion systems are directly dependent on the infrastructure for shore power.

In this report; shore power is referred to as using shore side electricity to power a ship's consumers and/or charging a ship's batteries while alongside a port facility.

Shore power used for covering hotel loads while the ship is moored is not new, with several installations in ports worldwide. However, using shore power for propulsion as facilitated by on-board energy storage facilities has only been realized for a few ships – mainly for ferries in Norway. This limited adoption of using electricity from shore is due to a number of barriers limiting a wider introduction of shore power. The ReCharge projects seeks to identify these barriers and how they should be addressed in order for shore power to scale commercially to the point where it delivers fleet- and nationwide environmental benefits.

In addition; in 2014, DNV GL introduced the unmanned, zero emission, short sea container concept ship ReVolt /5/. To achieve zero emission operation, the ReVolt made use of batteries for propulsion and auxiliaries. In order to realize a concept of a fully battery powered short sea cargo vessel, a charging infrastructure must be expanded. In this respect, a research question is to identify the added power capacity needed to serve a ship like the Revolt?

Consequently, the ReCharge project has the objective to analyse the emission reduction potential of developing charging- and shore power infrastructure for several Norwegian ports. The project has also estimated the investment costs of the proposed infrastructure on-shore and on-board in order to inform the stakeholders about opportunities and barriers for implementation. The secondary objectives that will lead to the achievement of the primary objective are:

WP1: Analyse the need for shore power at different ports.

WP2: Estimate the emission reduction potential.

WP3: Estimate the investment and operational expenses. The return of investment on both ship and shore side is to be calculated.

WP4: Propose new business models that render the development of charging- and shore power infrastructure possible. Barriers for implementation will be highlighted.

4 SHORE POWER, WHAT IS IT?

When a ship is moored, it no longer requires energy for propulsion. However, there are still consumers on board, including lighting, heating/cooling and auxiliaries etc. which needs energy. Traditionally, this energy requirement is largely met by on board diesel-powered generators. This leads to emissions of greenhouse gases, local pollutants and noise. These negative consequences also often occur close to populated areas where the general population can be directly exposed and experience negative health effects. As a mitigation alternative to using on board diesel-powered energy generation, electricity from shore power grids can be applied /2/. In addition, for plug-in battery-hybrid ships and for fully electric ships, shore power can be used for charging on board batteries for covering all or parts of the energy required for propulsion.

In this report; shore power is referred to as using shore side electricity to power a ship's consumers while alongside and/or charging on-board energy storage devices. Electrical power supply from shore when a ship is out of service, in a docking, maintenance and repair situation, is not considered as using shore power by this report.

4.1 Shore connection standards

To ensure a standardized, quality assured, safe and effective way for ships to connect to shore grids, both a high voltage (IEC/ISO/IEEE 80005-1)/6/ and a low voltage (IEEE/PAS 80005-3)/7/ standard have been established. The low voltage standard is, however, still pending final approval. The HV standard covers applications where the power requirement is in excess of 1000KVA and the LV standard covers power requirements below or equal to 1000KVA. By standardizing the shore connection systems, ships can call at multiple ports without the need of adjustments to their installed systems. In addition to the before mentioned benefits of efficiency and safety, a standardized way of connecting allow for more utilization for the installed connection systems on board and in port, improving the overall business case and return of investment. The standards set requirements to the design, installation and testing of the following HV and LV shore connection systems and components:

- Shore distribution systems
- Shore-to-ship connection and interface equipment
- Transformers/reactors
- Semiconductor/rotating convertors
- Ship distribution systems
- Control, monitoring, interlocking and power management systems

4.2 Shore power components

To power vessels at berth, additional infrastructure on shore and onboard ships is required, because electrical power available from on-shore grids is not adapted to vessels' requirements in terms of voltage, frequency and earthing. Furthermore, safety features need to be integrated, all of which are standardized as per the before mentioned standards.

4.2.1 Transformer station

An electrical substation is required to convert voltage and frequency of the electrical grid to those required by vessels and specified by relevant standards, including electrical protection equipment. Upstream and downstream medium voltage (MV) cable connections from the grid to the power conversion system, and from the conversion system to the connection point on the vessel are also required.

4.2.2 Frequency converter

One major component of the charging- and shore power system is the frequency converter (FC). As per the shore connection standards an FC needs to be supplied where the shore grid frequency deviates from the ship-board frequency. Most ships today operate with an on-board grid frequency of 60hz. The Norwegian shore grid has a frequency of 50hz, hence conversion is in many cases needed. An FC is the most costly component in a charging and shore power system.,

4.2.3 Cable management system

A cable management system (CMS) ensures safe handling of cables during connection and disconnection procedures. The position of the CMS is also defined in the IEC standard: for all vessel types, other than container ships, the CMS needs to be installed onshore. Container ships are required to have on board cable reels due to space constraints on the berth. Another key area to consider is choice of sockets, plug and connectors. The ship–based CMS consist of electrical connectors (up to 12kV), flexible cables, a slipring, an optical fiber accumulator, a motor reducer, a cable drum, an electrical control panel, a retractable hydraulic cable guide and an alarm system that monitors the cable for tension and drift. A second alternative is similar to the ship-based version, where the CMS fits inside a standard cargo container and stored on board the ship, either aft or forward of the accommodation block. As the system is entirely modular, the container can be moved per vessel or loading requirement's. For both systems, a pit that is installed into the quay is designed to occupy minimum amount of space, locations are spread out per vessel types at the quay.

4.2.4 On board connection panel and control system

On board installations include a MV connection switchgear to manage power and ground connections, step-down transformer to the vessels voltage(s) level(s) as required; a receiving control panel will include the adaption of the existing MV or LV switchboard to receive shore power and synchronization through the control device. If required, a power management system is installed on board the vessel to manage shore connection and disconnection operation.

4.2.5 On board transformer

Where applicable (ship voltage different from shore connection voltage), an onboard transformer is needed to adapt the high voltage supply to the ship's main switchboard voltage. This transformer is preferably located near the main switchboard in a dedicated room.

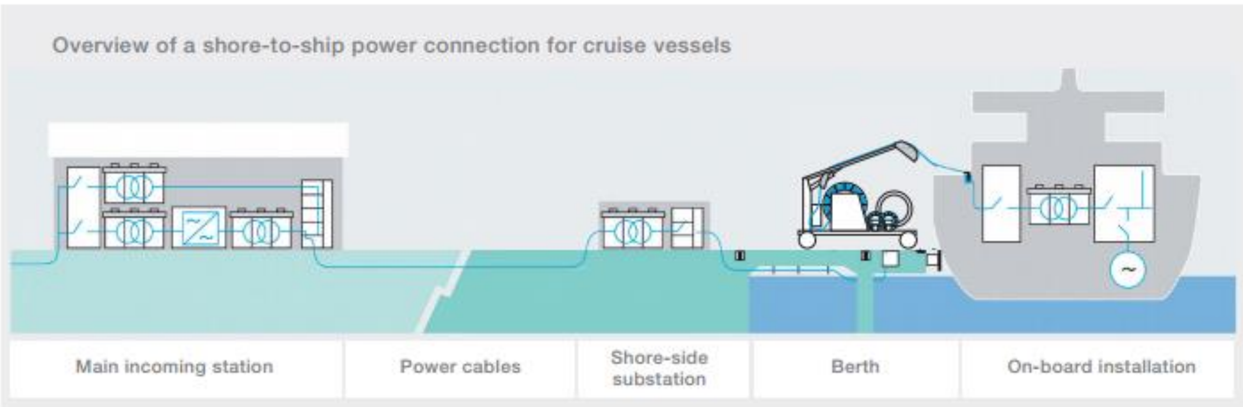

Figure 1: Overview of shore power components (source: ABB)

5 AIS

Originally designed as a collision avoidance system, the Automatic Identification System (AIS) automatically transmits information about any specific ship to all other ships in the area and to coastal authorities at intervals of a few seconds. The information transmitted includes a unique ship identity code, a precise position reference, and the ship's heading and speed. The ship identity can be used to extract additional information from other relevant ship registers and databases /8/.

Today, the use of AIS has extended beyond its original purpose. Authorities have developed applications ranging from identifying high-risk ships, to search and rescue operations and environmental inventory calculations /9/, while several commercial stakeholders offer business intelligence analyses and forecast services based on ship movements /10/.

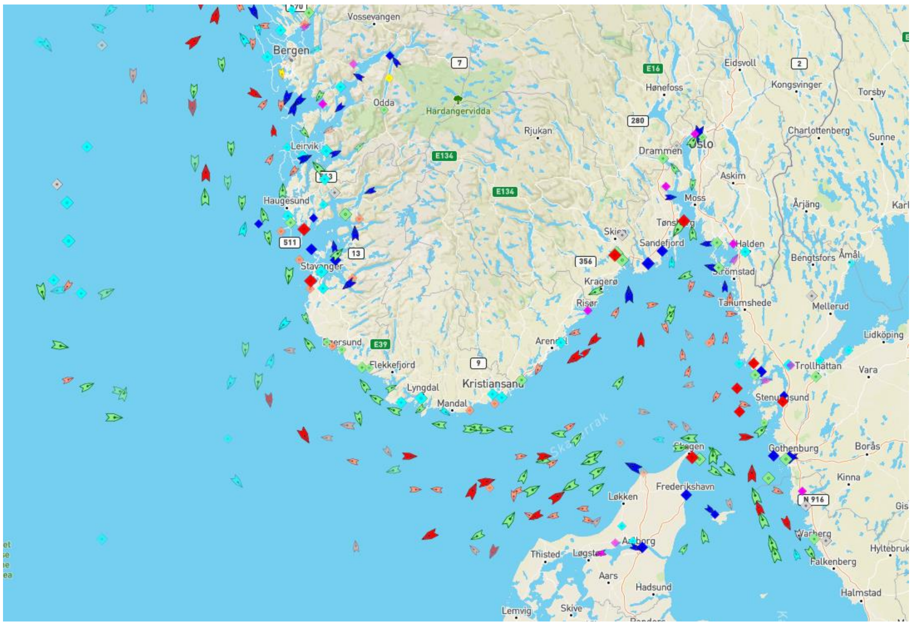

Figure 2: Snapshot of ship movements from MarineTraffic.com

DNV GL is in possession of AIS data that covers worldwide ship movements, and have for many years (2003) developed methodologies and competence within processing, analysing and visualization of AIS data. One particularly important feature required for achieving the objectives in this study is to accurately obtain ship fuel consumption and related emissions. Today, the fuel consumption for most ships is measured and monitored based on manual daily reports from the crew. These reports come in a variety of formats, are fragmented and are in many cases considered business sensitive information and not publicly available. Consequently, utilizing ship measurements for calculating fleet wide consumption and emission inventories is difficult. To overcome this challenge, DNV GL uses AIS-based models for gaining insight into operations and estimating fuel consumption and associated emissions. In this study, historical AIS data in combination with ship technical data, engine characteristics and emission factors has been extensively used to estimate fuel consumption, local and global emissions and for dimensioning the capacity of charging and shore power infrastructure to serve current traffic. These calculations can in turn also be assigned to any specific geographical areas, e.g. a port area. In this study, this is a feature that has been particularly important for identifying which ports that has the highest consumptions and emissions and therefore the biggest reduction potential.

5.1 Methodology for identifying and dimensioning shore power infrastructure

Figure 3 shows graphically the methodology developed in the ReCharge project for identifying locations of where development of shore power infrastructure is most promising and how to dimension this infrastructure based on existing traffic.

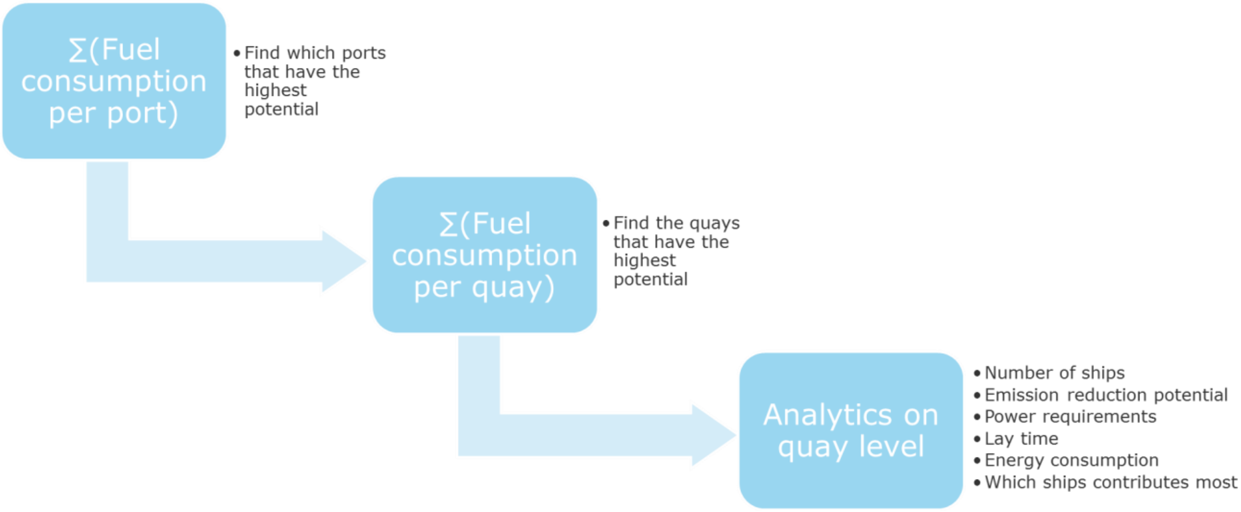

Figure 3: Methodology for dimensioning shore power infrastructure

The first step of this methodology builds on the approach first developed by (Martinsen K., et.al., 2015) /4/, for identifying which ports that have the overall biggest emission reduction potential. Based on auxiliary engine fuel consumption from ships laying still alongside, the ports with the highest yearly aggregated fuel consumption are prioritized and identified as the most promising ports in which to develop shore power. This information says something about the overall potential for reduction in a port, but since ports vary greatly in size, in terms of area and number of quays it is necessary to expand the granularity in order to find out where in a port the majority of fuel consumption takes place. Doing this is the next step in the methodology.

To easily being able to identify and pinpoint where in a port most fuel consumption is concentrated, the project has developed a map based solution. The map based solution is built on the QGIS[1] open source software. Based on coordinate-specific auxiliary engine fuel consumption from all the ships that has been calling a port, a heat map is added to the map. This heat map represents the density of all the auxiliary engine fuel consumption records within a given map view over one year, meaning the density of all the AIS records weighted on auxiliary fuel consumption. This approach makes it easy for the user to see where in the port the focal points are and where the reduction potential is the highest. An example of this step in the methodology can be seen in figure 4, where Bergen is detailed and Skoltegrunnskaien identified as the quay with the highest fuel consumption. Ships already capable of receiving, and are using, power from shore are filtered out.

[1] http://www.qgis.org/en/site/

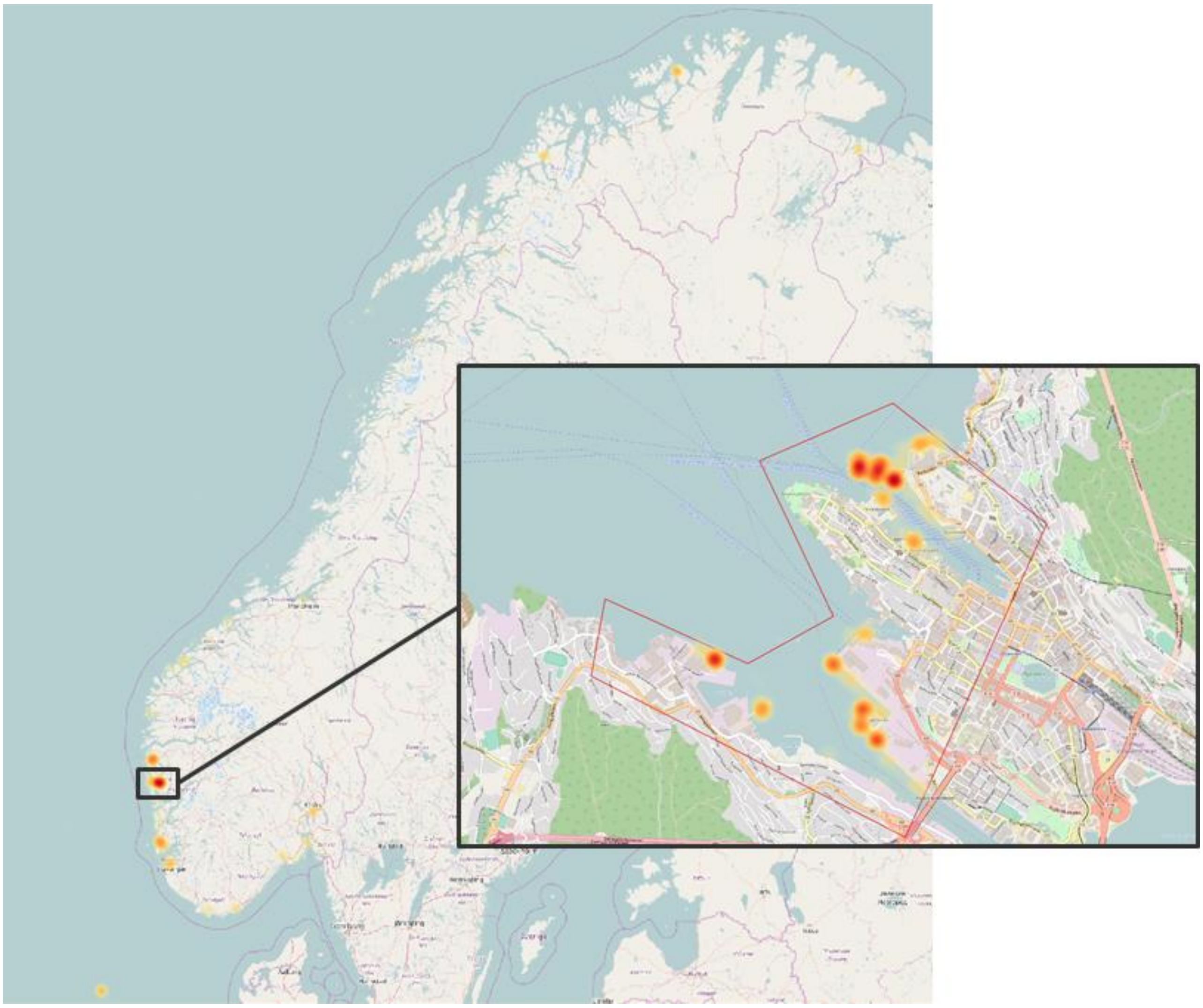

Figure 4: Heat map of auxiliary engine consumption in the port of Bergen

With the ability to pinpoint which quays in the port the reduction potential is the highest, the next step of the methodology is to dimension the shore power infrastructure needed to serve existing traffic on those quays. In the ReCharge project the following metrics are calculated:

- Total auxiliary engine consumption
- Total emissions (CO_2, NO_x, SO_x and PM)
- Number of ships calling the quay
- Which ships contribute the most to the total consumption
- Power requirement in port for each ship
- Power requirement to serve concurrent use and charging
- Lay time
- Energy consumption

In order to obtain the power requirement for the ships laying alongside on the selected quay, table 1 has been utilized. The matrix details average power requirements for different ship types of different sizes. This matrix is also used by ENOVA /11/ as guidance to applicants who seeks funding to develop shore power infrastructure and need to establish the kWh-potential for a quay.

