Electrification of harbours – Project report

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1. Introduction

Reducing emissions from marine related activities is an important global issue. Over the past decade, the focus has been on land transport and reducing related emissions. However, the recent introduction and implementation of regulations on international sulphur limits of 0,10% in emission control areas (ECAs) starting January 1, 2015 has seen drastic improvements in regional and local emission impacts around Europe, the greatest benefits having been felt in densely populated areas in and around the ECAs. The electrification of ports could further contribute to the reduction of emissions. An increasing proportion of new vessels are diesel electric and several Nordic ship projects are demonstrating hybrid or pure electric solutions. Another issue which is of high concern is the harbour emissions, i.e. docked ships burn fossil fuels to produce electricity, via auxiliary engines. Running ships on shore power, thus allowing the shut off of auxiliary engines, has great potential to decrease emissions local to ports and minimize local pollution.

Through the collaboration for this report it became clear that there is a crucial lack of comparable data for ship emissions and mitigation options for the Nordic countries. This would prove very useful in putting forward and sharing practical solutions and for evaluation of options for infrastructure build-up and prioritization. Thus, in this report, the status in each of the three partner countries has been analysed and compared as possible.

The goal of the project, *Electrification of harbours*, has been to map existing electric infrastructure of ports in participating Nordic countries. An additional objective of the project had been to explore business models for investment in the further electrification of harbours. Representatives from Polytec, Norway, VTT in Finland, and in Iceland, Hafið – Icelandic Centre of Excellence for Sustainable Use and Conservation of the Ocean in addition to Icelandic New Energy, have collaborated during the short working period of the project to produce preliminary findings on the status in their respective countries.

This report deals with the conclusions and findings of the project *Electrification of harbours* and suggests relevant next steps to expand the research. Available data is put forward for each country and comparison between countries is based on discussion rather than data analysis due to the aforementioned data comparison issues.

2. The background for shore power

Shore power connections are an important means to cut vessel emissions in harbours. Exhaust gas from burning fuel in ships' combustion engines is the main source of harmful air emissions. Of these exhaust gases and particles, carbon dioxide (CO_2) has only climate effects, while carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), methane (CH_4), black carbon (BC) and organic carbon (OC) have adverse impacts on human health and the environment. Shore power allows ships to cut combustion time in port, and plug into shore-side electricity supply, thus helping to bring cleaner air to ports and surrounding communities.

Over the last 20 years, there has been an increasing concern over air quality in harbours. This has resulted in growing awareness among port operators to reduce harmful emissions to air. Several studies have estimated the emission by ships to be 2 - 3% of CO_2, 10 - 15% of NO_x and 5 - 8% of SO_x of the total worldwide emissions.[1][2][3][4] IMO introduced a 0,5% global sulphur cap on fuel to come into force from January 1, 2020, and has enforced NO_x reduction measures by introducing Tier II and III (3,4 - 2 g NO_x/kWh) standards for marine engines.

[1] S.B. Dalsøren et al. (2009). 'Update on Emissions and Environmental Impacts from the International Fleet of Ships. The Contribution from Major Ship Types and Ports'. Atmospheric Chemistry and Physics:9, 2171.

[2] James J. Corbett et al. (2007). 'Mortality from Ship Emissions: A Global Assessment'. Environmental Science and Technology: 41(24) 8512.

[3] Øyvind Buhaug et al. (2009). Second IMO GHG Study. International Maritime Organization (IMO) London UK April 2009.

[4] V Eyring et al. (2005). 'Emissions from International Shipping: 1. The Last 50 years'. Journal of Geophysical Research 110.

3. Methodology

3.1 Background and preparation

Early on, during the preparation phase of the project in the summer of 2016, the project became aware that a study on the status and availability of shore power in Norwegian ports had been carried out and published by DNV GL.[5] The survey also produced an analysis on market conditions for further build-up of electric infrastructure in ports along the Norwegian coast, taking into account the type of vessels calling, docking time and grid capacity. Similar studies were not identified for the other Nordic countries, Denmark, Finland, Iceland and Sweden.

Contact was made with one of the authors of the Norwegian report, Mr. Kjetil Martinsen Chief Engineer at DNV GL, who was kind enough to share a questionnaire used during tele-interviews during the data collection phase of DNV GL's project.[5] Questions developed for port authorities and ship owners in Finland and Iceland were based on this questionnaire, following some tweaking and localizing.

In Iceland, the method chosen for data collection, using the aforementioned questionnaire as foundation, was in person interviews. Though slower and less extensive, the researchers felt this approach would yield more reliable data of quality in addition to enabling access to further information from discussions and subsequent email contact with the interviewees. For the purposes of this report, data was collected from Faxaflóahafnir, also known as Associated Icelandic Ports (4 distinct ports in Southwest Iceland) and the Port of Grindavík and analysis thereof will be presented in following sections. Contact was made with authorities at the Port of Akureyri (6 separate ports in North Iceland) and the Ports of Fjarðabyggð (7 distinct ports in East Iceland) and data was partially collected during the report writing phase of the project. Therefore, as the conclusions of the report suggest, a clear next step in extension to *Electrification of harbours*, would involve further investigation, collection and interpretation of the data from the latter two port associations.

Information on the legal framework for ports in Iceland was obtained with the help of the Icelandic Transport Authority and data on upcoming construction projects was gathered from The Icelandic Road and Coastal Administration.

In Finland, an online survey tool called Webropol was applied for data collection. This method was considered an efficient way to reach a large number of companies. Contact information was gathered from websites of, e.g., The Finnish Shipowners' Association and Finnish Port Association. Representatives of the Finnish Funding Agency for Innovation (Tekes) and Finnish Marine Industries provided useful guidance in drafting the survey and defining the ports and

[5] DNV GL AS Maritime. (2015). *Landstrøm i norske havner.* http://www.ksbedrift.no/media/1537/undersoekelse-om-markedsgrunnlaget-for-landstroem-oed-enova-dnv-gl.pdf

instances that could be contacted. To find out how shore power is currently utilized, a survey was addressed to 20 ship owners and to 23 port authorities. After two weeks, a reminder was sent to companies, which had not answered. Seven ship owners and nine ports filled in the questionnaire. Conclusions are based on these answers. To find out how shore power is currently utilized, a survey was addressed to 20 ship owners and to 23 ports. Seven ship owners and nine ports in Finland filled in the questionnaire.

3.2 General principles on calculating potential shore power (kWh) and emissions to air

The calculation of hours at berth is based on data for arrival (date and time) and departure given by port authorities. The numbers of hours for each vessel were then deducted 0,5 hours, which is the time assumed for connecting/disconnecting the shore power cables to the ship. In this calculation, we have assumed that it is not likely that vessels staying less than 1 hour at berth will connect to shore power, and thus all ship-stays less than 1 hour are taken out of the calculation. Additional data was acquired from maritime databases.[6]

All ships were categorised based on different gross tonnage (GT<999, 1 000-4 999, 5 000-9 999, 10 000-24 999, 25 000-49 999, 50 000-99 999, >100 000) and ship type (Oil Tanker, General cargo, Container, RORO Cargo, Reefer, Passenger, Offshore Supply, Other offshore, Other activity and Fishing vessels (see Table 1).

The hours at berth and potential for energy consumption for the different ship types were calculated by use of estimated data on average output power of engines for a given ship type and size. These estimations are given by DNV GL and also used by ENOVA (run by the Norwegian Ministry of Petroleum and Energy) when estimating ships energy consumption at berth. The values given are conservative, and most likely lower than actual output powers.