Table 1: Power requirement matrix

Skipskategori / Størrelse	<= 999 GT	1000 - 4 999 GT	5 000 - 9 999 GT	10 000 - 24 999 GT	25 000 - 49 999 GT	50 000 - 99 999 GT	>= 100 000 GT
	Estimert kraftbehov i havn per skip [kW]						
01. Oljetankere	37	161	352	476	646	834	1 032
02. Kjemikalie-/produkttankere	106	289	531	723	864	1 434	1 536
03. Gasstankere	111	254	667	836	1 078	2 816	3 556
04. Bulkskip	26	80	132	197	261	350	438
05. Stykkgodsskip	12	66	149	259	416	579	704
06. Konteinerskip	31	121	332	473	864	1 535	2 295
07. Ro Ro last	28	94	213	415	529	668	736
08. Kjøle-/fryseskip	44	153	319	542	672	800	960
09. Passasjer	20	119	272	570	1 194	2 100	2 912
10. Offshore supply skip	45	144	345	553	912	1 144	1 248
11. Andre offshore service skip	42	149	251	417	575	643	685
12.Andre aktiviteter	28	173	344	569	988	1 282	1 600
13. Fiskefartøy	43	149	284	454	454	454	454

Not only will this information serve as input for dimensioning the magnitude of power needed to be installed, but also when coupled with the lay time for each specific ship, the total energy consumption (kWh) and reduction potential can be obtained. This input is also important when calculating the cost benefit of shore power compared to burning fuels.

Another benefit associated with this methodology is the ability to highlight which ships that are contributing most to the fuel consumption. This is a parameter that give insight into how easy and realistic it will be for the calling ships to make use of the infrastructure, should this be developed. A quay, where few ships call frequently and contributes to most of the consumption and corresponding emissions, has a better chance of putting the infrastructure to good use as compared to a quay which sees a multitude of ships calling once because the business case for the frequent callers would be improved with increased use of the infrastructure. It is therefore important to look at the quays where the consumption is the highest, but also to balance this against the quays where the potential for making use of the infrastructure is most promising.

It should be noted that in a port facility, most ship types often have their designated terminals and quays that they call. However, there are exemptions, particularly for dry cargo ships (general cargo, container, car and bulk). The fact that similar ships often call the same quays is beneficial from a standardization point of view, as this makes it easier to adhere to the ship specific requirements in the LV and HV standards concerning voltages, frequencies and ship to shore interfacing.

6 PORT SELECTION

The first step in the beforementioned methodology is to identify the ports which, from a fuel consumption point of view, are most eligible and will reap the most benefits from developing a shore power infrastructure. In this section, only the consumption related to power requirements while alongside is accounted for.

Table 2 lists the top 22 ports in Norway with respect to aggregated auxiliary engine fuel consumption in 2016. This is the consumptions that can be mitigated and reduced by utilizing shore power. From the table, Bergen stands out with a distinctively higher consumption than the rest. One reason for this can be the recent drop in the oil price and corresponding downturn in activity for offshore supply ships, which has led to said ships spending more time in port. It should also be noted that oil and gas refineries are high up on the list (e.g. Mongstad, Kårstø, Slagentangen and Melkøya). These ports are often visited by big, high consuming tank vessels.

Table 2: Ports eligible for shore power

Port	Fuel consumption (mt)	CO2 emission (mt)	NOx emission (kg)
Bergen	23366	73671	1027583
Mongstad	13308	41563	605094
Husoy	8612	27253	377769
EKOFISK	7933	25148	356328
Agotnes	7899	24945	350744
Tromso	6114	19284	272272
Kirkenes	5432	17180	237978
Oslo	5406	16713	200966
Karsto	4228	13094	190519
Alesund	4207	13228	186868
Lyngdal	3808	12071	177863
Slagentangen	3707	11721	171228
Stavanger	3467	10843	152553
Hammerfest	3438	10871	172437
Batsfjord	3344	10302	142994
Floro	3325	10164	135973
Tananger	3291	10006	133179
Porsgrunn	2737	8569	117987
Trondheim	2701	7968	104814

Kristiansand	2466	7804	109286
Melkoya	2259	7162	117251
Bodo	2242	6591	87529

Even though the existing shore power infrastructure in Norway is modest, a few ships still connect and make use of such technology daily. In addition to this, alternative fuels like LNG and cleaning technology like catalysts and exhaust gas recirculation offer emission reductions to different extents. The figures in table 2 have been corrected to reflect this.

- Ships running on LNG are estimated to have a 90% reduction in NO_x emissions and 20% reduction in CO_2 emissions.
- Ships having catalysts installed are estimated to have an 80% reduction in NO_x emissions.
- Ships already utilizing shore power are estimated as having a 100% reduction in consumption and emissions from their auxiliary engines.

As a result of these abatement measures, the port of Oslo has a lower NO_x emission per fuel consumed.

Figure 5: Heat map of auxiliary engine consumption from Norwegian ports in 2016

It should also be noted that even though auxiliary engine consumption is reduced, fuel consumption from steam generating boilers would still occur for many ships. For some ship types, this consumption component could amount to as much as 50% of the total consumption in port /4/. One can also argue that boiler consumption in port would increase as a consequence of shutting down the auxiliary engines, as boiler water is often pre-heated by circulating the water via the engines. With cold engines, no pre-heating takes place. In the case where a ship has installed exhaust gas boilers on the auxiliary engines and normally utilizes these during port operation, it would require the ship to fire up the auxiliary boiler for heat generation during shore power usage. Auxiliary boilers also typically use the auxiliary engine water cooling circuits to pre-heat the boiler feedwater. With the auxiliary engines out of operation, there will be no pre heating taking place which in turn will potentially lead to more inefficient and higher fuel consuming operation of the auxiliary boilers. As a result of this, shore power can only mitigate all consumption in port for ships with electrical heating or other means of heating from shore /12/.

According (Eide et. al., 2016) /13/, 7% of the total fuel consumption for ships within Norwegian waters come from ships moored in a port facility. Accounting for the requirements for boilers in port for some ships, one can argue that the fuel reduction- and corresponding greenhouse gas emission reduction potential is marginal. (Global maritime energy efficiency partnerships, 2017) /14/ even states that shore power is not the most cost effective climate initiative. Even though the climate mitigation potential of shore power is limited, there is a great potential for reducing local pollution and noise. This is further emphasised by the fact that boilers have a much lower NO_x emission per consumed tonne fuel than combustion engines. Reducing auxiliary engine consumption would therefore be relatively more beneficial from a local pollution point of view as compared to greenhouse gas emissions. In addition to this, ports are often located in urban and densely populated areas where the general population can be directly exposed and experience negative health effects from pollution. Multiplying the NO_x emissions from table 2 with the number of inhabitants in the municipalities in which the ports are located gives an indication of the potential impact of local pollution on health. This is shown in table 3 below.

Table 3: List of ports eligible for shore power - corrected for inhabitants

Port	NOx emission (kg)	Inhabitants	Score	Index
Bergen	1027583	277391	2,85042E+11	1
Oslo	200966	658390	1,32314E+11	2
Stavanger	152553	132644	20235240132	3
Tromsø	272272	73480	20006546560	4
Trondheim	104814	187353	19637217342	5
Kristiansand	109286	88447	9666018842	6
Fredrikstad	64945	78967	5128511815	7
Bodø	87529	50488	4419164152	8
Porsgrunn	117987	35955	4242222585	9
Haugesund	90276	36951	3335788476	10
Drammen	44388	67895	3013723260	11
Sandefjord	60254	45820	2760838280	12
Harstad	86489	24695	2135845855	13
Kristiansund	82394	24526	2020795244	14
Hammerfest	172437	10455	1802828835	15
Lyngdal	177863	8497	1511301911	16
Narvik	75637	18787	1420992319	17
Horten	41302	27178	1122505756	18
Sandnes	13432	74820	1004982240	19
Molde	34831	26732	931102292	20
Larvik	20754	43867	910415718	21
Moss	23872	32182	768248704	22

Doing this correction, we see that it is the major cities in Norway which potentially would benefit most from reduced NO_x emissions, with Bergen still on top. Emissions from refineries, oil platforms and offshore bases have fallen out of the list. It should be noted that evaluating health effects from reduced ship emissions is not part of the scope of the ReCharge project. NO_2 concentration, weather effects like wind force and direction, temperature and inversion effects and local topography are just a few factors that contribute to the proliferation and health effects from NO_x. One can, however, say that in general shore power will have a more positive effect on health in populated areas as compared to remote and scarcely populated areas. Because of this, and the fact that local emission mitigation plays a relatively more important role than GHG emissions, the project has chosen to include the table in this study to highlight the importance of picking the correct projects to prioritize when developing shore power infrastructure.

When awarding funding support to mitigate emissions, governmental bodies like Enova and the NO_x fund do not consider where the emission take place, with the consequences being that sub-optimal projects could receive funding.

A detailed list of the top 44 consuming ports in Norway can be found in appendix A. This list is also split into the same ship categories as detailed in table 1. The list also includes number of ships and total energy consumed per port and per ship category.

7 SHIPS AND ROUTES ELIGIBLE FOR BATTERY POWER AND THEIR CORRESPONDING CHARGING NEEDS

The previous chapter detailed which ports were most eligible for traditional shore power, serving the existing ships power requirement while alongside. An important research question in the ReCharge project has been to consider how shore power requirements will change with an increased level of charging for plug-in-hybrid and fully electric ships. Currently, only one ship in Norway is fully battery powered. This is the 'Ampere' ferry which operates on the Lavik – Oppedal connection on the west coast of Norway. There are, however, several ongoing fully electric ferry projects[2]. The Norwegian road administration has an ambitious environmental plan for the ferry crossings under their jurisdiction, and have incorporated zero or low emissions as a requirement when new contracts are awarded. Commuter ferries are in general very good candidates for pure battery propulsion as they are a ship type with frequent crossings on shorter legs, as suggested by (Mjelde A., Martinsen K., Eide M., 2015) /15/ and (Bellona, Siemens, 2015) /16/. However, ferries usually call dedicated quays which means that land based infrastructure developed for ferries may not benefit other ships. The potential of electrification of ferries is already well documented, and the project has therefore chosen to exclude ferries when investigating which ships and routes are most eligible for fully electric and hybrid propulsion.

This chapter investigates, based on traffic information AIS data, which cargo ships and routes in Norway that, from a technical point of view, are eligible for pure battery powered propulsion. Their corresponding charging requirements and emission reduction potential is also studied. In the previous chapter, it was argued that traditional shore power is predominantly a local emission mitigation measure. However, with potentially all fuel consumption from all operational modes being reduced, battery powered ships can have a significant GHG mitigation potential - albeit as long as the batteries are charged with renewable energy sources.

The project has not been able to develop a generic methodology for identifying ships and routes that are applicable for hybridization, meaning that only parts of the total on board power requirement is served by batteries. The reason for this is that most ship types, from an energy efficiency point of view, would benefit from hybridization to various extents. The degree of hybridization, intended operational use and power requirement would from case to case vary too much for the project to generically identify specific ships, routes and their corresponding charging needs. Instead, the project has chosen to focus on developing a methodology for evaluating the applicability of hybridization on an in case by case basis. A specific case study where hybridization could be a possibility and how this would impact shore power infrastructure is described in chapter 10.

7.1 Ships and routes

Unlike ferries, cargo ships call multiple ports with varying sailing distance between them. This makes dimensioning the battery capacity and corresponding charging requirements more complicated. To determine whether a ship is eligible for battery power or not, the different ships and routes have been filtered against four criteria.

1) The ships would need to spend all their yearly operational time in Norwegian waters. Meaning that only domestic traffic is included and only routes between Norwegian ports are included. The reason for this criterion is to get an overview of the ships and routes where the Norwegian government can impact the development of charging infrastructure.

2) A vessel would need to have sailed a specific route at least twice to be included.

[2] http://www.tu.no/artikler/e39-far-to-tyrkiskbygde-el-ferger/348601

3) Rather than choosing crossing time /17/ as a criterion for applicability for battery propulsion, the project has chosen to set a limit on the energy requirement for the crossing. It is believed that this better incorporates the propulsion power requirement for each individual ship. The total energy consumption on the sea leg must be below 5000kWh. A ship would have to fulfil this requirement for all routes it operates to be eligible for battery propulsion. The energy requirement for each sea leg is calculated as follows:

$$P_{installed} \cdot 0{,}85 \cdot t_{sailing} = E_{sea\,leg} \quad \textbf{(1)}$$

Where:

$P_{installed}$ is the installed power of the actual ship in kW

The nominal continuous rating (NCR) is obtained by multiplying the installed power with a factor of 0,85

$T_{sailing}$ is the average sailing time for the voyage in hours

For a pure battery application, 5000kWh is quite substantial and some additional capacity would also be required to ensure a safety margin. As a reference, the battery ferry Ampere has a total battery capacity of 1000kWh installed, with an average crossing energy need of 150kWh, keeping in mind that the battery is not designed to be completely depleted for every crossing. However, there are significant investments in battery technology, and it is expected that batteries will deliver higher power density at a lower cost in the future /18/.

4) The charging power demand in the ports need to be less than 20MVA. This figure is chosen as it is the maximum recommended rating in the HV standard. The project has had to choose a general approach to estimate the charging needs for the different ships eligible for battery power. Charging power P is calculated as per the following formula:

$$\frac{(E_{sea\,leg} + E_{port})}{t_{laytime}} = P_{charging\ power}[kW] \quad \textbf{(2)}$$

Where:

E_{sea} leg is the energy demand on the sea leg in kWh

E_{port} is the energy demand in port in kWh

$t_{lay\ time}$ is the lay time in port in hours

This represents a very coarse way of identifying the most eligible ships and their corresponding charging requirements, and it is meant to serve as first step towards identifying the most promising candidates. Hence, more detailed calculations for each individual ship and routes will have to be carried out for more accurate dimensioning of battery size and charging requirements.

The ships eligible for battery power fall under 4 different categories:

- General cargo
- Fishing vessels
- Offshore supply vessels
- Other activities (typically tugs and smaller work boats)

Table 4 shows, as per the before mentioned criteria, how many ships within each ship category that are eligible for battery power.

Table 4: Number of ships, per ship type, eligible for battery power

Ship type	Number of ships
Fishing vessels	24
Other activities	21
Offshore supply vessels	7
Other offshore supply vessels	6
General cargo vessels	6
Total	**64**

The tugs and smaller work boats in the "other activities" category can be very good candidates for battery power or hybridization as they typically have time limited assignments with short transit times and high load variations. Such a solution can be applicable within a dedicated port, but transit between ports could prove more challenging for a pure electric solution. However, this can be solved by installing a diesel-powered generator as range extender in a plug-in hybrid solution. There are also several plug-in hybrid tugs having been deployed recently /19/.

Cargo ships, on the other hand, will have a much more diverse operational pattern. This is also the case for small general cargo ships, or so called tramp vessels. Tramp vessels carry a variety of cargo types, call at multiple ports and operate without a fixed schedule. All factors that makes it difficult to dimension battery sizes and corresponding charging needs. The type of cargo ship that lends themselves to utilizing pure electric propulsion are therefore ships operating on dedicated routes.

Several fishing vessels also figures on the list. This is a ship type which recently have explored battery propulsion /20/. Battery propulsion would, however, put restrictions the range and duration of individual trips.

There are also some offshore supply vessels (OSV) on the list. This is a ship category that, under normal operations, would not be eligible for pure battery propulsion. Carrying out dynamic positioning manoeuvres, with a high variation in transit times and cargo operations, would give a very high energy requirement. These ships likely figure on the list due to the recent downturn in oil related activity in Norway. Hybrid or plug-in hybrid solutions could, however, be very advantageous for OSVs.

The emission reduction potential, should all the cargo ships eligible for battery power be realized, is:

CO_2: 12517 mt

NO_X: 149133 kg

Table 5 gives the top 20 routes, sorted by number of voyages, in which the ships that are eligible for battery power currently traffic. The complete list can be found in appendix B.

Table 5: Routes where cargo ships eligible for battery power traffic

Route	# of ships	# of voyages	Total fuel consumption (mt)	Total CO2 emission (mt)	Total NOx emission (kg)
Alta - Alta	2	1096	72	229	3173
Karsto - Karsto	1	980	21	54	94
Narvik - Narvik	2	686	8	24	335
Kristiansund - Kristiansund	5	648	20	65	899
Hestvika - Hestvika	2	608	111	352	4898
Bergen - Bergen	6	578	217	686	9527
Horten - Horten	2	434	16	49	686
Farsund - Farsund	2	302	11	34	472
Husoy - Lenvik - Husoy - Lenvik	3	278	2424	7684	82731
Myre - Myre	3	250	62	195	2708
Berlevag - Berlevag	2	248	49	156	2167
Honningsvag - Honningsvag	3	220	73	233	3232
Harstad - Harstad	5	134	29	93	1288
Tromso - Tromso	4	84	5	16	224
Mo i Rana - Mo i Rana	1	84	1	3	48
Hoylandsbygda - Hoylandsbygda	2	82	7	21	270
Vedavagen - Vedavagen	1	68	7	22	312
Varoy - Varoy	1	60	13	40	553
Bremanger - Bremanger	2	52	34	108	1500
Askoy - Askoy	1	46	6	19	269

In total, there are 97 different routes that needs to develop charging infrastructure to facilitate the realization of the cargo ships eligible for battery power. Although the project has not calculated the investment cost on ship side and port side, the cost of facilitating such an infrastructure would be too high to defend the emission reduction. The ports are also spread out along the coast and are geographically fragmented to support a new logistic chain. The fact that many of the ports are remotely located, further emphasises the challenges as high investment cost in expanding existing grid infrastructure is likely to occur.

7.2 Ports with the highest freight potential

Depending on fuel prices, battery investment costs and the cost of infrastructure, battery powered ships have the potential to significantly reduce the energy and maintenance cost for a ship. Improving cost effectiveness can in turn lead to access to more cargo and hence alleviate some of the pressure put on Norwegian roads from road based transportation chains. Based on this, and the conclusion from the previous chapter where the ports were found to be too geographically fragmented to support a new logistics chain, the project rather wants to focus on the ports in Norway that handles most freight. Developing charging infrastructure in these ports could catalyse the uptake and building of new battery powered ships serving these ports as part of a new nationally integrated new logistics chain. This will also support the political decision on moving freight from road to sea as specified in the National Transport Plan /2/.

For 2016, the amount of cargo handled in a port *p* is estimated by the following equation:

$$\sum_{i=1}^{n} W_i \cdot C_{i,p} = Amount_p \tag{3}$$

Where:

W_i is the deadweight/cargo capacity of ship i

$C_{i,p}$ is the number of calls for ship i for port p

n is the number of distinct ships calling the port

As most large and weight intensive cargo already are predominantly transported on ships, only more volume intensive, dry and general cargo is accounted for in this analysis. Meaning that only the following ship types are included:

- General cargo
- Container
- RoRo
- Reefer

Table 6: Ports with the highest freight potential

Port	Amount (mt)
Oslo	7331943
Tananger/Risavika	6376821
Bergen	6006605
Husoy - Lenvik	5283535
Drammen	4328942
Larvik	4201360
Porsgrunn	3978229
Alesund	3904830
Brevik	3898171
Fredrikstad	3464739
Mo i Rana	3196532
Kristiansand	3046334
Moss	2870555
Tromso	2809694
Floro	2413040
Rekefjord	1794621
Sunndalsora	1635439
Trondheim	1600868
Thamshamn	1584149
Bodo	1463159

Many of the ports found in table 6 are located in some of Norway's biggest cities, which also figure in table 3. Table 3 details the ports where traditional shore power is found to be most promising taking number of inhabitants near the port into consideration. Hence, developing charging infrastructure will potentially further improve air quality in these cities and ports. So how would the power requirement change with expanding the infrastructure in these ports to include charging? As there currently are no battery powered vessels to draw experience from with regards to power requirements, we have estimated the energy requirements based on the distance between the identified ports.

The maximum distances between these 20 major ports are:

Trondheim – Mo I Rana: 257NM

Bodø – Tromsø: 196 NM

Sunndalsøra – Trondheim: 138 NM

Mo i Rana – Bodø: 118NM

Three of the above legs are in northern Norway (north of Trondheim). In southern Norway, the maximum distance is between Sunndalsøra and Trondheim with 138 NM. The rest of the distances in southern Norway are less than this. In addition, for the ports in the above table, 90% of the freight are handled in a port in southern Norway. When including all ports in Norway that handle dry and general cargo, 76% is handled in southern Norway and 24% is handled in northern Norway. Based on this information; small feeder vessels with low power requirements running on battery power, could operate in southern Norway if charging infrastructure were to be developed in key ports. This conclusion also coincides with the conclusions drawn in the development of concept ship ReVolt /5/, that it is possible to operate a small fully battery powered ship along the coast of southern Norway. The ReVolt has an average charging requirement of 456kW for 4 hours. In the worst case scenarios, this charging requirement goes up to 1356kW over 4 hours. However, by allowing for some extra charging time (6,8 hours) the charging power can be reduced to 800kW, well within the LV standard. Hence, it would not increase the power requirement for a traditional LV shore power system. Being within, and adhering to, the LV standard, this also allows for increased use by other ships wanting to make use of the equipment.

In northern Norway, hybridization will be a more suitable solution for cargo ships in the shorter term.

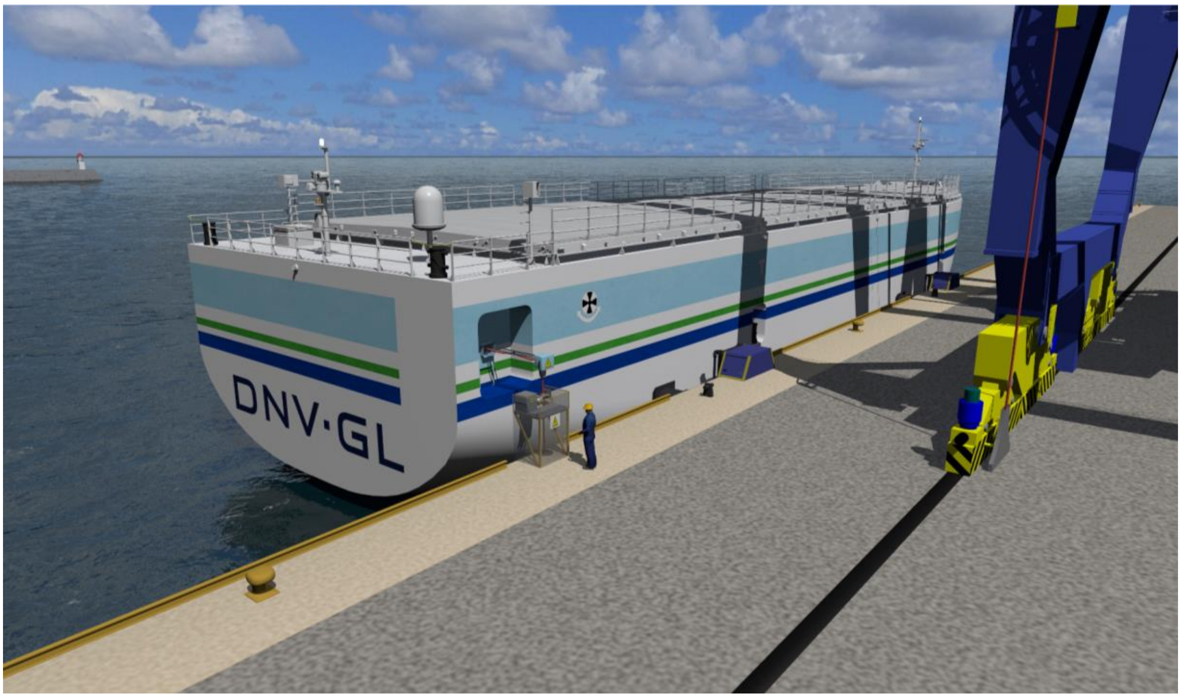

Figure 6: The ReVolt concept ship ((c) Toftenes Multivisjon AS)

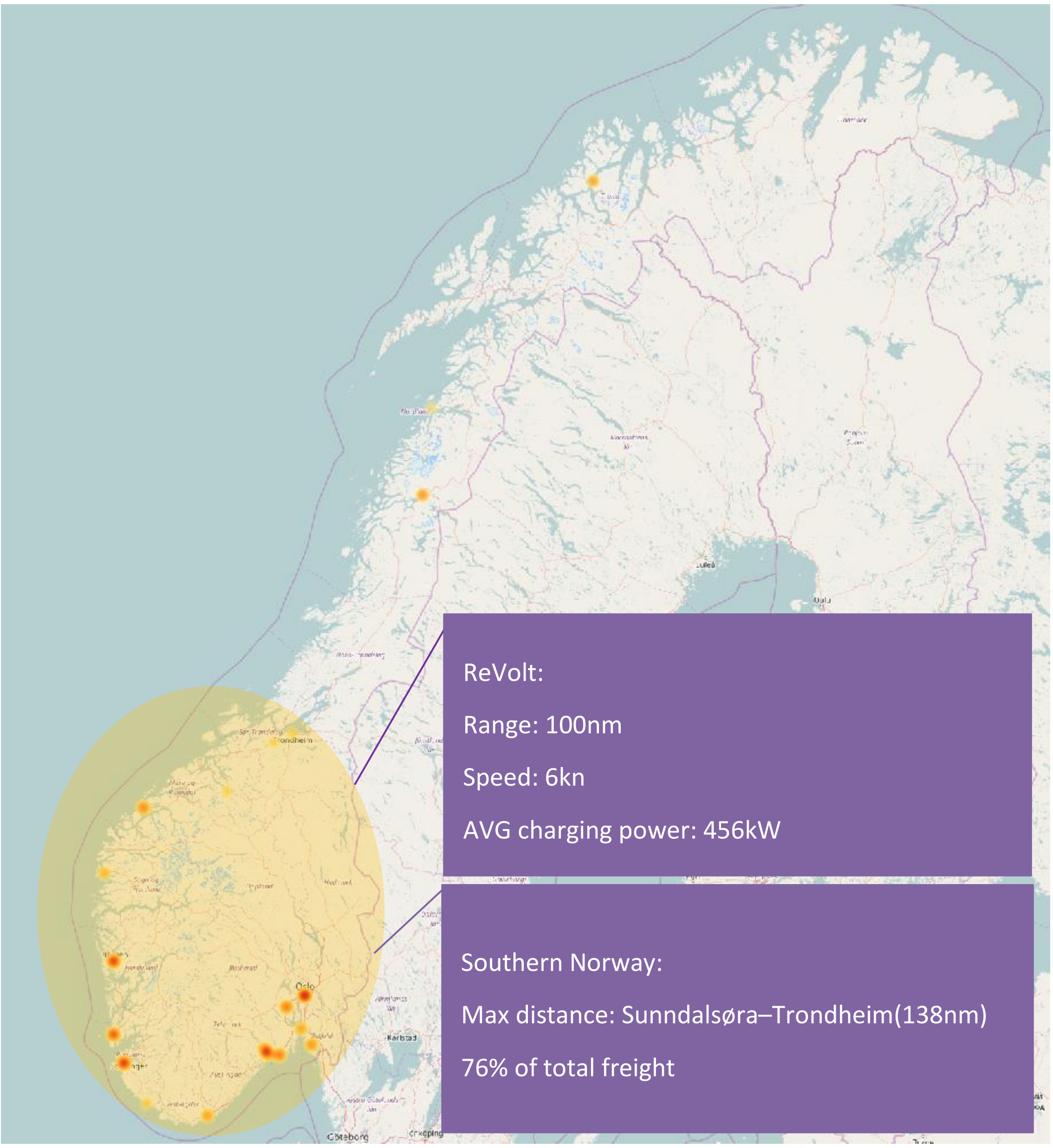

Figure 7: Heat map of ports that handles most freight

8 COST CALCULATOR

The previous chapters have detailed the approach and importance of choosing the right projects when investing in charging and shore power infrastructure from a geographical, traffic and emission reduction point of view. The next step is to further tune the methodology to evaluate the cost effectiveness of the different cases.

To determine the cost effectiveness of the potential charging and shore power infrastructure projects, the ReCharge project has developed a cost calculator, based on cost figures from existing and completed projects, to give users a rough estimation of cost and emission reduction potential. As there are many factors that can drive the cost in different directions from case to case, the cost calculator is meant to serve as a decision gate tool only. One major cost driver is the need to carry out investment in the on-shore power grid to support the different projects. This is a factor which vary heavily from port to port, and the ReCharge project have been unsuccessful in obtaining a generic [cost/cable meter] factor for calculating this. Consequently, the project has chosen to set the boundaries for the calculator to cover costs from the port transformer station to the ships. Reference is made to the components described in figure 1. The calculator is further split in two parts covering the ship side and port side respectively.

The cost effectiveness of the investment is calculated in two ways, financial and environmental:

1) Financially the cost effectiveness is based on calculating return on investment (*ROI*), in years, for investing in the infrastructure.

$$ROI\left[years\right] = \frac{\sum_{i=1}^{n} C_i}{I} \qquad \textbf{(4)}$$

Where:

C is the cost of the investment for year *i* over *n* depreciation years

I is the yearly income (for ports) or savings (for ships)

2) Environmentally the cost effectiveness *E* is calculated by dividing the investment cost on the emission reduction potential for emission component *e*.

$$E_e\left[NOK\,/\,Tonnes\ emissions\ reduced\right] = \frac{C}{\sum_{i=1}^{n} R_{i,e}} \qquad \textbf{(5)}$$

Where:

C is the total investment cost

R is the emission reduction for year *i* over the lifetime of the investment *n*

Capital cost is not included in the environmental cost effectiveness factor, as this cost has the potential to be covered by governmental funding bodies and is assumed to be depreciated immediately.

The cost calculator is set up to be in compliance with the LV and HV shore connection standards described in chapter 4.1, meaning that it will apply constraints as per the standards concerning ship type and power demand.

Further assumptions are:

- When calculating the kVA, an assumed power factor of 0,8 is used
- An on-board cable length of 45 m for cable management systems is assumed
- Two connection points per cruise ship is assumed
- In cases where the ship power demand is as per the HV standard, but the on-board rated voltage is low voltage, the cost of an on-board transformer is added.
- For hybrid and fully electric ships, the calculation is made based on the max power demand when charging.
- The cost of a centrally placed, on-board, cable management system is 1,2 times as high as a port or starboard placed one.
- The cost of a mobile cable management system is 1,2 higher than a fixed one.
- The calculator assumes that ships would require retrofitting of the on-board components.

Although the following ship types are not mentioned in the standards, the calculator assign them to the following corresponding standard:

Table 7: Ships not mentioned in the shore connection standards

Fishing vessels	IEC/ISO/IEEE 80005-3, Annex C, LVSC Systems General requirements
Chemical/product tankers	IEC/ISO/IEEE 80005-1, Annex F, HVSC Systems General requirements IEC/ISO/IEEE 80005-3, Annex E, LVSC Systems General requirements
Bulk ships	IEC/ISO/IEEE 80005-1, Annex F, HVSC Systems General requirements IEC/ISO/IEEE 80005-3, Annex E, LVSC Systems General requirements
PCTC's	IEC/ISO/IEEE 80005-3, Annex D, LVSC Systems General requirements IEC/ISO/IEEE 80005-1, Annex D, HVSC Systems General requirements
General Cargo	IEC/ISO/IEEE 80005-3, Annex D, LVSC Systems General requirements IEC/ISO/IEEE 80005-1, Annex D, HVSC Systems General requirements
Reefers	IEC/ISO/IEEE 80005-3, Annex D, LVSC Systems General requirements IEC/ISO/IEEE 80005-1, Annex D, HVSC Systems General requirements

It should be noted that ferries sort under RORO passenger ships in the standard. It is, however, likely that ferry crossings will be subject to much more tailor made shore power systems.

The cost calculator has been used when calculating cost in the case studies in chapter 9.

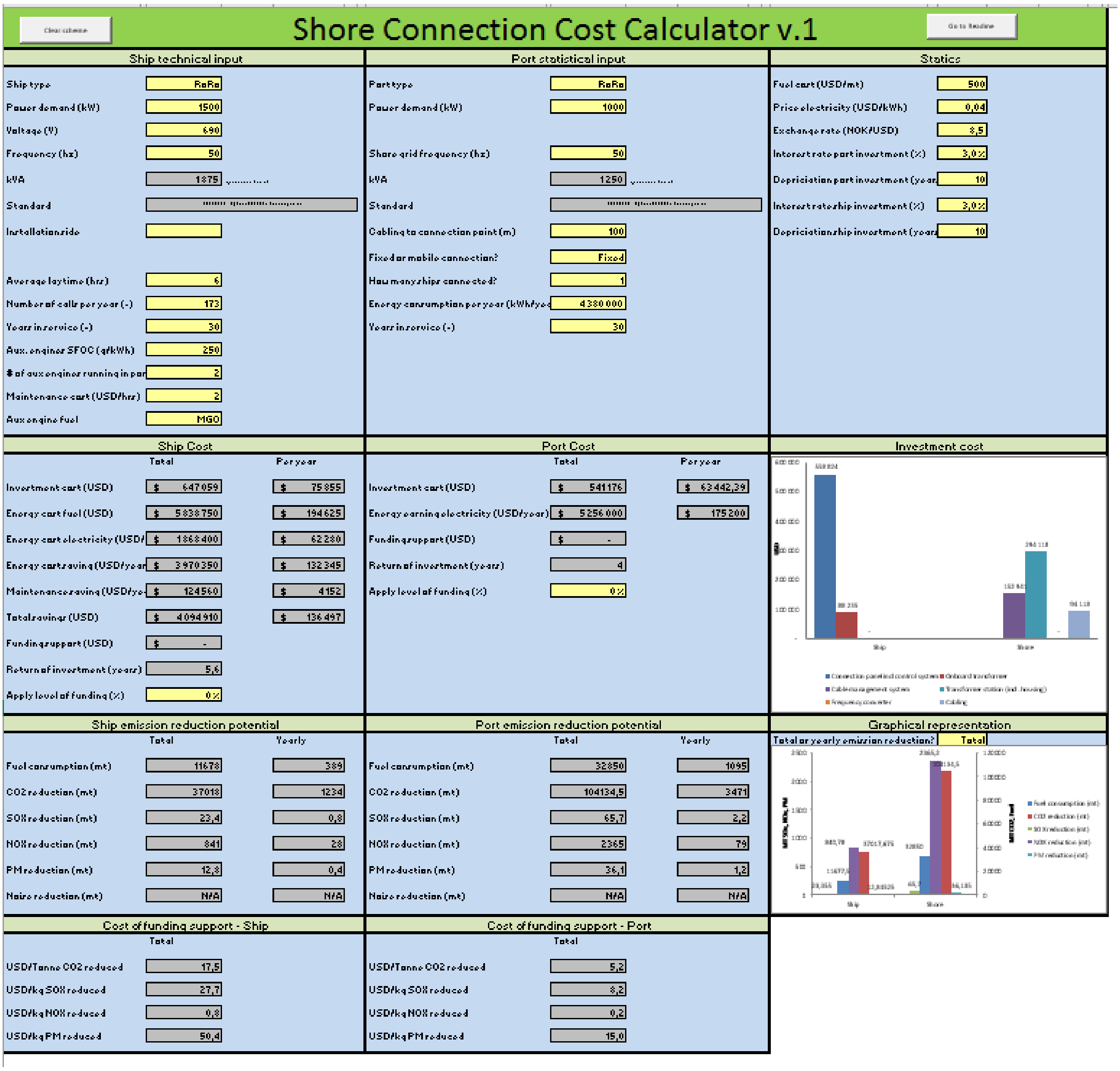

Figure 8: Shore power cost calculator

9 CASE STUDY – SHORE POWER IN THE PORT OF OSLO

In this chapter, the beforementioned methodology is applied to the port of Oslo. The decision to investigate the port of Oslo in detail is due to the following factors.