Energy consumption (kWh) while at berth is determined by multiplying power (kW) with hours (h) at berth. There are a total of 91 (13x7) different classes of ship type and given size class. The sum for each ship type is presented.

Table 1 shows the estimated power output for the different ship types and sizes while at berth.

[6] http://www.marinetraffic.com/

Table 1 Average power output at berth for different vessel types

	Average power output (kW) for different ship types and size (GT) while at berth						
Ship type	< 999	1000-4999	5000-9999	10000-24999	25000-49999	50000-99999	>100000
Oil Tanker	37	161	352	476	646	834	1 032
Chemical Tanker	106	289	531	723	864	1 434	1 536
Gass Tanker	111	254	667	836	1 078	2 816	3 556
Bulk	26	80	132	197	261	350	438
General cargo	12	66	149	259	416	579	704
Container	31	121	332	473	864	1 535	2 295
RORO Cargo	28	94	213	415	529	668	735
Reefer	44	153	319	542	672	800	960
Passenger	20	119	272	570	1 194	2 100	2 912
Offshore Supply	45	144	345	553	912	1 144	1 248
Other offshore	42	149	251	417	575	643	685
Other activity	28	173	344	569	988	1 282	1 600
Fishing	43	149	284	454	454	454	454

Calculation of emissions to air is based on the emission factors that states how much (g) of different components that are emitted when producing 1 kWh using a specific fuel. The Baltic Sea is established as an ECA[7] and after 1 January 2015 fuel oil sulphur limits are 0,10% m/m (expressed in terms of % m/m – that is by mass). Emission factors for Tier II engines using Marine Gas Oil (Light Fuel Oil) with 0,1% S is used for the calculations for Finnish ports. Emission factors for Tier II engines using Heavy Fuel Oil - 2,7% S is used for the calculations of Icelandic ports and therefore has a higher factor value for SO_x (10) as compared to fuels containing only 0,1% S. Emission factors are shown in Table 2.[8]

Table 2 Emission factors for different exhaust components

Emission factors (g/kWh) of different exhaust components	
Component	(g/kWh)
Black carbon (BC)	0,05
Organic carbon (OC)	0,2
Methane (CH4)	0,05
Carbon mono oxide (CO)	1
Nitrogen oxides (NOx)	12
Sulphur oxides (SOx)	0,4 and 10
Carbon dioxide (CO2)	570

[7] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Sulphur-oxides-(SOx)-–-Regulation-14.aspx

[8] Haakon Lindstad et al. (2015). Maritime shipping and emissions: A three-layered, damage-based approach, Ocean Engineering110: 94–101.

4. Status in Finland

4.1 Background - Previous studies on utilization of shore power

In 2005, the Port of Helsinki launched a study, which dealt with the connection of ships to shore power from the viewpoint of technology, economy and environmental friendliness. At the time, a few cruise-liners utilized shore power but most ships did not. The outcome was that upgrading shore power capacity and increasing of shore power utilization is technically possible, but the problem is variety in the preparedness of ships for connection to shore power and lack of standardization. It also proved to be unfeasible to connect ships to shore power for just one or two hours due to the time it takes to set up and disconnect charging equipment.

One reason to use shore power is to decrease emissions in harbour areas. In this case, comparison between emissions from ship engines and average emissions from production of electricity consumed in Finland should be carried out.

The most significant marine emissions are carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and particulates. Comparison between the emissions from Wärtsilä diesel engine, engines of Viking Line fleet and engines of Silja Line fleet is shown in Table 3.

Table 3 Emissions for three different vessel engines[9]

Emissions	Diesel engine, heavy fuel oil (Wärtsilä)	Viking Line (average emissions)	Silja Line (average emissions)
Nitrogen oxides (NO_2), g/$kWh_{electricity}$ - normal use - water injection - catalyst converter	 11-16,6 < 5 < 2	8,1 (auxiliary engines), 7,7 (main engines)	3,7
Sulphur oxides (SO_2),g /$kWh_{electricity}$ - fuel sulphur content 3,5 % - fuel sulphur content 0,5 % - fuel suplhur content 0,1 %	 16,6 2,3 0,5	2,2	2,3*
Carbon dioxide (CO_2), g/$kWh_{electricity}$	737	730	711
Particulates, g/$kWh_{electricity}$	0,38 (ash content 0,011 %)	0,26	0,26 (an estimate)

Emissions were compared to average electricity production in Helsinki and Finland, see Table 4.

[9] Study of Shore Power Connection Possibilities of Ships in South Harbour and Katajanokka in Helsinki from: http://www.helsinginsatama.fi-a.innofactor.com/instancedata/prime_product_julkaisu/helsinginsatama/embeds/helsinginsatamawwwstructure/13369_maasahkoselvitys_final_en.pdf

Table 4 Emissions related to energy generation in Finland[10]

Emissions	Helsinki Energy, 2004	Energy generation in Finland, 2003	Coal condensing power average specific emissions
Nitrogen oxides (NO_2), $g/kWh_{electricity}$	370	702	1350
Sulphur dioxide (SO_2), $g/kWh_{electricity}$	350	596	1260
Carbon dioxide (CO_2), $g/kWh_{electricity}$	300	517	838
Particulates, $g/kWh_{electricity}$	49	245	225

CO_2 emissions from production of electricity in Finland were 105 g/kWh in year 2016 and have been decreasing in 2000's. Finland is also importing electricity from Sweden, Norway and Russia, mostly hydroelectric and nuclear power.[11]

Also, CO_2 emissions from fuel production should be considered. The more fuel is refined, the more production from well to tank consumes energy and produces emissions. In Baltic Sea, only fuel with no more than 0,1% sulphur is allowed. The following emissions, see Table 5, were calculated by IFEU as part of JOULES WG2 activities and they are derived from a refinery model in UMBERTO which was created by IFEU. There are still high uncertainties in the actual processes behind so the accuracy of values cannot be confirmed.

Table 5 Sulphur content of two different marine fossil fuels

Description	Short name	CO_2 emissions per kg fuel
Low Sulphur Marine Gas Oil with 0,1 % sulphur content	LSMGO	482,52
Ultra Low Sulphur Heavy Fuel Oil with 0,1 % sulphur content	ULSHFO	572,18

4.2 Finnish maritime regulations and infrastructure

4.2.1 National port legal framework

In addition to EU directives, Finland's Ministry of Justice, Ministry of Transport and Communications, and the Ministry of the Environment set regulations for emissions and environment related issues of marine activities in Finland. This judicial information is available online in Finnish and Swedish.

[10] Study of Shore Power Connection Possibilities of Ships in South Harbour and Katajanokka in Helsinki from: http://www.helsinginsatama.fi-a.innofactor.com/instancedata/prime_product_julkaisu/helsinginsatama/embeds/helsinginsatamawwwstructure/13369_maasahkoselvitys_final_en.pdf

[11] http://www.slideshare.net/energiateollisuus/energiavuosi-2016-shk-71279186

The most relevant environmental laws are: ”Merenkulun ympäristönsuojelulaki” (Maritime environmental law)[12] and ”Valtioneuvoston asetus merenkulun ympäristönsuojelusta“[9]. Maritime environmental law has been updated to include regulations from MARPOL.