1) Oslo struggles with high concentrations of local air pollution. In order to mitigate pollution at days with pollution concentration considered to be harmful to health, diesel cars are being prohibited /21/. This occurs, especially during winter, with increased wood burning, driving with studded tires and increased NO_x emissions from cold car engines. The negative impact is further catalysed by weather effects like inversion which happens more frequently in the winter time /17/.

2) Oslo is the most populated city in Norway, and local emission mitigation could therefore give a significant health benefit.

3) As per findings in chapter 8.2, Oslo is the port in Norway which handles most general cargo. It is therefore a key port for expanding charging infrastructure to serve cargo vessels.

9.1 Traffic and emission reduction potential

All in all, 391 different ships called the port of Oslo in 2016. An overview of the different ship type and sizes can be seen in table 8. The ship category with the most ships is small general cargo vessels.

Table 8: Number of ships in the port of Oslo in 2016

# of ships	**Ship size**							
Ship category	**1. < 1000 GT**	**2. 1000 - 4999 GT**	**3. 5000 - 9999 GT**	**4. 10000 - 24999 GT**	**5. 25000 - 49999 GT**	**6. 50000 - 99999 GT**	**7. >= 100000 GT**	**Grand Total**
Other activities	32	1		1				34
Bulk ships	2	7	4	1				14
Chemical-/product tankers		22	24	34	4			84
Container ships		1	19	21				41
Oil tankers	2	1		3	1			7
Passenger ships	7	5	1	3	12	20	7	55
Ro Ro ships		1		3				4
General cargo vessels	8	116	26	2				152
Grand Total	**51**	**154**	**74**	**68**	**17**	**20**	**7**	**391**

However, as described in the beforementioned methodology, it is not about number of vessels calling the port, but rather the consumption and corresponding emission, where they take place and which ships that are consuming and therefore emitting the most. Table 9 details the auxiliary engine consumption for the ships that have been laying alongside in the port of Oslo in 2016. This represents the amount of fuel that can be reduced by implementing shore power.

Table 9: Auxiliary engine fuel consumption per ship type for the port of Oslo in 2016

AE fuel consumption (mt)	Ship size							
Ship type	**1. < 1000 GT**	**2. 1000 - 4999 GT**	**3. 5000 - 9999 GT**	**4. 10000 - 24999 GT**	**5. 25000 - 49999 GT**	**6. 50000 - 99999 GT**	**7. >= 100000 GT**	**Grand Total**
Oil tankers	0	18		21	3			43
Chemical-/product tankers		56	360	405	26			847
Bulk ships	0	32	143	1				176
General cargo vessels	25	239	190	2				456
Container ships		8	639	476				1122
Ro Ro ships		2		196				198
Passenger ships	125	452	1	13	1276	258	204	2328
Other activities	234	1		0				235
Grand Total	**385**	**808**	**1332**	**1114**	**1305**	**258**	**204**	**5406**

When investigating the distribution of consumption by ship type and size, we find that the general cargo ships play a relatively small part with only 8% of the total auxiliary consumption. It is the passenger ships (43%), the container ships (21%) and chemical and product tankers (16%) that are the biggest overall consumers. It should be noted that shore power is as much a local pollution mitigation measure, as it is a GHG reduction measure. In the case of Oslo, the DFDS ferries which is operating between Oslo and Copenhagen have installed NO_x reducing catalysts, and the local ferries to Nesodden run on LNG. These measures reduce NO_x emission up to 80% and 90% respectively. Consequently, the passenger ship segment has a relatively lower NO_x emission contribution (34%) than GHG emission. With the LNG powered ships, an additional 20% reduction in GHG is also assumed.

All in all; the total amount of NOx reductions that can be achieved by introducing shore power in Oslo is: 201mt. This is 4,8% of Oslo municipality’s total NOx emissions. This figure is based on numbers from 2008 where Oslo’s total NOx emission was 4231,5mt. As the amount of traffic to the port is expected to grow in the coming years, and with the introduction of the Euro 6 standards for diesel powered vehicles, this percentage is expected to grow as a consequence.

The total amount of CO_2 eligible for reduction by shore power in Oslo is: 14554mt. This is 1,2% of Oslo municipality’s total CO_2 emissions in 2013 (1425000 mt).

A heat map detailing where in the port of Oslo the consumption take place can be seen in figure 9. From this heat map, the majority of fuel consumption is seen to take place at the foreign ferries terminal at Vippetangen and at the container terminal at Sjursøya. These two quays have consequently been chosen to demonstrate the shore power need, emission reduction potential and cost.

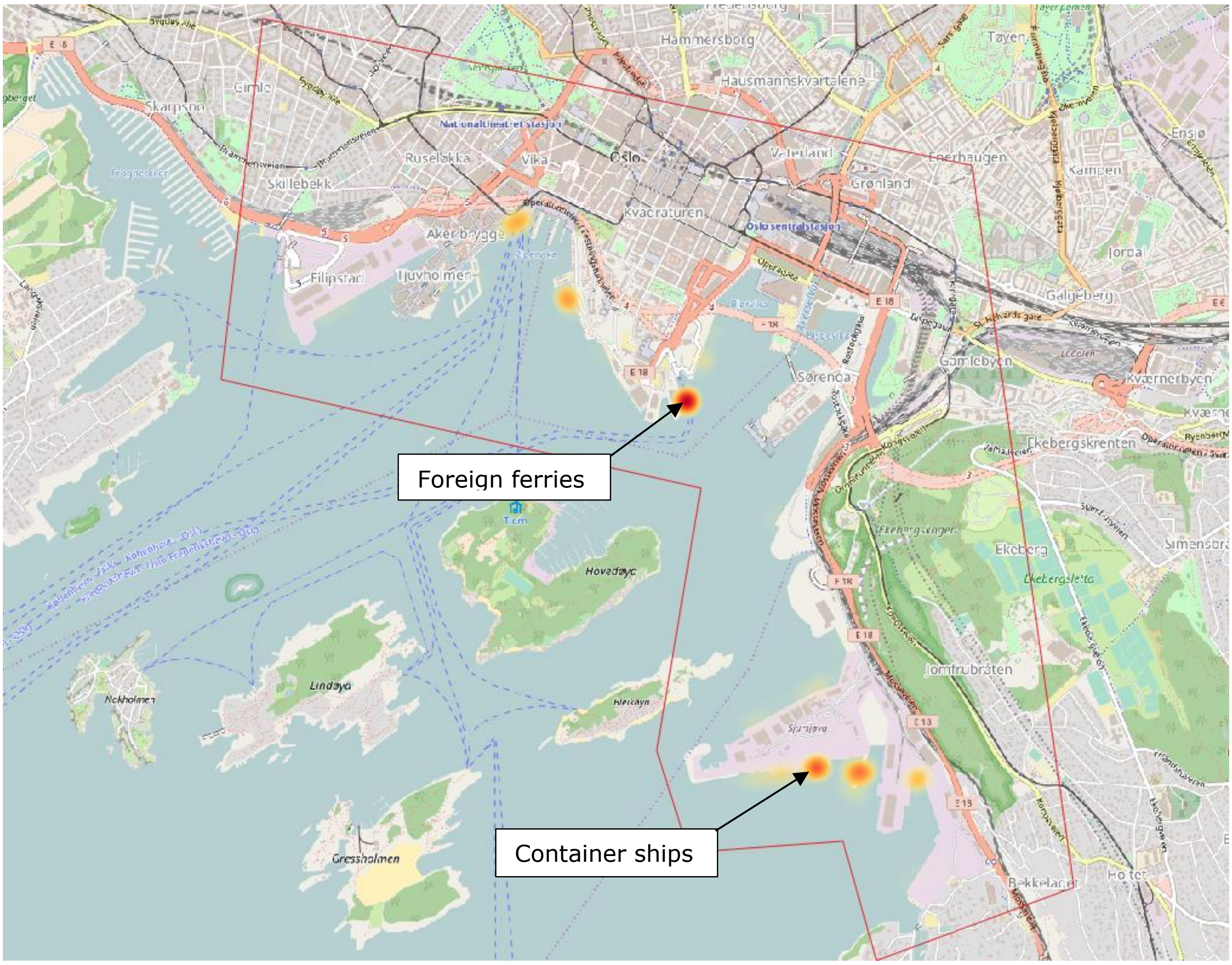

Figure 9: Heat map consumption for the port of Oslo in 2016

9.2 Sjursøya

9.2.1 Traffic

Sjursøya is the main container terminal in the port of Oslo. In 2016, 45 different ships called this quay, out of which 40 were container vessels. There have also been a few general cargo vessels and tugs calling at the terminal, but their contribution is marginal compared to the container vessels and they are therefore not taken into account in this example.

Table 10: Number of ships at Sjursøya

# of ships	Ship size				
Ship type	**1. < 1000 GT**	**2. 1000 - 4999 GT**	**3. 5000 - 9999 GT**	**4. 10000 - 24999 GT**	**Grand Total**
General cargo			1	1	2
Container		1	18	21	40
Other activities	3				3
Grand Total	**3**	**1**	**19**	**22**	**45**

9.2.2 Power requirement

For one vessel laying alongside the maximum daily power requirement is 473kW based on the ships that have been calling the terminal. However, peak loads and concurrent use of the installation needs to be accounted for. To be able to serve all traffic, the capacity required for serving two ships on 473kW needs to be developed. This means that two LV connections needs to be installed. A total of 946kW would cover existing traffic and traditional shore power only, however, the question remains what the capacity would be if a ship like ReVolt starts calling Sjursøya container terminal? On average, the ReVolt would require 456kW over 4 hours to be charged, well within the capacity requirement of the existing traffic. However, when the battery is completely drained, 1356kW over four hours is needed. If a longer charging time (6,8 hours) is allowed, the Revolt would not require increased capacity of the installation.

9.2.3 Lay time

The average lay time for the ships calling the quay is an important parameter as this says something about the potential utilization of the shore power system. The average lay time at Sjursøya is 12,5 hours. This is more than double of what the ReVolt would require in a worst-case scenario. The lay time for the different ships calling Sjursøya is rather evenly distributed over the day.

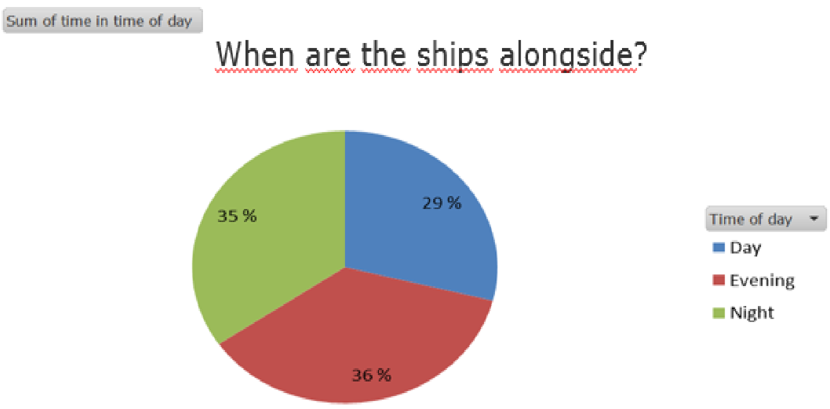

Figure 10: Lay time distribution Sjursøya

Another interesting finding here is the total lay time of 5923 hours. This figure can say something about how utilized the quay is and how much more traffic this quay can accommodate. In the case of Sjursøya, where two vessels can lay concurrently alongside, the utilization is 34%.

9.2.4 Emission reduction potential

The last part of the methodology is to establish which ships contributes most and stand to gain the most by installing shore power. Table 11 shows the top 12 vessels that contributes most to the fuel consumption at Sjursøya container terminal. Combined, these vessels contribute to 80% of the total consumption at this quay. The top 5 vessels contribute to 51% of the total consumption. Hence, the majority of emission reduction can be achieved by installing shore power equipment for the biggest consumers. Demonstrating this allows ports to enter into a dialogue with dedicated ship owners and have a more targeted approach when looking into investing in shore power.

Table 11: Emission reduction potential Sjursøya

IMO number	Calls	kW in port	Total lay time (hrs)	AVG lay time (hrs)	Fuel consumption (mt)	NOx emission (kg)	CO2 emission (mt)
Ship # 1	50	332	972	19	159	7009	505
Ship # 2	48	473	449	9	129	5696	410
Ship # 3	26	473	448	17	111	4881	352
Ship # 4	30	332	543	18	103	4511	325
Ship # 5	47	332	562	12	74	3268	235
Ship # 6	10	473	180	18	66	2907	209
Ship # 7	20	332	328	16	58	2570	185
Ship # 8	18	332	233	13	51	2224	160
Ship # 9	43	149	502	12	49	2163	156
Ship # 10	7	473	117	17	43	1894	136
Ship # 11	7	332	118	17	40	1746	126
Ship # 12	15	332	128	9	28	1233	89

All in all, the yearly emission reduction potential for Sjursøya is:

Fuel consumption: 1 129 mt

NO_x: 49 680 kg – 1,2% of Oslo municipality's total NO_x emission.

CO_2: 3 579 mt – 0,25% of Oslo municipality's total CO_2 emission.

9.2.5 Cost

The above identified numbers have been inserted in the shore power cost calculator in order to get an overview of the investment and operational cost of the proposed shore power system. Both the ship side and the port side costs have been calculated. For the ship side, the cost corresponding to the requirements and operation of ship # 1 has been calculated. It is also assumed that all container ships calling Sjursøya has an on-board grid frequency of 60hz, meaning that the cost of a frequency converter is added to the port side. The cost of the cable management system is included in the ship side cost as per the LV standard. For the port side, the cost of expanding the shore grid is not included as this has already been carried out by the port of Oslo. The total energy demand for the port (2 087 799 kWh[3]) forms the basis for the port earnings.

Further, the following parameters are assumed:

[3] The total energy demand is calculated as per table 1. Compared to the fuel consumption, this seems a bit too conservative.

Statics	
Fuel cost (USD/mt)	510
Price electricity (USD/kWh)	0,04
Exchange rate (NOK/USD)	8,4
Interest rate port investment (%)	3,0 %
Depriciation port investment (years)	10
Interest rate ship investment (%)	3,0 %
Depriciation ship investment (years)	10

In addition, a maintenance saving cost of 2 USD/hour of auxiliary engine running time is assumed.

Ship side:

Ship Cost	Total	Per year
Investment cost (USD)	$ 716 667	$ 84 015
Energy cost fuel (USD)	$ 1 188 141	$ 39 605
Energy cost electricity (USD/year)	$ 372 750	$ 12 425
Energy cost saving (USD/year)	$ 815 391	$ 27 180
Maintenance saving (USD/year)	$ 75 000	$ 2 500
Total savings (USD)	$ 890 391	$ 29 680
Funding support (USD)	$ -	
Return of investment (years)	28,3	
Apply level of funding (%)	0 %	

For a container vessel, the investment cost will be 716 667 USD. This cost is for the on-board connection panel and for the cable management system. The annual savings would amount to 29 680 USD. Although there is a potential energy cost saving, the return of investment (ROI) is 28,3 years, almost as long as the life expectancy of the vessel. The reason for this long ROI is the currently low fuel price and the fact that the cost of the cable management system must be covered by the ship. This is a major cost component for the vessel, amounting to 230 000 USD. However, if the vessel is eligible for governmental funding through the NO_x -fund, the ROI will change dramatically. By applying an 80% NOx-fund reduction, the ROI becomes 5,7 years and a critical factor for realizing the investment.

Shore side:

Port Cost		
	Total	Per year
Investment cost (USD)	$ 642 857	$ 75 362,47
Energy earning electricity (USD/year)	$ 2 496 000	$ 83 200
Funding support (USD)	$ -	
Return of investment (years)	9	
Apply level of funding (%)	0 %	

The investment cost for the port side will be 642 857USD, mainly attributed to the frequency converter needed. Without any funding the ROI becomes 9 years – assuming a yearly income of 83 200USD. By applying a 90% funding level from Enova, the ROI drops to 1 year. However, if only the top 5 consuming vessels make use of the investment, the ROI would double.

In total, the cost of reducing consumption from Sjursøya by 51% is corresponding to 5 investments on the ship side and one investment on port side. This tallies up to: 4,2 million USD ~ 35,5 Million NOK. The environmental abatement potential, as per equation 5 (assuming a 30 year life time of the system) would consequently be: 77 USD/CO_2-tonne ~ 643 NOK/CO_2-tonne and 5,5 USD/NO_x-kg ~ 46,2 NOK/NO_x-kg.

9.3 Vippetangen

9.3.1 Traffic

Vippetangen, or Utstikker 2 Øst, is the terminal where the RO-Pax ferries to and from Fredrikshavn and Copenhagen call. This is a dedicated terminal for three vessels going to and from Denmark.

9.3.2 Power requirement

Since the three vessels are of similar size, have similar power requirement and have no need for concurrent lay time, the power requirement need only to be dimensioned as per the peak power for one vessel. As per table 1, this power requirement is found to be 1194kW. This power demand requires a HV shore connection system.

9.3.3 Lay time

Since the ships calling this quay are ferries, they operate with fixed schedules and lay times. The average lay time for the two Copenhagen ferries are 6,8 hours, while the Fredrikshavn ferry has an average lay time of 1,8 hours. On average this becomes 4,4 hours as the Copenhagen ferries call every other day, while the Fredrikshavn ferry calls almost every day.

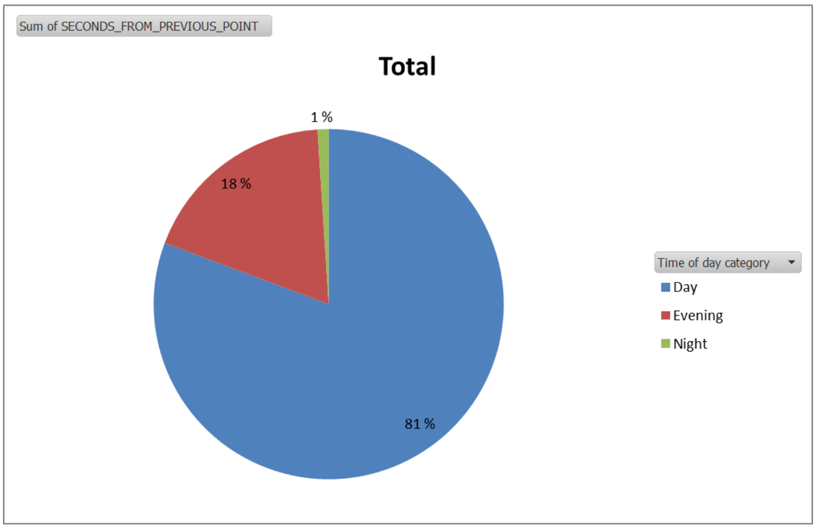

Figure 11: Lay time distribution Vippetangen

9.3.4 Emission reduction potential

The emission reduction potential for each of the three ferries can be found in table 12. Due to their substantially longer lay time, the Copenhagen ferries have a much higher consumption than the Fredrikshavn ferry. It should, however, be noted that the two ferries going to Copenhagen has catalysts installed on their auxiliary engines. This reduces auxiliary engine NO_x emission in port from these ships by 80%.