Finnish Transport Safety Agency (Trafi) lists legislation and regulations available in English on its website.[13]

On October 2016, the Marine Environment Protection Committee of the International Maritime Organization IMO approved the designation of the Baltic Sea and the North Sea as an emission control area for nitrogen oxides (NECA). The Finnish Ministry of the environment published this news. [14]

In these areas nitrogen oxide emissions are to be reduced by 80 percent from the present level. The regulation will be applicable to new ships built after 1 January 2021 when sailing in the Baltic Sea and the North Sea and other NECAs. The decision means that ships built after January 1, 2021 must have catalyst converters installed or use liquefied natural gas (LNG) as fuel.

Directive 2014/94/EU[15] might have some positive effect to shore power utilization depending on harbour. The main content related to shore power is

> Member States shall ensure that the need for shore-side electricity supply for inland waterway vessels and seagoing ships in maritime and inland ports is assessed in their national policy frameworks. Such shore-side electricity supply shall be installed as a priority in ports of the TEN-T Core Network, and in other ports, by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits.

4.2.2 Regional framework

In Finland, the local distribution system operator is obliged to connect electrical equipment that meets the requirements to the distribution network after appropriate inspection. In general, there can be only one permanent connection point per plot. Customers do not need their own connection point to the distribution network but must supply an electricity meter and there can be several meters connected in one connection point (for example, like in apartment house).

If the capacity of local distribution network is not sufficient for new equipment, the network operator is obliged to strengthen it. The customer or holder of new equipment to be installed is not responsible for direct costs caused by upgrading electric network but the price for a new or upgraded connection point is based on maximum power, distance from existing network and real costs of new line.[16]

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[12] http://www.finlex.fi/fi/laki/ajantasa/2009/20091672

[13] https://www.trafi.fi/en/maritime/regulations

[14] http://www.ym.fi/en-US/Latest_news/News/Nitrogen_emissions_from_ships_restricted%2840755%29

[15] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0094

[16] Terms of network service from: http://energia.fi/files/1065/Terms_of_Network_Service_TNS2014_20160118.pdf

In harbour, it is technically possible to install new electricity meter for each regular shore power user which enables ship owners to make a contract with electricity seller. Lack of space and new cable installations may cause challenges.

4.3 Finnish ports introduction

There are thousands of lakes in Finland and a lot of coastline. There are also numerous ports of various sizes. In this study, only Finnish sea ports with foreign traffic are explored, that is inland ports and small boat harbours are excluded at this time. Table 6 shows commercial ports with regular or at least almost daily traffic information in web service www.porttraffic.fi provided by the Finnish Transport Agency.

Table 6 Summary of Finnish ports with regular traffic

Location	Information
Eckerö (Åland)	one line to Grisslehamn, Sweden
Helsinki	biggest passenger port in Finland
Hanko	cargo to and from Rostock and Gdynia
Inkoo	cargo
Kaskinen	cargo
Kemi	cargo
Kokkola	cargo
Kotka - aka Haminakotka	cargo
Långnäs (Åland)	cruise liners, ferries, cargo
Mariehamn (Åland)	cruise liners and ferries
Naantali	cargo and ferries
Oulu	cargo
Pori	cargo
Raahe	cargo (SSAB)
Rauma	cargo
Kilpilahti – aka Sköldvik	biggest cargo port in Finland
Turku	cruise liners and ferries, some cargo
Tornio	cargo (Outokumpu)
Uusikaupunki	cargo
Vaasa	one line to Holmsund, Sweden and some cargo

4.4 Results of the survey

Results of the Finnish survey for ports and ship owners are presented in this section. The main outcomes of all the replies are summarised and more elaborate analysis is presented on the Port of Helsinki, Port of Rauma and Port of Vaasa. Altogether 9 port operators and 7 ship owners replied the survey.

4.4.1 Summary

According to the answers, it is easier and more common to use shore power if standard 3 phase 400 V connector is sufficient. Capacity of this connector type is 16 / 32 / 63 / 125 A which corresponds to 10 / 20 / 40 / 80 kW of power. Ship operators who are using shore power save some fuel and operating hours of auxiliary engines and staff do not have to be on duty when engines are stopped.

If more power is required, there is chicken and egg problem: ships may not have the necessary equipment because compatibility in all harbours is not guaranteed and harbours are not interested in installing connection points because ships are not able to utilize them.

For example, the shipping company Containerships has 11 container ships with capacity of 600–1100 twenty foot equivalent unit. Those vessels require 200–250 kW power when berthed but none has equipment for shore power. If it were technically possible, they would utilize shore power on all of their ships.

Ropax-ships of Finnlines require 1–1,5 MW and Cruise liners of Tallink Silja require 2,5–3,5 MW power when berthed and none of their vessels are equipped for shore power.

6 out of 9 ports who answered the survey are providing shore power: Port of Turku, Uusikaupunki, Tolkkinen, Kalajoki and Inkoo provide 400 V shore power up to 63–125 A.

Port of Oulu is providing 6 kV connection.

Information from other sources

In larger scale, shore power is utilized only on Viking Line ships at Helsinki and Stockholm ports where ships stay berthed for 6–8 hours each day. Due to shore power connections on Katajanokka terminal in port of Helsinki, Mariella and Gabriella ships have saved 2087 MWh of energy produced by diesel engines in year 2014 and 2528 MWh in year 2015. This means 1120 tons less CO_2 emissions in 2014 and 1380 tons in 2015.[17]

Ports of Kemi and Kotka are also providing 6,6 kV connection.[18]

Port of Turku, Port of Tallinn, Port of Helsinki and Ports of Stockholm are in cooperation working to increase shore power utilization. These ports will provide ships with 11 kV shore power in near future and they are encouraging other ports and ship companies to put shore power into operation in larger scale.[19]

[17] Helsingin Itämeri-toimenpideohjelman 2014–2018 tilannekatsaus from: https://dev.hel.fi/paatokset/media/att/de/decc0e45a2863f52539e0357296c4902b0ea89f1.pdf

[18] http://www.ops.wpci.nl/ops-installed/ports-using-ops/

[19] Aboard: Four ports agree on providing on-shore power to vessels from: http://www.port.turku.fi/files/attachments/liitteet/aboard_2_2016_eng_lowres.pdf

4.4.1 Port of Helsinki

Figure 1 Port of Helsinki

About the port of Helsinki

The port of Helsinki is the main harbour for foreign trade and passenger traffic services in Finland. The Port of Helsinki's market share of passenger traffic of Finnish ports is 79%. The value of the goods transported through the Port of Helsinki is 40% of the total value of Finnish foreign trade transported by sea. Harbours managed by the Port of Helsinki are: South Harbour, Katajanokka, West Harbour, Hernesaari, Vuosaari, Kantvik, Helsinki's coal quays and from 2017 Port of Loviisa.[20][21]

Description of current shore electricity connections.

The port of Helsinki offers shore power for vessels at many of its quays.

Harbour activity – ship arrivals

Port of Helsinki had in 2016 a total of 8468 calls, and 608 arrivals in December 2016. Data presented are vessels that arrived and had departure in December 2016 at Port of Helsinki. In addition, there were three Icebreakers (Other activity) at berth in Port of Helsinki in December 2016 that arrived in August, September and October 2016. These have been added to this calculation with 3*720 hours in the category Other activity.

Furthermore, there were 8 ships with arrival in December 2016 with departure in January 2017, and the hours of these ships have not been added in this calculation. The numbers given are thus conservative.