Table 12: Emission reduction potential Vippetangen

Ship	Calls	kW in port	Total lay time (hrs)	Average lay time (hrs)	Fuel consumption (mt)	NOx emission (kg)	CO2 emission (mt)
Fredrikshavn	319	1194	564	2	167	7552	530
Copenhagen 1	177	1194	1207	7	413	3729	1309
Copenhagen 2	171	1194	1163	7	442	3991	1402

The total emission reduction potential for Vippetangen is therefore:

Fuel consumption: 1 022 mt

NO_x: 15 272 kg – 0,35 % of Oslo municipality's total NO_x emission.

CO_2: 3 241 mt – 0,23 % of Oslo municipality's total CO_2 emission.

9.3.5 Cost

The main differences from the case at Sjursøya is that a HV instead of a LV system is needed at Vippetangen. For the ship side, the calculation is carried out for the Fredrikshavn ferry and the Copenhagen ferries respectively. It is assumed that all three ferries all have 50hz on board grid frequencies. Hence a frequency converter is not needed. The cost of the cable management system is now attributed to the shore side as per the HV standard. For the port side, the cost of expanding the shore grid is not included as this has already been carried out by the port of Oslo. The total energy demand for the port (3 504 163kWh[4]) forms the basis for the port earnings.

Further, the following parameters are assumed:

Statics	
Fuel cost (USD/mt)	510
Price electricity (USD/kWh)	0,04
Exchange rate (NOK/USD)	8,4
Interest rate port investment (%)	3,0 %
Depriciation port investment (years)	10
Interest rate ship investment (%)	3,0 %
Depriciation ship investment (years)	10

In addition, a maintenance saving cost of 2 USD/hour of auxiliary engine running time is assumed.

Cost for the Fredrikshavn ferry:

Ship Cost	Total	Per year
Investment cost (USD)	$ 565 476	$ 66 291
Energy cost fuel (USD)	$ 2 622 400	$ 87 413
Energy cost electricity (USD/year)	$ 822 714	$ 27 424
Energy cost saving (USD/year)	$ 1 799 686	$ 59 990
Maintenance saving (USD/year)	$ 68 904	$ 2 297
Total savings (USD)	$ 1 868 590	$ 62 286
Funding support (USD)	$ -	
Return of investment (years)	10,6	
Apply level of funding (%)	0 %	

For the Fredrikshavn ferry, the investment cost will be 565 476 USD. This cost is purely for the on-board connection panel. The annual savings would amount to 62 286 USD, with an ROI of 10,6 years. Since the current vessel is 36 years old, this could be a doubtful investment due to the limited remaining life of

[4] The total energy demand is calculated as per table 1. Compared to the fuel consumption, this seems a bit too conservative.

the vessel. However, should the vessel be eligible for governmental funding, the ROI will change dramatically. By assuming an 80% funding from the NO_x-fund , the ROI becomes 2,1 years and a very important factor for realizing the investment.

Cost for the Copenhagen ferries (one):

Ship Cost	Total	Per year
Investment cost (USD)	$ 565 476	$ 66 291
Energy cost fuel (USD)	$ 5 372 678	$ 179 089
Energy cost electricity (USD/year)	$ 1 685 546	$ 56 185
Energy cost saving (USD/year)	$ 3 687 132	$ 122 904
Maintenance saving (USD/year)	$ 141 168	$ 4 706
Total savings (USD)	$ 3 828 300	$ 127 610
Funding support (USD)	$ -	
Return of investment (years)	5,2	
Apply level of funding (%)	0 %	

Since the Copenhagen ferries have the same power requirement as the Fredrikshavn ferry, the investment cost would be the same. However, since the Copenhagen ferries have a much longer lay time, the business case becomes better with an ROI of 5,2 years. An already promising business case will become even better with governmental funding of 80%, resulting in an ROI of 1 year.

Shore side:

Port Cost	Total	Per year
Investment cost (USD)	$ 547 619	$ 64 197,66
Energy earning electricity (USD/year)	$ 4 204 996	$ 140 167
Funding support (USD)	$ -	
Return of investment (years)	5	
Apply level of funding (%)	0 %	

Without the need to invest in a on shore frequency converter, the investment cost for the shore side will be significantly reduced (-1.2 million USD). The investment cost tallies up to 547 619 USD. The ROI becomes 5 years, with estimated yearly earnings of 140 - 167USD. In the case of ferries, the ferry operators could in some cases purchase the electricity directly from the electricity provider. In this case, the potential earnings for the port is limited. This type of barrier will be further discussed in chapter 10, however, the need for governmental funding could potentially be vital. The ROI, given a 90% funding level, is 0,5 years. Being a ferry terminal, the need for automatic connection may also be important to save connection time. This will increase the port investment cost, and it will also limit the areas of application as it is not part of the standard – a criteria set by Enova to receive funding.

In total, the cost of reducing the consumption and corresponding emissions from Vippetangen is estimated as 2,2 million USD ~ 18,8 Million NOK. The GHG abatement potential, as per equation 5 (assuming a 30-year life time of the system) would consequently be: 23 USD/CO_2-tonne ~ 190 NOK/CO_2-tonne and 4,8 USD/NO_x-kg ~ 40,3 NOK/NO_x-kg.

9.4 Hybrid RO-Pax ferry to and from the Port of Oslo

As concepts investigating battery hybrid propulsion of RO-Pax ferries have recently been developed /23/, /24/, a case highlighting the increased capacity need and corresponding emission reduction potential if a new hybrid RO-Pax ferry were to operate on battery power between Filtvedt and the Port of Oslo has been included in the report.

9.4.1 Operation

The distance to and from Filtvedt is chosen for several reasons:

- Between the Port of Oslo and Filtvedt the speed is reduced to 14,5 knots by current ferries, yielding a lesser power requirement than in the outer Oslo fjord where the speed is increased to about 20 knots.
- Vessels operate close to shore between Filtvedt and the Port of Oslo. Reducing emissions in this area may have a higher positive health effect.

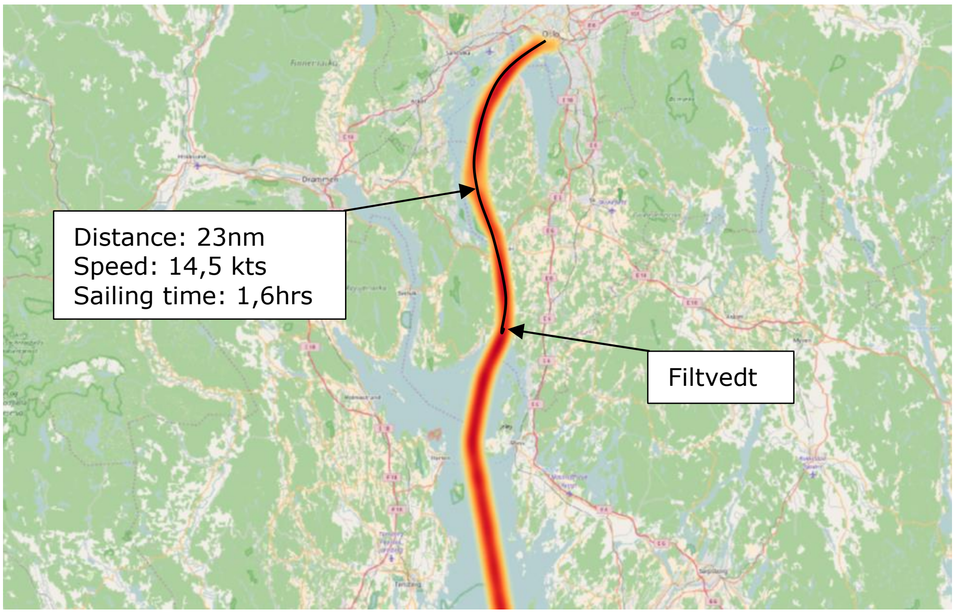

Figure 12: Consumption heat map of ferries operating in the Oslo fjord

The distance between Filtvedt and the Port of Oslo is 23 nautical miles. With a sailing speed of 14,5 knots, this distance is covered in 1,6 hours. This is the operational parameters used when dimensioning the battery size and the corresponding charging needs for the vessel.

9.4.2 Ship

To have an optimized ship, in terms of energy need and battery size, that covers the operational requirements, it is likely that a newbuild would be introduced. In addition to be optimized for battery propulsion, future cargo and passenger capacity requirements would need to be adhered to.

9.4.3 Power requirement

The power needed to propel a ship through the water is increasing exponentially with the speed of the ship. Taking the below speed/power curve of a 2000 pax Ro-Pax ferry into consideration, the average power requirement at 14,5 knots is estimated to 6700kW including hotel loads.

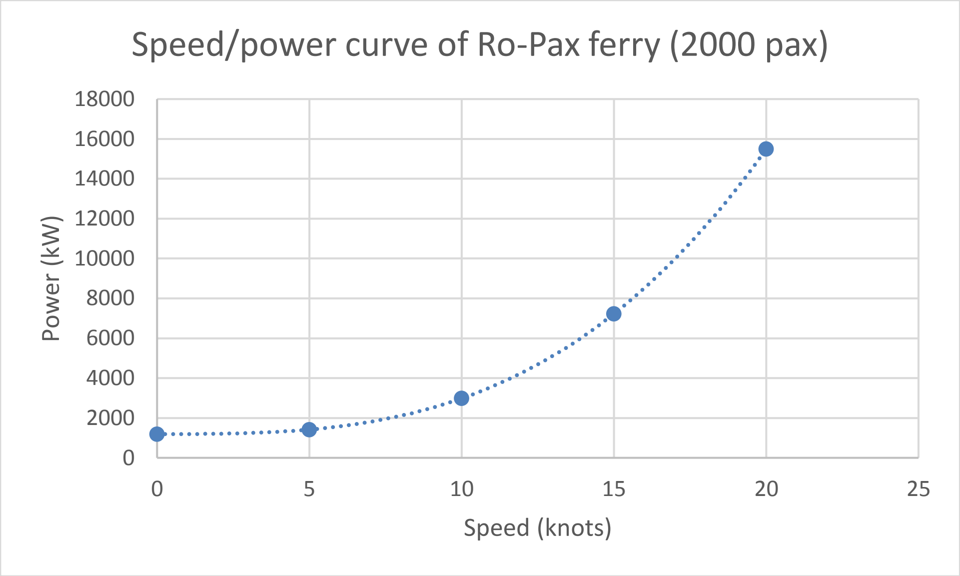

Figure 13: Speed power curve of 2000 pax RO-Pax ferry

The average power requirement, energy consumption, battery size, charging time and corresponding charging power can be found in table 13 below. The energy consumption is found by multiplying the average energy demand of 6 700 kW by the average sailing time of 1,6 hours. To avoid complete depletion, the battery is dimensioned to reach an 80% state-of-charge at most. Not having deep discharging's will increase the battery life expectancy. Since the vessel has the opportunity to quickly be able to switch to diesel power, a safety margin is less relevant. The charging power will highly depend on the time allowed for charging. Current use of the terminal varies from 1,5 hours to 7 hours. For this case, the charging time is set to 4,4 hours, the average lay time identified in the previous case study. Charging power is found by dividing the energy consumption by the charging time.

Table 13: Power requirement

Avg power requirement (kW)	Energy consumption/trip (kWh)	Battery size (kWh)	Avg charging time (hrs)	Charging power (kW)
6 700	10 720	13 400	4,4	2 436

To allow for a new battery hybrid ship to charge, the capacity at the Port of Oslo therefore needs to be 3 631kW, as an additional 1 195kW is needed to cater for the energy demand in port.

9.4.4 Emission reduction

The fuel and emission reduction due to the battery powered operation, as compared to the same ship running on diesel, is as per table 14. 340 round-trips per year is assumed. It is assumed that both sailing in and out between Filtvedt and the Port of Oslo is carried out on battery power. Since the before mentioned operation require charging infrastructure to be developed in both ports of the trade, consumption and emission reduction potential for both ports are included in the calculation.

Table 14: Yearly consumption and emission reduction due to hybridization

Operational mode	Fuel consumption reduction (mt)	NOx emission reduction (kg)	CO2 emission reduction (mt)
At sea	1 677	120 700	5 315
In port	822	59 201	2 606
Total	**2 499**	**179 901**	**7 921**

9.4.5 Cost

Ship side:

Due to increased power demand, the cost of the shore connection system also increases. In addition to this, the cost of batteries will also apply. The battery cost is assumed to be 1000 USD/kWh, resulting in an additional cost for the vessels as follows:

Table 15: Ship side added investment cost due to hybridization

Shore connection system (USD)	Batteries (USD)	Total (USD)
586 905	13 400 000	13 986 905

The corresponding savings are as follows:

Table 16: Yearly ship savings due to hybridization

Fuel cost (USD)	Electricity cost (USD)	Difference (USD)	ROI (years)	ROI w/80% funding (years)
1 274 469	434 602	839 867	16,7	3,3

While expanding the shore power infrastructure to include charging does not increase the ship side cost much, the batteries represent a substantial investment. This leads to an ROI of 16,7 years. However, if 80% NO_x -funding is applied, the ROI drops to 3,3 years.

Shore side:

With increased demand for charging, the total yearly charging energy (kWh) for one of the ports in the trade becomes: 5 431 976 kWh. This number accounts for the fact that the ports in the trade could only provide charging power once for each voyage. Together with the peak power of 3 631kW, this number forms the basis for the cost calculation for one shore side installation.

Port Cost		
	Total	Per year
Investment cost (USD)	$ 595 238	$ 69 780,06
Energy earning electricity (USD/year)	$ 6 518 371	$ 217 279
Funding support (USD)	$ -	
Return of investment (years)	3,2	
Apply level of funding (%)	0 %	

For this case; the increased charging demand from facilitating a new plug-in hybrid RO-Pax ferry only marginally increases the cost for the cable management system and the transformer station, as compared to regular shore power. This leads to an investment cost of 595 238 USD per port. However, as charging batteries increases the potential for using electric energy, this leads to an ROI of 3,2 years. However, for the same reasons described in the previous case study, in the case of ferries there might be a case where the ferry operators have a customer-supplier relationship with the electricity provider directly. Hence, the potential for earning is more limited for the port. 90% funding will give an ROI to 0,3 years.

All in all, the added cost of developing 2 charging power installations in the ports, and having a plug-in hybrid RO-Pax ferry utilizing it, is calculated to 15,17 million USD ~ 127,5 million NOK. The environmental efficiency, as per equation 5 (assuming a 30 year life time of the system) would consequently be: 64 USD/ CO_2-tonne ~ 537 NOK/ CO_2-tonne and 2,8 USD/NO_x-kg ~ 23,5 NOK/NO_x-kg.

10 BARRIERS FOR INTRODUCTION

The previous chapters show that shore power can be beneficial both in terms of emission mitigation and cost. Shore power is also not a novel technology. Still, the use of shore power in Norway is not widespread. This chapter maps some of the barriers and concerns identified by the project, and provide some thoughts on how to overcome these. The barriers are broken down into the following categories:

- Technical
- Financial
- Regulatory
- Environmental
- Market

10.1 Technical barriers

Table 17: Technical barriers

<table>
<tr><th>Barrier</th><th>Description/concern</th></tr>
<tr><td>The grid quality and stability is not good enough to support shore power.</td><td>The shore grid needs to have sufficient quality and stability to cater for the increased power requirement from shore power. A ship's power system can be vulnerable to fluctuating power loads. How to avoid this?</td></tr>
<tr><th colspan="2">Mitigation measures</th></tr>
<tr><td colspan="2">1) One of the purposes of the LV and HV standards is to ensure the quality of the shore side power supply. By adhering to the standards, this will be documented and assured.

2) The major ports in Norway are located close to urban areas where the capacity and quality of the grid is good. These are also the ports where the local pollution and noise benefits of shore power will be highest.

3) In Norway, the electricity providers have a legal obligation to connect new customers, invest and upgrade the grid and provide sufficient electrical energy.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><th>Barrier</th><th>Description/concern</th></tr>
<tr><td>The standards don't apply to all ship types.</td><td>The LV and HV standards only apply to the following ship types:

LV:
• Offshore supply and working ships
• Container ships
• Tankers

HV:
• Ro-Ro ships</td></tr>
</table>

	• Cruise ships • Container ships • LNG carriers • Tankers How should other ship types adhere to the standards?
Mitigation measures	
The general description of the standards is universal for all ship types. However, the standard has extra requirements for some ship types. Ships not mentioned in the annexes have no additional requirements. However, there is a need to include all ship types in the annexes to avoid confusion on voltages, frequencies and the placement of the cable management system. The project will forward this concern to the standardization committee. Table 7 details how the ReCharge project suggests to include other ship types in the standards.	

Barrier	Description/concern
Non-standardized shore power systems exist.	Although standards exist, several projects have chosen not to adhere to the standards. How to then make use of the equipment at different berths?
Mitigation measures	
It is true that several vendors of shore power systems exist, and that some do not adhere to the standards. This is however mostly prominent for ferry applications. Ferries typically have frequent calls at fixed terminals. This has led to operators opting for more automated and tailored solutions to reduce connection time and to save on handling cost. However, this significantly reduces the potential for using the equipment on other trades and berths. For ocean going cargo ships the situation is different. The EU directive stating that TEN-T ports will need to supply shore side electricity to ships within 2025, require that this electricity is supplied as per the HV standard. This requirement should be expanded to include the LV standard going forward. This will ensure a wider expansion of standardized shore power systems.	

Barrier	Description/concern
The system doesn't scale.	The shore power infrastructure is typically dimensioned to serve existing traffic and corresponding capacity. What happens if the power requirement increases because of bigger ships and the need for charging?
Mitigation measures	
Shore power systems are typically scalable within the LV and HV range, meaning that a LV shore power system can provide power up to 1000kVA, and a HV shore power system can provide power from 1000kVa and upwards. In order to supply the whole LV range, it is recommended that the shore side make the maximum number of feeders/cables available. To supply 1000kVA at 400V requires 5 feeders. The HV standard sets requirements for nominal voltages for different ship types. These voltages are set	

high to accommodate a variety of ship sizes and power demands. If power requirement move from LV to HV, two options arise: 1) Replacing the LV equipment with HV equipment on the secondary side of the frequency converter (HV transformer, HV switchboard, HV cables and HV cable management system) 2) Add an extra connection on the secondary side of the frequency converter and add the HV equipment there If the power increase is higher than the existing rated power of the frequency converter, a new main transformer station needs to be built. It is therefore recommended to cater for enough capacity in the main transformer station to allow for future power capacity increases.

Barrier	Description/concern
Technology development is too fast.	Technology development is fast. Will the old shore power equipment be obsolete long before the estimated life expectancy?
Mitigation measures	
Yes, technology development is fast – and this is a good thing. Advances in shore power technology may lower investment and operational cost as well as improving safety and efficiency. The standards will, in the future, still have to be adhered to by the technology providers to secure utilization of the equipment. In fact, recent technological advances have rather been on new novel cable management solutions. For the ferry industry, new concepts for inductive charging and automated connection systems have been developed.	

10.2 Financial barriers

Table 18: Financial barriers

Barrier	Description/concern
The investment is too high.	The investment cost of the equipment needed is too high. How to defend the potentially long return of investment (ROI)?
Mitigation measures	
Governmental funding bodies like ENOVA and the NO_x -fund can support an investment in shore power infrastructure both on shore and on board. ENOVA support port owners who wants to invest in shore power infrastructure by up to 90% of the investment cost. Investment cost concerning the complete shore power infrastructure, including investments in the grid infrastructure can be included in an application for funding. ENOVA prioritizes projects where the kWh-reduction potential per supporting cost is highest. However, this approach does not take emission location into account. This can lead to funding being awarded to a project with little or no impact on local air quality. The ReCharge project recommend that emission location is included in the criteria for funding. ENOVA also supports ship owners who wants to invest in making their vessels shore power ready, however this funding is not under the “shore power” support framework.	

The NO_x -fund also support ship owners and port owners wanting to invest in shore power infrastructure with 250 NOK per kg NO_x reduced with a maximum of 80% of the total investment. As for ENOVA, the NO_x -fund does not take emission location into consideration. The NO_x -fund also only support ships who trades solely in Norway. There have been cases where ships that, not solely, but regularly trades in Norway has received funding. There is, however, a need to better define what constitutes regular trading and hence would qualify for support. This is particularly important for cargo ships in foreign trades which contributes to a substantial amount of emissions in Norwegian ports.

As per (Martinsen K., et. al., 2015) /4/, 12 out of 21 port owners cites that ENOVA funding is vital or crucial for investing in shore power infrastructure. This was further emphasised during an experience seminar on shore power, hosted by KB Bedrift on 30.06.2016, where only one of the attending port owners informed that they would initiate development of shore power without ENOVA funding.

No business case for ports, meaning that there is little possibility for ports to get a satisfactory return on their investment, can be a major barrier for a wider introduction of shore power. For a port, the investment in shore power would hence be limited to more intangible benefits like:

- Potentially increased traffic from ships able to connect
- Transfer of cargo from road to sea
- Decreased environmental footprint and improved air quality

Reduced local pollution is one of the main advantages of shore power, as it can have a positive impact on the health of the people living in the vicinity of the port. Improved health of the general public will consequently reduce pollution-related health cost which typically is covered by the local municipality. The question remains whether it is the port responsibility to cover this cost?

It is important to continue a long-term support perspective from the governmental funding bodies to secure that more and key ports are developing the necessary infrastructure to support increased uptake of shore power.

Barrier	Description/concern
The potential saving is too low.	The potential cost-savings from shore power are too small, how to keep the electricity cost below the fuel cost?

Mitigation measures

Electricity tax:

In Norway, there is a general tax relief on fuel oil for ships. In order not have the electricity tax act as barrier for using shore power, the government has decided to reduce the tax to 0,48 NOK kWh. This tax relief includes ships of all sizes. The CO_2 tax on fuel oil for domestic shipping was increased in the latest state budget, further tipping the cost in the favour of electricity.

Network tariff:

The network tariff for ships can be very high as this often is calculated per the power capacity of the installation. This is predominantly the case for large consumers with low usage of the infrastructure, as the tariff is based on the highest hourly consumption each month. To maintain an advantageous price difference between electricity and fuel oil, it is important to maintain a low tariff. The use of

interruptible tariff, where the ships can be disconnected from the shore grid with or without prior notice, should be sought where possible. This is a tariff especially beneficial to ships which already have potential for power generation on board. In cases where extra capacity on land is needed, ships can even support this need with their own generators. Another way is to move to a network tariff based on consumption rather than capacity. Grid companies should strive to maintain a standardized way of price -setting the network tariff so as not to confuse the ships with different principles and price levels. With today's fuel price of around 510USD/mt[5] the break-even price for electricity is around: 1,1NOK/kWh.

10.3 Regulatory barriers

Table 19: Regulatory barriers

Barrier	Description/concern
Shore power is not mandatory	Why chose to invest in equipment which yields questionable cost advantages when there is no national/international legislation on the use of shore power?
Mitigation measures	
There are currently no international legislations that explicitly require use of shore power. However, many emission reduction incentives can impact the uptake of shore power. (Martinsen K. et. al., 2015) /4/ which details the status of many of these national and international incentives will not be repeated here. The following is a review of recent developments and recommendations. **EU Directive 2014/94/EU:** The Norwegian ministry of transportation has had the directive out for hearing in the public and private industry /25/. Feedback is positive, however, the need for governmental funding, beyond what is expected in the directive, is highlighted. There is also a positive notion concerning standardization of equipment. Hence, the directive will most likely take effect in Norway in 2025. As further indicated in the national transport plan for 2018-2029. **National transport plan:** The national transport plan has the following plans for cutting GHG's using electricity in the transport sector. Examples include: • new ferries on bio fuel, low- or zero emission technology • charging and shore power infrastructure in place in the biggest ports, and the ports with the highest emission reduction potential, by 2025. • have 40% of all ships in coastal shipping using bio fuel or low- or zero emission technology • transport sector shall be virtually climate neutral by 2050 The national transport plan will be politically decided in the spring of 2017. **State budget 2017:**	

[5] Bunkerworld.com

In the state budget for 2017, it was decided to demand shore power for cruise ships in all major port in Norway/26/. How this is to be effectuated is not yet known. The only place in the world where it is mandatory to make use of shore power is in California. Because of this mandatory policy, the port of Long Beach has reduced particulate matter (PM) emissions by 85%, NO_x emissions by 52%, SO_x emissions by 97% and GHG emissions by 21%. Still, there has been an increase in freight handled by 2% /27/. This goes to show that regulation has an effect. However, the regulatory playing field has to be internationally level, and strict regulation needs to be followed up with strict enforcement.	
Barrier	**Description/concern**
Ports are not allowed to sell electric energy	How can ports earn money on shore power when they are not easily allowed to sell electricity.
Mitigation measures	
In Norway, entities that trades in electric energy in a monopoly situation needs to have a trading licence issued by NVE (Norges Vassdrags- og Energidirektorat). In a case where a port is the customer of an electricity provider and wants to further sell electricity to ships using the shore power infrastructure, the port would need to obtain a trading licence. By just redistributing the cost from the electricity provider, a trading licence is not needed. Just redistributing the cost will, however, render the port with no profit margin. A simplified trading licence can be obtained for facilities with a limited area of application – like a port. As per /28/, by obtaining a trading licence one must adhere to the terms of the licence, amongst others income limitations. NVE sets yearly income limits for each entity holding a trading licence. This limit is set as to be able to cover depreciation and operational cost of the infrastructure and give the entity a fair return of investment. It is then up to the port to set a sales price for electricity, under the limitations of the trading licence, which is beneficial as compared to the cost of producing fuel on board.	

10.4 Environmental barriers

Table 20: Environmental barriers

Barrier	**Description/concern**
Is shore power a climate mitigation measure?	Shore power is only as climate friendly as the way the electricity has been generated. How can one be sure that shore power is a good climate mitigation measure?
Mitigation measures	
Yes, shore power is a climate mitigation alternative. A diesel generator typically has a specific fuel oil consumption on auxiliary engines of 250g/kWh - taking performance degradation and low load factor into consideration. With an emission factor of 3,17 g CO_2/g_fuel, the CO_2 emission for on board generation of electricity is 790g CO_2/kWh. Figure 14 below shows the country specific CO_2 emissions per generated kWh of electricity in Europe. Only a few countries (Poland, Greece, Malta and Estonia) will have a negative climate effect by utilizing shore power. Norway will yield a particularly high benefit	

since 99% of power generation comes from renewable hydropower /29/. However, Norway is part of the Nordic power market and an emission factor of 72g CO_2/kWh give a more correct picture of the situation.

In addition, shore based power plants emitting air pollutants are often located a distance away from urban areas and have lesser negative health impact. Power plants on shore also have the possibility of operating closer to an optimal load setting, hence emitting less GHG's per kWh generated than an on-board diesel engine.

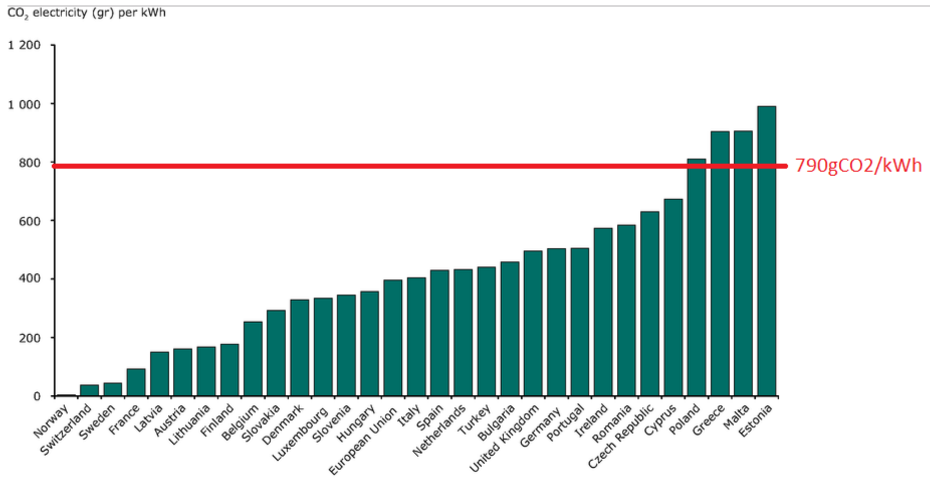

Figure 14: g CO_2/kWh in Europe (Source: /30/)

Barrier	**Description/concern**
Alternative fuels and other mitigation alternatives are equally good	Why go for shore power when the advantages using alternative fuels and other mitigation measures work equally well?

Mitigation measures

As advocated throughout this report, it is very important to assess emission location, all consumption and emission components and existing and future traffic before deciding where to develop shore power infrastructure. This also means adjusting for ships that run on alternative fuels or have emission reduction technology installed. By doing so the most promising candidates from a cost- and environmental effectiveness perspective can be prioritized. The advantages with shore power is that elimination of all GHG's and air pollutants and noise can be achieved in the case where the electricity comes from renewables. This is seldom the case for alternative fuels, although some of them may have some endearing qualities. LNG is currently the most widespread alternative fuel. Offering an elimination of SO_x and PM emissions and significant reduction in NO_x emissions (90%), making it a very attractive solution for local air emission mitigation. LNG can also lead to reduced GHG emissions; however, this heavily rely on the methane-slip of the engine, meaning how much unburned methane there is in the exhaust gas. As methane is a much more potent GHG than CO_2, the climate reduction potential in LNG versus diesel range from a 20% reduction to no reduction. Presently there is about 75 LNG vessels in operation and another 80 under construction /31/. Ships with cleansing technology like SCR (selective

catalyst reduction), EGR (exhaust gas recirculation) or scrubbers can reduce NO_x and SO_x significantly. In the future, a likely scenario is that ports will act like energy hubs for both shipping and hinterland transportation, supplying a variety of fuels and energy carriers. Historically, shipping has relied on one preferred type of fuel. In the foreseeable future, there will be no one "silver bullet" solution, but rather a much higher degree of diversification. Different ship types, cargo segments and operational areas will pick their fuels – and not merely based on price. We believe that the selection will be based on a compromise between benefits and drawbacks related to safety, affordability, reliability and sustainability. The benefit with shore power is that it is complementary to the alternative fuels.

10.5 Market barriers

Table 21: Market barriers

Barrier	Description/concern
Ship owner vs charterer	Why should ship owners invest when the charterer is the one who pays the fuel bill?
Mitigation measures	
For many cargo ships, it is often the case that the charterer of the ship pays the fuel bill. In such situations, the ship owner could get left with the investment cost without being able to yield any direct benefit. There is, however, a trend of the times that charterers and cargo owners pay more attention to the environmental footprint of their whole value chain, including transportation. Charterers could therefore prefer to charter ships with improved environmental performance, and in the case where long term charter parties exist, charterers and owners could cooperate and split the bill for mutual advantage. The charterer will experience reduced environmental footprint, potentially reduced energy cost, potentially reduced port fees as a result of an improved ESI (environmental ship index). Owners would get a more attractive ship and a ship fit for future legislation where shore power is a "ticket to trade". This approach would require close cooperation between charterer and owner and is maybe most beneficial for long term charter party agreements.	
Barrier	**Description/concern**
Chicken and egg problem	Why should ports invest in shore power infrastructure when no ship can make use of the infrastructure and vice versa?
Mitigation measures	
This is one of the first fundamental barriers identified, limiting the uptake of shore power infrastructure. Infrastructure, in the widest sense of the term, is a key governmental responsibility. Infrastructure in this context means, but is not limited to; roads, power grids, fairways, communication or energy supply. Having the appropriate infrastructure in place and allowing the industry to innovate on that infrastructure, will lead to more rapid introduction and development of environmentally friendly technology. To break the "chicken and egg" cycle and to create a supply before a demand exist, ENOVA is funding shore power projects without demanding that ships are able to connect. By increasing the availability of	

such infrastructure, it would be easier to both build and retrofit ships to connect. To secure that the ships retrofit and get shore power ready, close cooperation between the ship side and shore side stakeholders is recommended. The methodology developed in the ReCharge project also provides a tool to specifically pinpoint the ships which most frequently uses and consumes the most in a port. This tool can be used to start discussions on how to develop infrastructure that is most commonly beneficial.	
Barrier	**Description/concern**
Bad times impacts negatively	Shipping is a cyclic and conservative industry; what global trends will impact the development of shore power infrastructure in the future.
Mitigation measures	
Shipping is an international industry and follow the trends of the global economy and trade. An increase in world GDP with corresponding increased trade and globalization, will increase the worlds transport demand, put pressure on oil prices and lead to diversification of the fuel mix. In such a future scenario, shore power will from a cost-efficiency perspective become more beneficial. In a scenario with low GDP growth and weak transportation demand the demand, for oil will decrease and keep prices low. The low price of oil will out-compete alternative fuels and shore power on price. In such a scenario, market mechanisms will not advance the use of alternative fuels and shore power. It would then rather be up to legislation and public funding schemes to ensure the uptake. (Grønt Kystfartsprogram, 2016) /32/ points at several measures that can be carried out which will improve the competitiveness of green technology. These include, but are not limited to; intermediate funding schemes, environmentally differentiated port dues and demand environmental friendliness for the transport concerning public procurement. /32/ also advocates a possible future establishment of a CO_2-fund, based on the same principles as the NO_x -fund. The establishment of such a fund could prove vital, especially in a technology development phase. The fund would, however, need to be complimentary to existing funding aids.	

11 BUSINESS MODELS

The previous chapter pointed to financial, regulatory and market barriers that could render a traditional business model for stakeholders looking to invest in shore power difficult. In this context, a traditional business model means that an investment is effectuated for the reason of gaining a future financial advantage, that being increased revenue or reduced cost, to justify the investment. The barriers that disrupts this model are:

- High investment cost (too high to get a reasonable return of investment)
- High electricity cost (limited potential for reduced cost)
- Need for trading licence (ports not easily allowed to sell electric power)
- Small customer base (chicken and egg)

This chapter aims at giving some input to how the different stakeholders may organize and conduct business in order to financially benefit from developing and utilizing shore power infrastructure.

Determining the customer-supplier relationship is a prerequisite when defining a business model. In the context of shore power, the customer is the entity that purchases electrical energy, while a supplier is the entity which sells the electric energy. In the case of shore power these roles can differ from ship segment to ship segment. The ReCharge project have found it beneficial to split the business models in two:

1. Regular traffic
2. Irregular traffic

This division has also been suggested by (Halvåg O.-P., 2016) /33/.

11.1 Business model for regular traffic

Regular traffic is in this context typically defined as transportation of passengers or cargo at regular intervals and between fixed berths. Passenger ferries and dedicated cargo routes are typically segments which sort under this category. They have a regular schedule and call at dedicated and often tailored berths. In this case, it is the individual ship owner which invest in the shore power infrastructure both on board and on shore. These ship owners will then become a direct customer of the electricity provider. The role of the port will be limited to being the landlord of the area to be used for the transformer station, cable management system and cabling. A graphical depiction of this business model can be seen in figure 15.

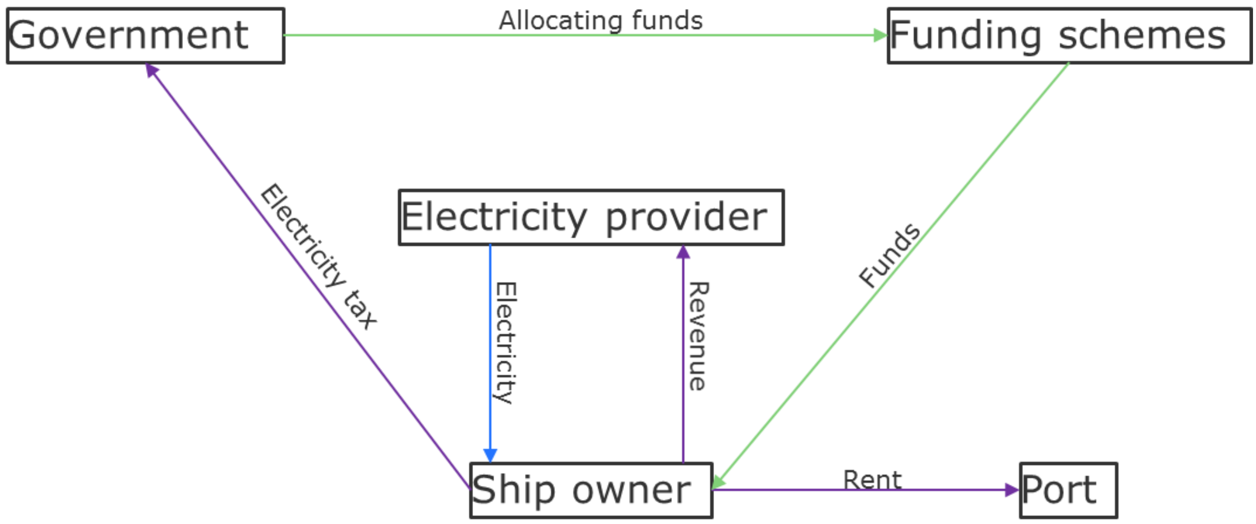

Figure 15: Business model regular traffic

Benefits:

With a setup like this, there will be an assured high utilization of the infrastructure as both the decision to invest and the investment on shore and on board is covered by the ship owner. Further, a predictable and long term use of the infrastructure is secured.