Table 7 shows how many hours the different ship types were at berth and an estimation of power consumption (MWh) in Port of Helsinki in December 2016.

[20] http://www.portofhelsinki.fi/helsingin-satama (February 2017)

[21] Annual report 2016
from: http://www.portofhelsinki.fi/sites/default/files/attachments/ Vuosikertomus%202016%20englanti%20low%20res.pdf

Table 7 Hours spent at berth at the Port of Helsinki

Total hours at berth and energy consumption (MWh) for different shiptypes		
Ship type	Hours	MWh
Oil Tanker	324	163
General cargo	93	22
Container	276	197
RORO Cargo	268	127
Passenger	396	519
Offshore Supply	19	3
Other offshore	20	5
Other activity	2 414	765
Total	3 810	1 800

Emissions to air

It is assumed that LFO fuel with 0,1% sulphur content is used by engines with IMO Tier II classification. There have been several studies on how much (in grams) engines and ship types emit of different gases when producing 1 kWh. Emission factors used for this study are given in Table 2.[22]

Emissions to air of different exhaust components of the different ship types in December 2016 are given in Table 8.

Table 8 Emissions to air at the port of Helsinki

		Emission to air (kg)						
Ship type	MWh	BC	OC	CH4	CO	NOx	SOx	CO2
Oil Tanker	163	8,1	32,6	8,1	162,8	1 953,3	65,1	92 784
General cargo	22	1,1	4,5	1,1	22,4	269,0	9,0	12 779
Container	197	9,8	39,3	9,8	196,7	2 360,9	78,7	112 141
RORO Cargo	127	6,3	25,3	6,3	126,6	1 519,6	50,7	72 180
Passenger	519	26,0	103,9	26,0	519,4	6 233,2	207,8	296 076
Offshore Supply	3	0,1	0,5	0,1	2,7	32,3	1,1	1 533
Other offshore	5	0,3	1,0	0,3	5,1	60,8	2,0	2 886
Other activity	765	38,2	152,9	38,2	764,7	9 176,3	305,9	435 872
Total	1 800	90	360	90	1 800	21 605	720	1 026 252

[22] Haakon Lindstad et al, Maritime shipping and emissions: A three-layered, damage-based approach, Ocean Engineering110(2015)94–101.

4.4.2 Port of Rauma

Figure 2 Port of Rauma

About Port of Rauma

In 2015, turnover was 11.2 M€ and profit before appropriations and taxes was 3.1 M€ and net profit 1.6 M€. Export was 3.98 M tons and import 1.76 M tons. Total container traffic was 2 M TEU.

Description of current shore electricity connections.

No shore electricity connections installed.

Port of Rauma activity – ship arrivals

In 2016, Port of Rauma had a total of 1086 calls, and 136 arrivals in November and December 2016. Data presented are vessels that arrived and had departure in November and December 2016.

Table 9 shows how many hours the different ship types were at berth and an estimation of power consumption (MWh) in Port of Rauma in November and December 2016.

Table 9 Hours spent at berth at Port of Rauma in Nov. and Dec. 2016

Total hours at berth and energy consumption (MWh) for different ship types - Port of Rauma		
Ship type	Hours	MWh
Oil Tanker	2 332	1 318
Chemical Tanker	2 184	1 181
Gas Tanker	515	289
Total	5 031	2 788

Emissions to air

It is assumed that LFO fuel with 0,1% sulphur content is used by engines with IMO Tier II classification. There have been several studies on how much (in grams) engines and ship types emit of different gases when producing 1 kWh. Emission factors used for this study are given in Table 2.[23]

[23] Haakon Lindstad et al, Maritime shipping and emissions: A three-layered, damage-based approach, Ocean Engineering110(2015)94–101.

Emissions to air for different exhaust components by the different ship types in November and December 2016 are given in Table 10.

Table 10 Emissions to air at the Port of Rauma in Nov. and Dec. 2016

		Emission to air (kg) - Port of Rauma						
Ship type	MWh	BC	OC	CH4	CO	NOx	SOx	CO2
Oil Tanker	1 318	65,9	263,6	65,9	1 317,9	15 814,2	527,1	751 175
Chemical Tanker	1 181	59,0	236,2	59,0	1 180,8	14 169,5	472,3	673 050
Gas Tanker	289	14,5	57,9	14,5	289,4	3 472,7	115,8	164 955
Total	2 788	139	558	139	2 788	33 456	1 115	1 589 180

2.2.3 Port of Vaasa

Figure 3 Port of Vasa

About Port of Vaasa

The port of Vaasa works in close cooperation with port of Umeå in Sweden. In 2015, goods traffic in these ports was 3,4 M tons in total. 168557 passengers travelled between Vaasa and Umeå.

Description of current shore electricity connections.

Port of Vaasa is providing shore power but no information about capacity.

Harbour activity – ship arrivals

The port of Vaasa had in 2016 a total of 592 calls, and 35 arrivals December 2016. Data presented are vessels at Port of Rauma that had arrival and departure in December 2016. Table 11 shows how many hours the different ship types were at berth and an estimation of power consumption (MWh) in December 2016.

Table 11 Hours spent at berth at Port of Vaasa in Dec. 2016

Total hours at berth and energy consumption (MWh) for different ship types - Port of Vasa		
Ship type	Hours	MWh
Oil Tanker	30	12
Chemical Tanker	18	10
Bulk	99	83
General cargo	87	6
Passenger	241	114
Total	476	225

Emissions to air

Emissions to air in the Port of Vaasa for different exhaust components by the different ship types in December 2016 are given in Table 12.

Table 12 Emissions to air at the Port of Vaasa in Dec. 2016

		Emission to air (kg) - Port of Vasa						
Ship type	MWh	BC	OC	CH4	CO	NOx	SOx	CO2
Oil Tanker	12	0,6	2,4	0,6	12,2	146,6	4,9	6 961,4
Chemical Tanker	10	0,5	2,0	0,5	9,8	117,4	3,9	5 574,2
Bulk	83	4,2	16,6	4,2	83,2	998,2	33,3	47 413,7
General cargo	6	0,3	1,2	0,3	5,8	69,4	2,3	3 294,6
Passenger	114	5,7	22,8	5,7	114,0	1 368,3	45,6	64 994,0
Total	225	11	45	11	225	2 700	90	128 238

4.5 Obstacles to increasing shore power utilisation

Based on our survey, it seems that the main obstacles to increase the utilization of shore power in Finland are

- High power connection point is expensive
- Price of electricity is not always competitive
- Connecting and disconnecting takes too long
- Not all ships have equipment for shore power
- Some ships have 60 Hz electric system
- Location and type of connector on ship is not standardized
- Several voltage levels in use: 0,4 kV / 6 kV / 11 kV
- Ships should have connectors on both sides

5. Status in Iceland

5.1 Icelandic maritime regulations and infrastructure

5.1.1 National port legal framework

Iceland is party to MARPOL and Annex VI on emissions from ships is currently being processed for implementation. Issues related to alternative fuels and shore power in Iceland belong to a diverse set of laws and regulations. Thus, different ministries and government institutions are involved with implementing the following directives. The fact that so many government bodies are responsible makes an overview a complex task to put forward. Therefore, the list has been compiled as an effort to cover maritime and energy related legislation in Iceland.

Hafnalög (e. **Harbour law**) No. 61/2003[24]

This is the general law on harbours in Iceland, their establishment, construction and maintenance, operations and governance. Under paragraph 3, item 5, the service functions of a harbour are listed and one of those is the sale of electricity.