In addition, the ship owner will be able to define the capacity need, infrastructure and interface, tailored to the need and operational profile. Hence, there will be a clear and ideal supply and demand situation, which reduces the chance of oversizing the infrastructure. Although the infrastructure can be tailored, it is recommended that the dimensioning and design of the system is carried out within the framework of the applicable standards, as this could be a pre-requisite for receiving funding as well as maintaining flexibility to transfer the infrastructure to other ships and berths. It is also recommended to opt for a movable infrastructure which would be possible to relocate to other ports and berths.

By being a direct customer of the electricity provider, a possible cost-adding intermediary is avoided, ensuring that a premium is not added to the electricity price from the port side. More frequent use of the infrastructure will also be beneficial with regards to keeping the network tariff cost down. The ship owner should further strive for an interruptible network tariff agreement with the electrical grid provider where possible.

Drawbacks:

Although the setup is straightforward in terms of customer-supplier relationship and predictability, there are also some drawbacks. The ship owner would potentially need to take the total investment alone. This also includes additional investments in adjacent grid infrastructure, which can be a substantial cost element. This will be the case unless other stakeholders and/or funding schemes are willing to bear some of the financial burden for the sake of environmental benefits.

Further, the infrastructure would take up potentially valuable cargo handling area on the port side. This could lead to ports demanding rent for the space used. This practice is up to individual ports to decide, and it is likely that ports will prioritize environmental benefits and ensured long use to the lost cargo space.

For these drawbacks not to act as a showstopper for the profitability of the investment, ship owners need to have access to funding schemes that covers cost on shore.

11.2 Business model for irregular traffic

Irregular traffic is in this context typically defined as transportation of passengers or cargo at irregular intervals calling a variety of berths. Cruise ships and most cargo ships typically sort under this category. In this case, it is the port that invests in the shore-side infrastructure, including investment contribution to the grid provider, while the individual ships calling the port invest in their respective on-board infrastructure. The port then becomes a customer of the electricity provider, whilst each individual ship becomes a customer of the port. It is the port which defines the needed capacity and interface to serve existing and future traffic. A graphical depiction of this business model can be seen in figure 16.

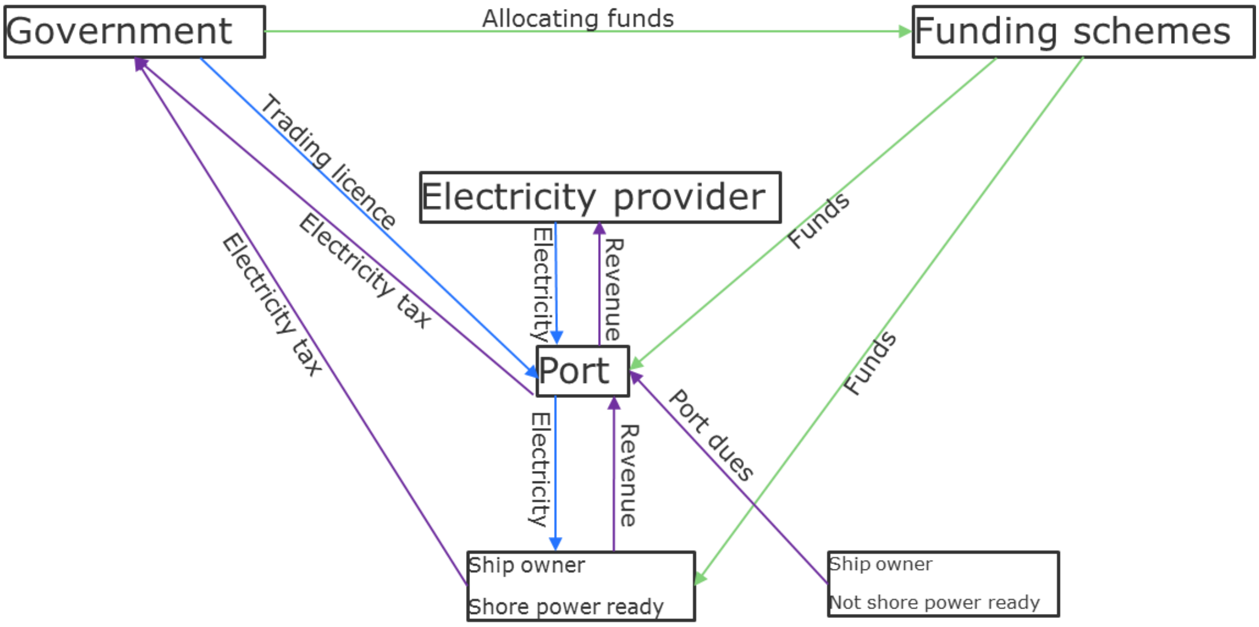

Figure 16: Business model irregular traffic

Benefits:

Although the utilization of the infrastructure very much lies with the calling ships' ability to connect to the system, the investment cost for this business model is split between the port and the ships wanting to make use of the infrastructure. This allows both the port and the ships to seek individual funding, potentially spreading the funding exposure to more funding bodies. As opposed to regular and fixed traffic, the market potential could prove to be greater, allowing for more ships using the infrastructure at complementary time slots. Developing the infrastructure as per the standards is in such a case a prerequisite.

Drawbacks:

If the port is to be allowed to sell electric power, a trading licence needs to be obtained. For infrastructure with a limited area of application, like shore power infrastructure, a simplified trading licence can be obtained. Following the requirements of the trading licence will however put extra administrative burden on the port. The trading licence also sets limits as to how much an electricity provider is able to earn. In addition to this, the port also needs to balance the cost of electricity against cost of fuel such that ships will not be switching back to on board power generation. One way of avoiding the need for a trading licence is to not re-sell the electricity, but rather redistribute or give it away. In such a case, ports could rather use other revenue streams to cover the shore power investment and offer shore power as a service free of charge. One possibility of regaining the investment is increasing the port dues for ships not shore power ready. This will reward environmentally friendly ships and encourage other ships to follow suit and invest in shore power equipment. Getting more ships on shore power will in turn improve the business case for the ports.

The ports will also have a customer-supplier relationship with the grid provider, who also will demand a network tariff from the port. This tariff is often set as per the power capacity of the installation. If there is little use of the equipment, this network tariff can get high. Forwarding this premium to the end-users, the ships, can lead to ships not connecting. In such a case, a consumption based interruptible tariff should be sought. Another way is to have funding schemes to also support running cost while the customer base matures.

As ports are left with the responsibility of defining the capacity, number of connection points and interface of the shore power equipment, they run the risk of needing to dimension the equipment to satisfy the peak load need. This is beneficial as it includes a larger number of ships and sizes and allows for the system to scale for increased future demand. The drawback is, however, that the infrastructure can remain oversized for most of the time. Hence, the port needs to balance the cost of developing increased capacity against a future customer base.

12 LIMITATIONS AND RECOMMENDATIONS FOR FURTHER WORK

The following recommendations for further work have been identified through the course of the project:

- **Ship specific power requirement:** Table 1 details average power requirement for different ship types of different size. It is understandable that this division is used by ENOVA to give ports that is applying for funding a conservative estimate of the potential for energy reduction, however, it is debatable whether this division is accurate enough to serve as input to dimension shore power infrastructure. As a reply to this concern, the project has used ship specific fuel consumption to identify the best candidates for shore power. DNV GL is, and will in the future, continuously improve the accuracy of its AIS service offerings.
- **Emission location:** Governmental funding bodies like ENOVA and the NO_x-fund does not take location of emissions into account when awarding funding. Since shore power, in addition to a climate mitigation measure, is a local air pollution mitigation measure, it is recommended that the point of emissions is incorporated into the funding criteria.
- **Network tariff:** The use of interruptible tariff, where the ships can be disconnected from the shore grid with or without prior notice, should be sought where possible. This is a tariff especially beneficial to ships which already have potential for power generation on board. In cases where extra capacity on land is needed, ships can even support this need with their own generators. As interruptible tariff is a voluntary tariff, grid companies should strive to maintain a standardized way of price-setting the network tariff so as not to confuse the ships with different principles and price levels.
- **Long term funding:** As many stakeholders list high investment cost as a main barrier, and corresponding need for funding support as vital, it is important to continue a long-term support perspective from the governmental funding bodies to secure that more and key ports are developing the necessary infrastructure to support increased uptake of shore power.
- **Governmental support of ships trading outside Norwegian waters:** As governmental funding bodies, only on a case by case basis supports ships that only regularly trades in Norway, there is a need to better define what constitutes regular trading and hence would qualify for support. This is particularly important for cargo ships in foreign trades which contributes to a substantial amount of emissions in Norwegian ports.

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APPENDIX A
Port consumption and emission overview

Port	# ships	Fuel consumption (mt)	NOx emissions (kg)	Energy (kWh)
Bergen	**621**	**23366**	**1032609**	**83440391**
Other activities	144	1752	76989	7652673
Other offshore supply vessels	23	990	43564	3839406
Bulk ships	9	126	5526	110026
Fishing vessels	66	323	14167	1326219
Gas carriers	1	1	22	3138
Chemical-/product tankers	16	79	3432	278959
Reefers	8	15	675	67365
Container ships	10	184	8099	844562
Offshore supply vessels	76	16402	721279	54756064
Oil tankers	7	91	4015	193024
Passenger ships	129	2700	124210	11245982
Ro Ro ships	10	434	18924	2198066
General cargo vessels	122	269	11707	924907
Mongstad	**536**	**13308**	**618065**	**52105255**
Other activities	21	557	24502	820823
Other offshore supply vessels	8	88	3884	598832
Bulk ships	2	13	555	17053
Fishing vessels	6	1	24	1406
Gas carriers	38	921	40922	4681803
Chemical-/product tankers	150	3542	154022	14277987
Reefers	3	2	76	5339
Container ships	1	0	15	2191
Offshore supply vessels	92	3392	147421	16473939
Oil tankers	120	4678	241658	14670677
Passenger ships	3	0	0	46
Ro Ro ships	4	1	59	7151
General cargo vessels	88	112	4927	548008
Husoy	**302**	**8612**	**378521**	**21463461**
Other activities	36	362	15920	997833
Other offshore supply vessels	15	670	29466	3082124
Bulk ships	2	0	7	1175
Fishing vessels	92	1001	43908	4023797
Chemical-/product tankers	17	76	3336	308435
Reefers	12	14	620	64505
Container ships	6	41	1824	204177

Offshore supply vessels	28	6087	267832	10993975
Passenger ships	2	0	3	305
Ro Ro ships	13	114	4997	578659
General cargo vessels	79	246	10607	1208476
EKOFISK	**26**	**7933**	**356349**	**19799649**
Other activities	4	7438	334572	15628042
Other offshore supply vessels	6	145	6398	1474957
Offshore supply vessels	16	350	15379	2696650
Agotnes	**220**	**7899**	**352695**	**50586484**
Other activities	39	6399	287346	43278768
Other offshore supply vessels	27	183	8042	1409349
Bulk ships	2	3	136	2837
Fishing vessels	5	1	25	4524
Chemical-/product tankers	19	71	3071	248041
Reefers	7	1	39	2566
Container ships	1	1	26	2866
Offshore supply vessels	75	1180	51389	5374946
Oil tankers	4	18	811	49000
Passenger ships	3	1	23	7846
Ro Ro ships	5	12	494	60595
General cargo vessels	33	29	1293	145146
Tromso	**563**	**6114**	**273210**	**24336935**
Other activities	88	713	31103	2472897
Other offshore supply vessels	4	371	19642	1617908
Bulk ships	3	68	3006	54524
Fishing vessels	278	3344	146480	13482268
Chemical-/product tankers	7	90	3906	266803
Reefers	22	155	6799	576387
Offshore supply vessels	11	174	7642	568481
Oil tankers	4	76	3342	385450
Passenger ships	67	678	31754	3611336
Ro Ro ships	5	24	1005	125077
General cargo vessels	74	421	18530	1175804
Kirkenes	**205**	**5432**	**238769**	**16079782**
Other activities	55	1701	74776	5862543
Other offshore supply vessels	1	7	296	35408
Bulk ships	2	6	249	25760
Fishing vessels	91	3246	142833	8407693
Chemical-/product tankers	6	56	2263	200333
Reefers	11	26	1150	106511
Offshore supply vessels	3	41	1823	246282

Oil tankers	2	9	387	16719
Passenger ships	15	266	11747	901856
General cargo vessels	19	74	3246	276677
Oslo	**391**	**5406**	**200966**	**28745386**
Other activities	34	235	741	1152295
Bulk ships	14	176	551	274235
Chemical-/product tankers	84	847	2582	3044801
Container ships	41	1122	3557	5560404
Oil tankers	7	43	138	91807
Passenger ships	55	2328	7069	15497977
Ro Ro ships	4	198	629	999631
General cargo vessels	152	456	1445	2124236
Karsto	**196**	**4228**	**196948**	**17587589**
Other activities	19	438	17625	714428
Gas carriers	111	2092	92287	9860875
Chemical-/product tankers	23	262	11559	981014
Oil tankers	35	1433	75332	6014568
Ro Ro ships	2	0	15	1537
General cargo vessels	6	3	130	15167
Alesund	**536**	**4207**	**187072**	**16127330**
Other activities	95	162	5985	667148
Other offshore supply vessels	4	13	575	83891
Bulk ships	2	4	185	17509
Fishing vessels	213	2077	91134	8613403
Gas carriers	1	0	2	203
Chemical-/product tankers	15	118	5213	369924
Reefers	11	86	3771	325350
Container ships	5	197	8673	919025
Offshore supply vessels	25	675	29705	1493410
Oil tankers	5	25	1090	117936
Passenger ships	84	741	35990	3229973
Ro Ro ships	4	1	50	7790
General cargo vessels	72	108	4699	281768
Lyngdal	**42**	**3808**	**177863**	**17255457**
Other activities	14	1909	83934	6916135
Other offshore supply vessels	2	1159	61363	5649756
Chemical-/product tankers	1	0	9	6513
Offshore supply vessels	8	721	31716	4613201
Oil tankers	1	2	79	5320
Passenger ships	4	7	323	28208
Ro Ro ships	2	4	163	18729
General cargo vessels	10	6	276	17595

Slagentangen	**151**	**3707**	**171846**	**11296866**
Other activities	8	93	4112	263525
Gas carriers	10	36	1596	128800
Chemical-/product tankers	100	2396	105392	8238288
Oil tankers	33	1181	60746	2666253
Stavanger	**338**	**3467**	**155298**	**19085839**
Other activities	66	430	18876	3190273
Other offshore supply vessels	19	423	20117	2555675
Bulk ships	5	23	1024	103596
Fishing vessels	8	10	257	45151
Gas carriers	1	43	1882	236008
Chemical-/product tankers	19	197	8666	821947
Reefers	1	1	34	4298
Offshore supply vessels	66	1231	53765	6539766
Oil tankers	3	21	926	22824
Passenger ships	77	980	45037	5001263
Ro Ro ships	4	4	189	23746
General cargo vessels	69	103	4526	541292
Hammerfest	**248**	**3438**	**172860**	**21135426**
Other activities	39	92	3973	582430
Other offshore supply vessels	7	6	245	39301
Bulk ships	1	0	4	83
Fishing vessels	83	67	2949	459091
Gas carriers	15	2468	130195	16998720
Chemical-/product tankers	5	142	6408	591570
Reefers	7	7	306	25428
Offshore supply vessels	24	317	13872	1062545
Oil tankers	5	22	1014	101766
Passenger ships	36	313	13762	1257723
Ro Ro ships	2	1	48	5969
General cargo vessels	24	2	86	10800
Batsfjord	**195**	**3344**	**142995**	**13941500**
Other activities	17	128	5635	550055
Fishing vessels	133	2834	120539	11240007
Chemical-/product tankers	2	20	895	55028
Reefers	18	290	12765	1872732
Offshore supply vessels	2	8	332	10522
Oil tankers	3	13	573	24878
Passenger ships	12	48	2126	167364
General cargo vessels	8	3	131	20914
Floro	**374**	**3325**	**143595**	**19557166**
Other activities	52	682	29906	3530392

Other offshore supply vessels	15	177	7778	1527466
Bulk ships	11	95	4172	406818
Fishing vessels	52	333	14602	1541052
Gas carriers	2	2	110	13111
Chemical-/product tankers	24	96	4198	372995
Reefers	9	6	282	36116
Container ships	5	27	1176	113374
Offshore supply vessels	58	1431	60605	9742129
Oil tankers	5	6	251	9539
Passenger ships	39	261	11463	1081425
Ro Ro ships	8	39	1596	193023
General cargo vessels	94	170	7458	989726
Tananger	**352**	**3291**	**142199**	**21032334**
Other activities	30	35	1498	80954
Other offshore supply vessels	53	226	9965	1913544
Bulk ships	8	120	5296	127039
Fishing vessels	11	8	356	22535
Gas carriers	3	216	9513	974203
Chemical-/product tankers	39	235	10098	767858
Reefers	7	2	100	7314
Container ships	9	111	4898	464123
Offshore supply vessels	100	1727	74793	14126672
Oil tankers	2	38	1687	40763
Passenger ships	4	340	13794	1537736
Ro Ro ships	11	87	3813	461113
General cargo vessels	75	145	6387	508480
Porsgrunn	**470**	**2737**	**120217**	**12549156**
Other activities	10	86	3802	231009
Bulk ships	69	455	20216	1989466
Gas carriers	24	615	26335	3129213
Chemical-/product tankers	62	705	31274	3256154
Container ships	1	2	93	8207
Offshore supply vessels	1	0	18	2755
Ro Ro ships	1	1	29	3254
General cargo vessels	302	872	38451	3929098
Trondheim	**265**	**2701**	**116624**	**7703648**
Other activities	43	290	12654	1000041
Other offshore supply vessels	1	4	177	24254
Bulk ships	6	152	6684	133125
Fishing vessels	14	17	715	73600
Chemical-/product tankers	13	152	6265	512025
Reefers	5	21	904	94690