Reglugerð um hafnamál (e. **Regulation on harbour issues**) No. 326/2004[25,26]

This regulation applies to all harbours under the abovementioned **Harbour law**. In chapter IV *government supported construction in harbours*, under paragraph 11, item d) it mentions

24 http://www.althingi.is/lagas/nuna/2003061.html
25 http://www.reglugerd.is/reglugerdir/allar/nr/326-2004
26 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/samgonguraduneyti/nr/18261

infrastructure build-up for shore power, connections and equipment for electricity sales to ships exclusively.

Reglugerð um brennisteinsinnihald í tilteknu fljótandi eldsneyti (e. **Regulation on sulphur content in certain liquid fuels)** No. 124/2015[27,28]

This regulation states in paragraph 11 - *Ships berthing*, that to ensure air quality and reduce pollution, all ships berthing should use shore power rather than marine fossil fuels, when possible.

If electricity from shore connections is not available or employable, ships berthing shall not use marine fuel with a sulphur content of more than 0,1% (m/m).

Reglugerð um útnefningu skipaafdrepa á Íslandi[29] (e. **Regulation on the appointment of safe harbours in Iceland**) No. 614/2014

Reglugerð um vaktstöð siglinga og eftirlit með umferð skipa (e. **Regulation on the Joint Rescue and Coordination Centre (JRCC) and ship traffic monitoring**) No. 80/2013[30,31]

Reglugerð um raforkuviðskipti og mælingar (e. **Regulation on sale of electricity and meters**) No. 1050/2004[32,33]

5.1.2 Regional framework

All Icelandic harbours have a specific regulation on the harbour, its construction, operations and governance. Associated Icelandic Ports and Grindavík port both have their respective regulation, detailed below.

Hafnarreglugerð fyrir Faxaflóahafnir sf (e. **Port regulation for Associated Icelandic Ports (AIP) – Faxaflóahafnir sf.**)[34] Faxaflóahafnir have an extensive harbour regulation due to the widespread operations and number of ports within the cooperation. Considerable power lies with the board of directors and the harbour master. The sale of electricity is briefly mentioned in paragraph 6, *Pilot services and other services to ships*, but not detailed. Associated Icelandic Ports – Faxaflóahafnir issued a recommendation[35] on September 16, 2015, to all ships berthing in their harbours. All ships are, as of January 1, 2016, required to connect to electricity as long as facilities are available and compatible. Ships that can connect to shore power are prohibited to run auxiliary engines, unless the stopover is less than 6 hours.

27 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/umhverfis--og-audlindaraduneyti/nr/19517
28 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/umhverfis--og-audlindaraduneyti/nr/19968
29 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/innanrikisraduneyti/nr/19179
30 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/samgonguraduneyti/nr/18444
31 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/innanrikisraduneyti/nr/19915
32 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/idnadarraduneyti/nr/4906
33 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/idnadarraduneyti/nr/7063
34 http://www.reglugerd.is/reglugerdir/eftir-raduneytum/samgonguraduneyti/nr/15723
35 http://www.faxafloahafnir.is/fjarhagsaaetlun-arsins-2016-samthykkt/

Hafnarreglugerð fyrir Grindavíkurhöfn (e. **Port regulation for Grindavík harbour**)[36] This regulation mainly details on allocation of responsibility between the community, the harbour board of directors and the harbour master. It has the same brief mentioning of electricity sales in paragraph 6, *Pilot services and other services to ships, as in the regulation for the AIP.*

5.2 Icelandic ports introduction

Around the Icelandic coast of 6088 km, there are some 80 port areas making up 35 port authorities under the Icelandic Port Association. Their size and sectors of service vary widely but generally the ports are divided into the following categories: large fishing harbours, medium fishing harbours, boat harbours, marinas and industrial harbours. Each provides diverse services to calling vessels, including cargo ships, tourism and transport ferries and research vessels, attending to and unloading catch from fishing vessels of various sizes, ship repair, services to large scale industry and other port related operations. Five ports identify as industrial, servicing industrial plants producing aluminium and ferro-silicone. Ten ports handle 85% of the total cargo and fishing industry 's catch[37] in the country and eleven ports are cruise ship destinations.

Much of port authority income is based on providing various services to the Icelandic fishing fleet and, to a lesser extent, servicing cargo vessels and cruise liners. Since the 2000s, tourism has been on a steep rise and this has been felt by coastal and maritime tour operators and ports alike. The number of cruise passengers quadrupled between 2003 and 2012, reaching roughly 210.000 guests aboard 85 ships calling at 11 Icelandic ports and is expected to rise annually be 4-11% in the next 15 years.[34]

Nearly all Icelandic ports are partly or in full owned by neighbouring municipalities and many are operated as public companies. Public funding is limited to research and construction and maintenance for the smaller harbours.

Most Icelandic ports are provided with supply service cables of a size ranging from 160 A each and the largest reaching 1200 A. For smaller harbours, it is common to have a few 160-250 A cables and berths offering connections of 16A, 32A, 63A and 125 A and low voltage (O,4 kV, 50 Hz). Current infrastructure is aimed to service smaller vessels: fishing boats of gross tonnage less than 50 and tourist boats 50-500 tonnes although many can service research vessels, trawlers and others of the scale of over 1000 tonnes. However, it is mostly fishing vessels of different sizes that are the current main users of electric infrastructure in Icelandic ports.

Larger vessels, such as those carrying cargo or cruise ships transporting passengers in the thousands require high voltage equipment; servicing those types of vessels would require an enormous investment to bring high voltage capacity to each of the ports. Even then the vessels calling might not be able to utilise the infrastructure or want to.

[36] http://www.reglugerd.is/reglugerdir/eftir-raduneytum/samgonguraduneyti/nr/4956

[37] Icelandic Ocean Cluster. (2013). *Flutninga- og hafnahópur Íslenska sjávarklasans: Stefna til 2030*. Haukur Már Gestsson (editor). Retrieved on January 21, 2017 from http://www.sjavarklasinn.is/wp-content/uploads/2013/10/Stefna-2030-low.pdf.

This issue, the extent of infrastructure availability and utilization will be explored further in the following sections.

5.2.1 Associated Icelandic Ports - ports in Faxaflói Bay

Associated Icelandic Ports (AIP), or Faxaflóahafnir as it is known in Icelandic, was founded in 2004 when the Port of Reykjavík merged with three others, Akranes, Borgarnes and Grundartangi. It is jointly owned by the municipalities of Reykjavík, Akranes, Hvalfjarðarsveit, Borgarbyggð and Skorradalshreppur. The four ports are in the Southwest of Iceland, in and around the capital of Reykjavík and form a network of ports capable of handling both large and small vessels and a high volume of cargo, marine catch and passenger traffic. In 2012, 49,7% of cargo went through three of AIP 's ports and all larger cruise liners (81 in total) arriving in Iceland docked at Sundahöfn or Reykjavík's Old Harbour. 10% of Iceland 's annual catch is unloaded at Reykjavík harbours.

Figure 4 Sundahöfn harbor © AIP[38]

The total berth length at AIP harbours is approximately 4700 m at varying depths of 4,5-12 m. The average annual number of port calls is 1500, of which about 100 are large cruise ships carrying a total of 100.000 passengers.

Electricity is available at most berths at 125 A and 63 A, sold at a price of ISK 16,1 per kilowatt hour. The total available capacity for the port area in Reykjavík is 8400 A, 400 A for Grundartangi and 1230 A for Akranes.

During the preparation of this report AIP published a comprehensive report on emissions from ships in its ports for 2016 focusing on emissions within the harbour limits[39].

[38] http://faxaports.is/area/sundahofn/

[39] http://www.faxafloahafnir.is/wp-content/uploads/U5817-Final-report.pdf

Table 13 Summary of relevant AIP specifications

Port	**Services**	Number of berths	Total length	Total electricity available
Reykjavík	Export, main port of Iceland			
Sundahöfn	Cargo, large passenger vessels	6	2378 m	2*1200A
Old harbour	Fishing, ship repair, small passenger vessels	6	1170 m	1*63A, 4*200 A, 2*315A, 6*630A, 1*1200A
Akranes	Fishing port	3	329	2*200 A, 630A
Borgarnes	Maritime leisure			
Grundartangi	Cargo	2	755 m	

Electric infrastructure

Information on the current availability and utilization of electric infrastructure at AIP ports was collected during meetings with AIP representatives in late October, 2016 in addition to preceding and subsequent electronic communication. A questionnaire (see Appendix I) was used to guide the discussion during interviews and further communication with representatives of AIP.

The current available infrastructure at AIP is designed to service domestic fishing vessels, which make up a large proportion of calls to the associate ports annually, some 871 calls out of a total of 2348 (in 2015). Although the number of cargo vessel calls was 994 in 2015, the system is not able to service vessels of that scale or other types of large vessels, such as tankers, research vessels or cruise vessels. The grid includes 0,4 kV, 50 Hz connection points of 16 A, 32 A, 63 A, 125 A and 200A and for vessels having a greater energy requirement, two 125 A connections are available.

Findings

According to AIP, a total of 100-110 vessels make regular use of the electric infrastructure available at the Associated Ports and 40% of those calling at the Old Harbour and Akranes, mostly local fishing vessels, take advantage of the electric infrastructure. Generally, the stop requires 16-18 hours of electricity during each call. The smaller vessels, less than 20 tons, connect immediately upon docking.

Generally, in AIP ports, vessels of any size docking for less than 6 hours do not utilize shore power. The reasons for this, however, have not been completely established via survey or by other means.

According the interviewees the main reasons for vessels not using available infrastructure at AIP in Reykjavík included:

- Requiring a frequency converter (for conversion from 60 to 50 Hz)
- Requiring more than 125 A (or 200 A) connection, which was not available at the time investigated
- Use of energy intensive equipment aboard vessels, i.e. cranes and refrigeration or freezing units, which is not managed by current available connections

- Damage to connections (on port side and/or vessel side) due to inadequate work procedure
- The number of connections is higher than the dock length, that is dock space is the occasionally the issue, rather than the availability of electrical connection

These issues coincide with the findings of Bergsdóttir[40], who demonstrated that capacity of the supply service at AIP's Old Harbour was not a limiting factor during the period studied, 2012-2014, for the bulk of ships calling, i.e. fishing and leisure or tourism-related vessels. However, and to elaborate on the bullet points above, many of the larger vessels, such as research, container, military and passenger ships in addition to some larger trawlers are powered by engines operated at 60 Hz. In these cases, a frequency converter is required. Furthermore, the larger vessels calling, such as cruise ships, require upwards of 5 MW power, a scale the current grid at AIP is not built to service. This applies to all Icelandic harbours and is an issue that regularly comes up in the discussion of the electrification of harbours and strengthening thereof. One viewpoint involves the necessity of infrastructure build-up such that its capacity and specifications allow service of all vessels, large and small, foreign and domestic. Another perspective focuses on rather making the effort to attend to the majority of the local fleet of each harbour, those stopping for hours in addition to those docking for longer.

A recent report[41] dealing with the consumption of electricity and other renewable energy sources at AIP, estimated that should the port need to supply electricity to each and every vessel calling, the requirement would be sevenfold its 2015 capacity of 4300 MWh, or roughly 29.000 MWh. The same report maintained that the current (2016) 28% gross profit of electricity sales alone would not cover the cost of investment and further construction of electric infrastructure at AIP. Although Icelandic ports can apply for partial government grants to cover construction projects, a business case for the financing of infrastructure would be a welcome means of further development in many Icelandic ports. Another possibility might be the re-examination of electricity and connection pricing to calling vessels and yet another, the reconsideration of economic or other incentives to promote the use of shore power or to discourage fossil fuel combustion during docking time. This, however, would call for collaborative action on behalf of industry, utilities, regulators, port authorities and, in some cases, related municipalities to create a common policy with the collective aim of reducing local emissions, utilizing domestic energy and promoting healthy port communities.

The kWh potential of the AIP ports in Faxaflói bay (2015)

AIP ports in Faxaflói bay that have been taken into consideration are Akranes, Grundartangi, Reykjavík – the Old Harbour, Reykjavík – Sundahöfn. Ports in Faxaflói bay have more diverse ship type arrivals as compared to Grindavík and other typical fishing ships ports. Table 14 shows the ship type and arrivals in the different AIP ports. Note that *Önnur hafnarsvæði* in Table 14 refers to

[40] Bergþóra Bergsdóttir. (2015). Samantekt um landtengingar skipa – Gamla höfnin í Reykjavík og Akraneshöfn. Internal report done for Faxaflóahafnir Sf.
[41] Darri Eyþórsson. (2016). Forkönnun á aukinni notkun endurnýjanlegra orkugjafa við Faxaflóahafnir. Verkefni unnið fyrir hönd Faxaflóahafna, Orkuveitu Reykjavíkur, Veitur ohf og Reykjavíkurborgar. Report available at http://www.faxafloahafnir.is/wp-content/uploads/Forkonnun-Orkumal-i-hofnum-loka.pdf.

other areas within AIP. The two largest ports are in Reykjavík with 80 % of the arrivals. The two ports in Reykjavík are also have the largest number of fishing vessel arrivals.

Shore electricity consumption for each ship is recorded in each month. Furthermore, there was information on how many total days (24 h) ships stayed at port in each month. Data material for April was incomplete and is left out. The data associated with Table 15 indicated that vessels have a higher energy consumption at port in the colder months of the year and that the energy consumption mainly is used for heating the ships while at port.

Table 14 Ship arrivals in ports in Faxaflói bay undir AIP

	Ship arrivals (2015) in Ports in Faxaflói					
Ship Type	Akranes	Grundartangi	Reykjavík - Gamla höfnin	Reykjavík – Sundahöfn	Önnur hafnarsvæði	Sum Ship Type
Oil Tanker	1		116	9	2	128
Chemical Tanker	2		46		3	51
Bulk	6	18			6	30
General cargo	8	122	11	151	27	319
Container		162	3	461	2	628
Reefer	3		3	11		17
Passenger			36	73		109
Other activity	1	1	161	21	11	195
Fishing	60		643	155	12	870
Sum Harbours	81	303	1019	881	63	**2347**

The 2.347 ships that arrived in 2015 stayed in the different ports for a total of 164.084 hours and had an estimated MWh consumption of 20.837 MWh. The hours at berth and corresponding MWh potential has been estimated as described in the case for the Finnish ports. Table 15 shows that Fishing and Container vessels have the largest MWh potential with over 58% of the total MWh potential. Other activity includes among others; tugs, sail ship, research-, patrol-, suction dredger- and whaling ships.