Offshore supply vessels	1	3	121	2721
Oil tankers	4	25	1103	27959
Passenger ships	55	1823	78515	4962248
Ro Ro ships	3	9	389	47025
General cargo vessels	120	207	9098	825960
Kristiansand	**221**	**2466**	**109493**	**19430021**
Other activities	38	201	8862	565819
Other offshore supply vessels	7	813	35743	7022393
Bulk ships	29	83	3639	297522
Fishing vessels	11	5	187	32074
Chemical-/product tankers	34	182	7950	807452
Reefers	4	3	121	13230
Container ships	20	338	14878	1454351
Offshore supply vessels	3	3	144	17868
Oil tankers	4	29	1297	36541
Passenger ships	18	741	33700	8855719
Ro Ro ships	4	32	1399	161626
General cargo vessels	49	36	1574	165426
Melkoya	**42**	**2259**	**117251**	**13751723**
Other activities	2	17	737	80742
Gas carriers	20	2076	109047	13074083
Chemical-/product tankers	8	73	3273	332571
Offshore supply vessels	1	43	1912	48675
Oil tankers	8	45	2080	199151
Passenger ships	2	2	89	9741
General cargo vessels	1	3	113	6760
Bodo	**253**	**2242**	**93589**	**9751127**
Other activities	49	89	3852	404149
Other offshore supply vessels	3	23	1005	137982
Bulk ships	1	9	406	7372
Fishing vessels	53	989	40493	4112995
Chemical-/product tankers	17	89	3711	319165
Reefers	7	12	541	54974
Offshore supply vessels	5	32	1399	64956
Oil tankers	4	10	335	26046
Passenger ships	43	830	34931	4027721
Ro Ro ships	4	19	744	93422
General cargo vessels	67	141	6172	502345
Haugesund	**223**	**2207**	**90483**	**9333589**
Other activities	57	774	27626	3803542
Other offshore supply vessels	12	615	26973	3825384
Bulk ships	2	0	8	824

Fishing vessels	37	115	5027	489627
Chemical-/product tankers	11	18	749	72544
Reefers	1	0	1	176
Container ships	1	0	1	97
Offshore supply vessels	7	640	28118	922747
Oil tankers	3	5	227	5342
Passenger ships	10	8	357	46908
Ro Ro ships	5	1	35	4071
General cargo vessels	77	31	1362	162327
Snohvit Statoil Liquifaction	**39**	**2200**	**114645**	**13613178**
Other activities	2	2	97	9239
Gas carriers	20	2076	109021	13069016
Chemical-/product tankers	8	73	3273	332571
Offshore supply vessels	1	4	190	4586
Oil tankers	8	45	2064	197766
Harstad	**255**	**2031**	**88656**	**8424716**
Other activities	56	356	15210	1052286
Other offshore supply vessels	1	0	5	479
Bulk ships	1	2	86	4210
Fishing vessels	67	779	34234	3498031
Chemical-/product tankers	5	76	3204	268591
Reefers	8	10	455	45198
Offshore supply vessels	6	106	4652	177537
Oil tankers	4	6	264	16322
Passenger ships	44	409	17946	1952812
Ro Ro ships	5	141	6145	658480
General cargo vessels	58	147	6456	750770
Langevag	**34**	**2014**	**88595**	**6381632**
Other activities	14	494	21736	1513558
Other offshore supply vessels	2	1	52	9523
Fishing vessels	8	580	25503	2967414
Offshore supply vessels	2	918	40397	1806492
Passenger ships	3	4	192	17474
Ro Ro ships	1	16	698	66244
General cargo vessels	4	0	16	927
Rubbestadneset	**105**	**2007**	**88168**	**10449832**
Other activities	18	137	6019	278703
Other offshore supply vessels	5	309	13587	2783410
Fishing vessels	27	955	42009	4100759
Offshore supply vessels	6	340	14809	1781582
Passenger ships	25	173	7609	1103082

Ro Ro ships	4	12	523	51091
General cargo vessels	20	82	3614	351205
Kristiansund	**325**	**1971**	**85713**	**8700772**
Other activities	74	491	21607	1662922
Other offshore supply vessels	15	264	11584	1403203
Bulk ships	2	2	85	7253
Fishing vessels	55	149	6535	690522
Gas carriers	1	1	45	5301
Chemical-/product tankers	9	45	1982	154694
Reefers	7	3	119	10016
Offshore supply vessels	30	451	19213	2819142
Oil tankers	5	7	323	42586
Passenger ships	51	260	11610	1117223
Ro Ro ships	8	10	439	53353
General cargo vessels	68	288	12171	734557
Dusavik	**199**	**1869**	**81367**	**10141205**
Other activities	22	20	872	75330
Other offshore supply vessels	21	279	12260	1936400
Bulk ships	3	8	354	7349
Fishing vessels	4	3	126	9956
Chemical-/product tankers	25	96	4191	321469
Reefers	4	2	78	4775
Offshore supply vessels	75	1354	58733	7356134
Oil tankers	1	6	268	6092
Passenger ships	2	0	3	297
Ro Ro ships	4	17	750	87080
General cargo vessels	38	85	3732	336323
Stura	**101**	**1706**	**84836**	**9668369**
Other activities	8	568	24993	4863174
Gas carriers	7	47	2095	227901
Oil tankers	86	1090	57749	4577294
Brevik	**102**	**1704**	**75233**	**4051556**
Other activities	7	15	656	44214
Other offshore supply vessels	1	2	82	43665
Bulk ships	13	981	43177	1005976
Gas carriers	1	6	225	14023
Container ships	17	174	7667	850716
Offshore supply vessels	2	119	5257	805182
Ro Ro ships	6	299	13433	819779
General cargo vessels	55	108	4736	468001
Narvik	**171**	**1567**	**75637**	**6947388**
Other activities	13	295	12993	993345

Bulk ships	128	1199	59441	5713376
Reefers	1	0	2	177
Offshore supply vessels	1	0	2	535
Oil tankers	2	0	6	443
Passenger ships	5	10	456	30365
Ro Ro ships	1	0	1	137
General cargo vessels	20	62	2736	209010
Rypefjord	**150**	**1526**	**65108**	**9546801**
Other activities	17	147	6416	777525
Other offshore supply vessels	4	42	1840	341029
Bulk ships	1	0	6	531
Fishing vessels	55	274	12044	1452562
Chemical-/product tankers	6	56	2277	230496
Reefers	14	23	1004	85652
Offshore supply vessels	25	969	40880	6591006
Oil tankers	1	1	55	1226
Passenger ships	3	2	64	7304
Ro Ro ships	2	4	174	21689
General cargo vessels	22	8	349	37781
Fredrikstad	**308**	**1488**	**65349**	**7003287**
Other activities	17	75	3268	536686
Other offshore supply vessels	2	45	1973	278233
Bulk ships	18	140	6216	613014
Gas carriers	2	163	7153	733551
Chemical-/product tankers	57	319	14057	1374449
Reefers	6	29	1294	129679
Container ships	20	411	18104	2067387
Passenger ships	1	8	339	32969
Ro Ro ships	4	52	2170	260475
General cargo vessels	181	245	10775	976844
Storebo	**149**	**1449**	**63687**	**4950463**
Other activities	16	23	1022	116363
Other offshore supply vessels	3	180	7929	895578
Fishing vessels	80	330	14512	1085241
Chemical-/product tankers	5	21	937	153055
Reefers	10	4	157	12329
Container ships	1	0	6	716
Offshore supply vessels	7	885	38884	2662478
Oil tankers	1	0	18	248
Passenger ships	5	1	35	3409
Ro Ro ships	2	0	17	5775
General cargo vessels	19	4	167	15271

Sandefjord	**18**	**1435**	**60254**	**5646770**
Other activities	11	75	184	413478
Fishing vessels	1	0	4	435
Chemical-/product tankers	2	3	122	20507
Offshore supply vessels	1	0	6	208
Passenger ships	3	1357	59937	5212142
Honningsvag	**210**	**1354**	**61362**	**5365586**
Other activities	22	18	690	51400
Other offshore supply vessels	1	62	2725	329993
Fishing vessels	106	468	20539	1833865
Chemical-/product tankers	2	3	145	20427
Reefers	10	53	2348	444200
Offshore supply vessels	3	118	5175	208896
Oil tankers	1	0	2	71
Passenger ships	53	629	29585	2455309
General cargo vessels	12	4	154	21425
Sandnessjoen	**222**	**1239**	**54410**	**6108577**
Other activities	57	387	16938	1497615
Other offshore supply vessels	1	8	336	6075
Bulk ships	1	1	43	925
Fishing vessels	31	43	1872	143677
Chemical-/product tankers	7	27	1183	81162
Reefers	7	6	256	24547
Container ships	2	1	41	3608
Offshore supply vessels	9	89	3916	639386
Oil tankers	2	1	31	1735
Passenger ships	60	624	27466	3507849
Ro Ro ships	2	7	287	35875
General cargo vessels	43	46	2043	166123
Svolvar	**206**	**1172**	**49390**	**5184034**
Other activities	50	225	9537	1076754
Other offshore supply vessels	2	18	769	105841
Fishing vessels	77	361	14059	1846380
Reefers	7	8	341	35261
Oil tankers	1	0	4	387
Passenger ships	47	556	24498	2097813
Ro Ro ships	2	1	43	5262
General cargo vessels	20	3	140	16336
Ulsteinvik	**51**	**1136**	**49941**	**6835198**
Other activities	17	6	276	25337
Other offshore supply vessels	5	259	11347	1807775

Fishing vessels	4	1	23	15628
Reefers	1	0	1	66
Offshore supply vessels	10	869	38214	4977801
Oil tankers	1	0	0	65
Ro Ro ships	2	0	11	1279
General cargo vessels	11	2	70	7247
Elnesvagen	**34**	**1075**	**47320**	**4526267**
Other activities	4	1	23	1302
Bulk ships	5	174	7668	600887
Chemical-/product tankers	14	880	38732	3838863
Oil tankers	1	0	1	1390
General cargo vessels	10	20	897	83825
Sortland	**150**	**1052**	**45827**	**2409115**
Other activities	28	302	12784	835904
Fishing vessels	50	108	4769	364705
Reefers	13	41	1825	144713
Container ships	1	23	1020	97038
Offshore supply vessels	3	490	21581	664257
Oil tankers	2	0	17	1694
Passenger ships	17	74	3258	246487
Ro Ro ships	3	0	6	965
General cargo vessels	33	13	567	53352
Drammen	**205**	**1010**	**44458**	**4648786**
Other activities	16	192	8424	765755
Other offshore supply vessels	1	1	50	10213
Bulk ships	11	30	1287	118298
Chemical-/product tankers	8	21	903	66949
Container ships	18	185	8145	1000013
Offshore supply vessels	1	0	12	1807
Oil tankers	9	167	7354	514542
Ro Ro ships	19	226	9980	1435258
General cargo vessels	122	189	8303	735951
Askoy	**43**	**1007**	**44313**	**2005850**
Other activities	5	0	13	1264
Other offshore supply vessels	1	1	60	54643
Fishing vessels	1	0	0	2
Chemical-/product tankers	1	0	0	7
Offshore supply vessels	2	693	30499	1127960
Oil tankers	4	278	12216	667264
Passenger ships	9	27	1200	125735
General cargo vessels	20	7	326	28975

APPENDIX B
Routes for ships eligible for battery power

Route	# of ships	# of voyages	Total fuel consumption (mt)	Total CO2 emission (mt)	Total NOx emission (kg)
Alta - Alta	2	1096	72	229	3173
Karsto - Karsto	1	980	21	54	94
Narvik - Narvik	2	686	8	24	335
Kristiansund - Kristiansund	5	648	20	65	899
Hestvika - Hestvika	2	608	111	352	4898
Bergen - Bergen	6	578	217	686	9527
Horten - Horten	2	434	16	49	686
Farsund - Farsund	2	302	11	34	472
Husoy - Lenvik - Husoy - Lenvik	3	278	2424	7684	82731
Myre - Myre	3	250	62	195	2708
Berlevag - Berlevag	2	248	49	156	2167
Honningsvag - Honningsvag	3	220	73	233	3232
Harstad - Harstad	5	134	29	93	1288
Tromso - Tromso	4	84	5	16	224
Mo i Rana - Mo i Rana	1	84	1	3	48
Hoylandsbygda - Hoylandsbygda	2	82	7	21	270
Vedavagen - Vedavagen	1	68	7	22	312
Varoy - Varoy	1	60	13	40	553
Bremanger - Bremanger	2	52	34	108	1500
Askoy - Askoy	1	46	6	19	269
Mehamn - Mehamn	2	36	6	20	282

Andenes - Andenes	1	36	6	18	247
Forsol - Forsol	1	36	11	34	474
Drammen - Drammen	1	30	5	15	208
Bergen - Solund	1	21	7	23	317
Fosnavag - Fosnavag	1	20	26	81	1127
Olen - Olen	1	20	21	66	917
Bergen - Askoy	1	15	10	31	425
Floro - Floro	2	14	1	3	45
Hammerfest - Hammerfest	2	14	35	112	1548
Sandviksberget - Sandviksberget	2	14	9	27	376
Solund - Bergen	1	14	9	30	414
Svolvar - Svolvar	2	14	1	2	25
Sorvar - Sorvar	1	12	1	4	58
Batsfjord - Batsfjord	1	12	4	12	165
Askoy - Bergen	1	11	5	15	205
Namsos - Namsos	1	10	6	19	257
Lodingen - Lodingen	2	10	6	19	264
Vedavagen - Haugesund	1	9	6	18	245
Fonnes - Fonnes	2	8	5	17	239
Henningsvar - Henningsvar	1	8	0	1	20
Leirvik - Leirvik	1	8	3	10	141
Haugesund - Vedavagen	1	8	22	69	956
Fosnavag - Alesund	2	8	176	558	7744
Stamsund - Henningsvar	1	7	1	2	29

Askvoll - Bergen	1	7	4	13	175
Kristiansund - Hestvika	1	7	8	26	361
Agotnes - Agotnes	1	6	0	0	2
Ulsteinvik - Ulsteinvik	3	6	168	533	7397
Hestvika - Kristiansund	1	6	5	16	225
Finnsnes - Finnsnes	1	6	1	3	37
Stamsund - Stamsund	1	6	5	15	214
Alesund - Alesund	3	6	45	142	1975
Henningsvar - Stamsund	1	6	1	4	54
Alesund - Fosnavag	1	5	2	5	70
Solund - Askvoll	1	5	2	5	76
Rypefjord - Rypefjord	1	4	0	1	11
Leknes - Leknes	1	4	2	6	80
Sorvar - Skjervoy	1	4	2	6	82
Skjervoy - Skjervoy	1	4	0	1	10
Haugesund - Haugesund	1	4	22	69	957
Mehamn - Berlevag	2	4	1	3	45
Langevag - Sula - Langevag - Sula	1	4	0	2	22
Agotnes - Bergen	1	4	4	14	196
Sandnessjoen - Sandnessjoen	2	4	2	7	99
Havik - Havik	1	4	5	17	234
Skanland - Skanland	1	4	1	2	26
Maloy - Maloy	2	4	1	4	50

Henningsvar - Svolvar	1	3	0	1	19
Skjervoy - Sorvar	1	3	1	3	43
Trana - Trana	1	2	0	0	2
Moskenes - Moskenes	1	2	0	1	14
Vardo - Batsfjord	1	2	1	3	37
Rubbestadneset - Olen	1	2	5	17	236
Storebo - Storebo	1	2	0	1	7
Bodo - Bodo	1	2	0	0	6
Trondheim - Trondheim	1	2	0	2	21
Floro - Bremanger	1	2	2	5	73
Dusavik - Dusavik	1	2	49	156	2170
Hanoytangen - Askoy	1	2	0	0	2
Honningsvag - Mehamn	1	2	1	2	30
Svolvar - Harstad	1	2	1	2	23
Husnes - Hoylandsbygda	1	2	14	45	622
Batsfjord - Vardo	1	2	1	2	30
Torsken - Torsken	1	2	0	1	10
Melbu - Melbu	1	2	1	3	38
Askoy - Knarrevik	1	2	0	0	2
Midsund - Midsund	1	2	11	33	463
Oksfjord - Oksfjord	1	2	0	1	9
Solund - Solund	1	2	0	1	8
Varoy - Finnsnes	1	2	2	7	104
Askoy - Agotnes	1	2	0	0	5

Ornes - Ornes	1	2	0	1	14
Molde - Molde	1	2	0	1	14
Vikan - Smola - Kristiansund	1	2	3	10	134
Knarrevik - Knarrevik	1	2	0	0	3
Kristiansand - Kristiansand	1	2	0	1	10

APPENDIX C
Dissemination of results

Articles:

- Teknisk Ukeblad (24.09.2015); https://www.tu.no/artikler/na-skal-det-bli-fart-pa-elektrifiseringen-av-norsk-skipsfart/275623
- Teknisk Ukeblad (21.10.2015); https://www.tu.no/artikler/landstrom-over-600-skip-er-klare/275798
- Cavotec Blog (16.10.2015); http://blog.cavotec.com/tag/dnv-gl/
- Marine Propulsion (04.07.2016); http://www.mpropulsion.com/news/view,dnv-gls-revolt-project_43599.htm
- The Motorship (16.10.2015); http://www.motorship.com/news101/industry-news/project-recharge-launched-to-boost-norways-shore-power-capabilities
- Port Strategy (); http://www.portstrategy.com/news/environment/oslo-and-cavotec-join-ship-recharging-initiative
- Bunkerworld (); http://www.bunkerworld.com/news/Nordic-shore-power-project-started-139420
- Ctech (16.10.2015); http://fathom-ctech.com/news-item/-cavotec-launches-ship-electrification-project/16-10-2015/1522/

Conferences and presentations:

- KS Bedrift; Erfaringsseminar om landstrøm (30.06.2016, Oslo)
- KS Bedrift; Presentation to the port steering committee (02.06.2016, Oslo)
- DNV GL; Internal seminar (06.06.2016, Høvik)
- ENOVA; Presentation of the project (27.09.2016, Trondheim)
- Electric and hybrid marine world expo 2017. Abstract accepted. (6-8 June 2017, Amsterdam)
- Green Port Congress 2017. Will submit abstract. (11-13 October 2017, Amsterdam)

Film:

A promo video has been made. The project partners will use the film in presentations and at conferences. ENOVA is profiled in the video.

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our professionals are dedicated to helping our customers make the world safer, smarter and greener.