Table 15 Total hours at berth and energy consumption

Total hours at berth and energy consumption (MWh) for different shiptypes				
Ship type	Hours	MWh	Hours	MWh
Oil Tanker	5 364	256	3,3 %	1,2 %
Chemical Tanker	984	533	0,6 %	2,6 %
Bulk	3 673	738	2,2 %	3,5 %
General cargo	10 477	947	6,4 %	4,5 %
Container	11 742	4 526	7,2 %	21,7 %
Reefer	457	70	0,3 %	0,3 %
Passenger	2 095	2 271	1,3 %	10,9 %
Other activity	51 658	3 798	31,5 %	18,2 %
Fishing	77 635	7 697	47,3 %	36,9 %
Total	164 084	20 837		

The emissions from these ships while at berth has been estimated, using the methodology described earlier, in section 3, and is shown in Table 16.

Table 16 Emissions to air per ship type

		PM		Emission to air (kg)				
Ship type	MWh	BC	OC	CH4	CO	NOx	SOx	CO2
Oil Tanker	256	13	51	13	256	3 077	103	146 166
Chemical Tanker	533	27	107	27	533	6 401	213	304 026
Bulk	738	37	148	37	738	8 853	295	420 536
General cargo	947	47	189	47	947	11 362	379	539 696
Container	4 526	226	905	226	4 526	54 313	1 810	2 579 847
Reefer	70	3	14	3	70	838	28	39 819
Passenger	2 271	114	454	114	2 271	27 253	908	1 294 522
Other activity	3 798	190	760	190	3 798	45 577	1 519	2 164 926
Fishing	7 697	385	1 539	385	7 697	92 364	3 079	4 387 285
Total	20 837	1 042	4 167	1 042	20 837	250 038	8 335	11 876 821

Fishing ships stayed at port for more than 77.000 hours in 2015 and therefore are estimated to have the highest potential for reducing emissions in these ports - and especially in Reykjavík. These figures do not account for shore power connections that are already being used. For the year 2015 those were not considerable.

Next steps

At this point, further information and details are required in order to complete the task the project set out to achieve, that is to map the current infrastructure, how it is used by calling vessels and analyse the demand that is or is not being met at AIP. Data still needed include details on time spent by each vessel each time it connects to shore power at AIP ports. This is important to get an accurate picture of current use. Moreover, a survey conducted among AIP customers, that is owners of ships calling at the four ports, could provide valuable information, covering reasons for using or not using infrastructure and needs, in order to boost demand for it, evaluate the need for increased capacity or number of connections and, indeed, reduce local emissions.

In 2017, AIP carried out a thorough analysis of the total demand for electricity at its ports, specifically what changes would be necessary for the ports to be able to service every single vessel calling, domestic and foreign. This was revealed during an interview with a port representative. It will be interesting to learn of the outcome of AIP's research.

In order to quantify the economic potential for electric infrastructure and create a business case thereof for AIP, data on the cost elements of current infrastructure are essential. Furthermore, an accurate assessment of construction required on behalf of the utility company, Veitur, is needed in order to provide access to electricity for larger vessels, such as cruise liners, tankers, research vessels and foreign vessels whose equipment is incompatible with the current infrastructure.

5.2.2 Grindavík port

Grindavík is a very active fishing harbour on the south coast of the Reykjanes peninsula in SW Iceland. Grindavík, home to just below 1% of the population, has close to 4% of the total catch in Iceland unloaded there[42]. Most of the ships berthing in Grindavík are local fishing ships. Social

[42] www.hagstofa.is

responsibility is an important factor of the society and several bigger firms are proud to support environmental and social advancements and participate, where needed.

Fishing has been a part of everyday life in Grindavík since the start of the settlement. Docks were first constructed there in 1932 followed by dredging and developments that constitute the start of Grindavík harbour as we know it. Today Grindavík harbour has total berth length of 1195 meters with depth of 2,5 - 9 meters[43].

Figure 5 Port of Grindavík © Grindavík[44]

Electric infrastructure

Grindavík harbour has put emphasis on providing shore connections to ships and is in cooperation with a private company developing an elaborate system for monitoring power usage with regard to sales and optimization of power usage, for ships in harbour. The motivation for this is to reduce cost and increase shore power options for ships, boost service to customers, reduce maintenance cost, maximize sales and reduce emissions in the harbour area. A further gain towards the future is hoped to be increased self-service for connections with reduced personnel requirements and lowered cost.

This infrastructure build-up has ensured an increase in shore power usage and total electricity sales amounting to 1.140.323 kWh (including freezer containers on shore) in 2015, an increase of 10% from 2014[45]. Further build-up is under way, work has started on new berths by *Miðgarður* pier, that is being completely renewed to be 220 meters long, with a depth of 8 meters, including

[43] Grindavík harbour, 31 October 2016 interview: Sigurður A. Kristmundsson, Harbour master
[44] http://www.grindavik.is/hofnin
[45] Grindavík harbour, electronic communication, 4 November 2016 Sigurður A. Kristmundsson harbour master

a planned installation of 3 x 125A, 1 x 64A and 1 x 16A shore connections. This should be in operation by end of 2017[46].

Table 17 Grindavík harbour: Shore power connections overview

					Number of connection points and size						
Port	**Pier**	**Length (m)**	**Depth (m)**	**Total power supply**	**16 A**	**32 A**	**63 A**	**125 A**	**250 A**	**Other**	**Reference**
GRINDAVÍK	Eyjabakki	390	5 - 7,5	Est. 500A	4		10	12		12*	*Container freezer conn. 63 amp
	Miðgarður	350	3,5 - 5	Est. 300A		4	7	2			
	Norðurgarður	100	8	400A	2		2	4			
	Suðurgarður	160	9	500A	4		5	8		10*	*Container freezer conn. 63 amp
	Small craft docs	195	2,5-4	Est. 150A	40						
	Total	**1195**		1850A	50	4	24	26		22*	

Findings

Grindavík already sees close to all small craft; small fishing boats, pleasure craft and rescue boats, connect to shore power when tying up in harbour. These are small users in comparison to larger fishing vessels but are generally in overnight and frequently tied up for several days consecutively. Grindavík seeing mostly local fishing ships they see a high percentage of ships connecting to shore power when staying overnight. Many of the fishing ships in Grindavík are long liners that bring the catch ashore and head out again the same day. Generally, these ships do not connect to shore power unless staying overnight.

Grindvík harbour is an interesting case study where a general interest in social responsibility altogether has supported infrastructure advancement in shore power connections for ships and the implementation and use of those connections.

5.3 Next steps for port data collection

Details on infrastructure and electricity consumption at ports under the Port of Akureyri, North Iceland are needed. Contact has been made with the port authorities; next steps would include following up with a visit and gather data.

Next steps include gathering details on infrastructure and electricity consumption at ports in East Iceland. Contact has been made with the port authorities of Fjarðabyggð; next steps would include following up with a visit and gather data.

[46] Grindavík harbour, 31 October 2016 interview: Sigurður A. Kristmundsson, Harbour master

6. Status in Norway

6.1 Infrastructure regulations in IMO, EU and Norway

A common principle in Norwegian maritime regulatory authorities is that the government tries not to promote or suppress types of technology – the authorities try to be technologically neutral. Instead of technological requirements they form requirements for functionality. In other words, they do not say what type of technology to be used - but instead say that your vessel should "be safe" and "pollute less".

On the other hand, it is a desire for more Norwegian ports to offer sea shore power and Norway has incentives and funding for the introduction and installation of sea shore power infrastructure through ENOVA[47].

When it comes to international regulations, the International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. All six MARPOL Annexes are ratified and implemented by the member states.

MARPOL Annex VI sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances, but there are no regulations that make sea shore power supply in ports mandatory.

European authorities (EU parliament) have a slightly different approach which can be seen in the "DIRECTIVE 2014/94/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 on the deployment of alternative fuels infrastructure" [48] where it says:

> 5. Member States shall ensure that the need for shore-side electricity supply for inland waterway vessels and seagoing ships in maritime and inland ports is assessed in their national policy frameworks. Such shore-side electricity supply shall be installed as a priority in ports of the TEN-T Core Network, and in other ports, by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits.
>
> 6. Member States shall ensure that shore-side electricity supply installations for maritime transport, deployed or renewed as from 18 November 2017, comply with the technical specifications set out in point 1.7 of Annex II.

It is noteworthy that in point 5 it is stated that "unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits" which implies that this is not

[47] https://www.enova.no/about-enova/about-enova/framework-conditions/262/0/

[48] http://www.ops.wpci.nl/_images/_downloads/_original/1420722517_directive2014_94.pdf

an unalterable regulation. By using this wording, the EU parliament puts strong pressure on their member states to develop and implement the use of shore power.

There are in general no national or international regulations that make it mandatory for ports to offer sea shore electricity except for California in the United States, where it is mandatory to turn off engines at berth.

Over the last decade a standard for sea shore power installation has been developed. IEC/ISO/IEEE 80005-1:2012(E) describes high voltage shore connection (HVSC) systems, on board the ship and on shore.

In June 2016, a standard that also covers the low voltage shore connections was published. IEC/IEEE 80005-2:2016 describes the data interfaces of shore and ships as well as step by step procedures for low and high voltage shore connection systems communication for non-emergency functions, where required. This standard specifies the interface descriptions, addresses and data type. This standard also specifies communication requirements on cruise ships, in annex A. Application of this standard relates to annexes of IEC/ISO/IEEE 80005-1. This standard does not specify communication for emergency functions as described in IEC/ISO/IEEE 80005-1.

ENOVA in Norway requires that these standards are implemented and followed by applicants for funding.

6.2 Norwegian ports status and infrastructure

As covered in section 3, a study was carried out and published by DNV GL on the status and availability of shore power in Norwegian ports in 2015. Thus, such an analysis was seen as complete and Norway was not explored as part of this report on the *Electrification of harbours*. DNV GL report showed that although some issues are common among the Nordic countries, such as the ability to provide only certain types of vessels with shore power, Norway is by far the most advanced when it comes to the electrification of ports. Nearly all the ports surveyed offered simple connections, enough to power lighting aboard vessels and basic functions. The interest and implementation of shore power equipment has been increasing fast and the study found that 10 of the 21 ports surveyed had plans to initiate or expand on their current capacity but cited a clear need for government based funding opportunities. For further information, refer to DNV GL's report *Landstrøm í norske havner*[49].

[49] DNV GL AS Maritime. (2015). *Landstrøm i norske havner.* http://www.ksbedrift.no/media/1537/undersoekelse-om-markedsgrunnlaget-for-landstroem-oed-enova-dnv-gl.pdf

7. Discussion

As already mentioned, the availability and compatibility of data from the different Nordic countries has hampered the attainment of the project goals. This can however prove to be valuable to further evaluation as it is apparent that the situation with regard to electrification of harbours is very different in the respective countries. All three countries face the chicken and egg dilemma when it comes to supplying infrastructure and investment in shore power connections for marine vessels with high energy needs.

It is significant to note that the calculations for emissions in Finland are based on LFO and in Iceland are based on HFO. These are mere generalizations for the purposes of data analysis and they do not depict the actual emissions. In fact, the use of HFO in Iceland has been rapidly decreasing.

Further information and details are required to complete the task of mapping the current infrastructure, how it is used by calling vessels and analyse the demand that is or is not being met. Data still needed include details on time spent by each vessel in harbour and shore power connection time. This is important to obtain an accurate picture of current use. To create a database of comparable information for the Nordic countries, a template of sorts would be useful. Based on the experiences of this project, such a template could be generated without great efforts.

In order to quantify the economic potential for electric infrastructure and create a business case thereof, data on the cost elements of current infrastructure are essential. These were not accessible or available to this project as the responsibility for harbour infrastructure, energy infrastructure lies with different authorities and private entities. This remains a very interesting task important to further development of electric infrastructure.

Technological equipment cost for shore power installations aboard vessels needs to be explored and put forward to encourage ship owners to invest in shore power equipment. Frequency converters could be included in harbour infrastructure build-up as this is a common reason cited by crew and harbour staff for not utilizing available connections. Furthermore, transparency in infrastructure planning would prove beneficial to all involved players, be they on the shore side or vessel owners or operators. This would enable investment in vessel technology to go hand in hand with advancement in harbour power facilities.

Though work of this project has raised more questions than it has answered, it has definitely laid the groundwork for a more comprehensive and focused approach to the issue of electrification of harbours in the Nordic countries.

Appendix I - Survey questions

Questions addressed to ports:

What is the total number of quays/berths in the harbour area?

Does port provide shore power for ships? Capacity? Voltage?

What is the total number of berths with access to shore power?

Have you encountered incompatibility issues with: Voltage? Frequency? Power? Connectors?

Do you have inverters for 60 Hz supply?

Limitations: How many vessels can be connected simultaneously, that is, what is the total power (kW) supplied to the ships?

Are there limits to the electrical grid supplying the port which could prevent full utilization (example: low ambient temperature)?

Do you have plans for increasing shore power capacity? If not, why not?

If yes, please elaborate. What does the plan entail and what is the estimated date of completion?

Is there demand for shore power? Capacity? Voltage?

For how long do ships typically stay at berth?

Which ships or how many ships call at port regularly?

Do those ships use shore power? How much those use shore power (power / energy)?

How many kilowatt-hours ships consume electricity at your port per year?

What would be the estimated potential for growth if all ships used shore power?

What is the pricing strategy for shore power services? Please describe.

Are records available on port calls for the various berths? If yes, are they accessible and how?

Are you interested in battery or hybrid electric work machines at port?

Do you expect battery electric or plug-in-hybrid ships to become more common?

Please describe the investments undertaken so far for the provision of shore power at your port, including cost per berth and connection to the grid.

Are you aware of any incentives in place for the electrification of ports? **If yes**, how did these affect your choices and strategy for supplying electric infrastructure? **If no** would these influence your choices and strategy for supplying electric infrastructure?

To what extent does international development with regard to the provision of shore power (for example regulatory requirements in California and Alaska, EU directive 2014/94/EU on the deployment of alternative fuels infrastructure) affect the adaptation to your port or in your country?

Questions addressed to ship owners:

What is typical power for your ship while at berth?

Do you have ships that can utilize shore power? Power? Voltage?

Do those ships call at some ports regularly?

Do those ports provide shore power for ships? Do your ships utilize it?

Is the provided power sufficient?

Have you encountered incompatibility issues with: Voltage? Frequency? Power? Connectors?

How long ship typically stays at berth?

Do you profit from utilizing shore power?

What would be the estimated potential for growth if all ships used shore power?

Are you interested in increasing shore power utilization?

Do you expect battery electric or plug-in-hybrid ships to become more common?