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Energy analysis and costs estimation of an On-shore Power Supply system in the Port of Gävle

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ABSTRACT

The Port of Gävle is one of the most important harbours in Sweden as far as size and freight capacity is concerned. Marine traffic is increasing greatly, thus environmental pollution as well as noise and vibrations are of major concern in port cities. Shore to ship power supply systems might be a feasible solution to curtail emissions because the Auxiliary Engines are instead shut down while the ship stays alongside the quay. The literature review shows they are reliable and very appealing in all respects, thereby contributing to sustainable development. Taking into account the kind of vessels that call at the Port of Gävle, a High Voltage Shore Connection is recommendable, in compliance with the International Standards. An own technical survey is developed to gather all the information, as well as personal interviews to collect first-hand data. Technical issues such as the synchronisation procedure and the ground system with regard to safety are briefly discussed. Due to the lack of data, calculations consist of average values: peak and average demand, and fuel consumption during a typical call. Considering updated energy prices for both electricity and fuel, results show that an on-shore power supply system make energy costs decrease by 71% at berth in comparison with burning marine fuel, which is saved by around 4 tonnes per call. Additionally, up to 5126 tonnes of CO_2 are avoided per year, among other pollutants. Shore-side power has proven to be profitable and appealing to the Port of Gävle; however, vessels need to be retrofitted, which implies relatively high investments. Collaboration agreements and shipping companies' willingness to undergo changes are key issues that still need to be solved.

Keywords: On-shore Power Supply, Alternative Marine Power, High-Voltage Shore Connection, Shore-side Power, Ship's emissions, Marine fuel.

PREFACE

My special gratitude goes to Niklas, who has been overseeing my work during the development of the thesis in the Port of Gävle. I am grateful to Linda and Pontus, who relied on me to set out on the first steps of the project. It was fantastic to have the opportunity to work in your facilities and in such a new environment for me.

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NOMENCLATURE

AE	Auxiliary Engines
AMP	Alternative Marine Power
CARB	California Air Resources Board
CHE	Cargo Handling Equipment
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMO	International Maritime Organization
ISO	International Organization for Standardization
EF	Emission Factors
GT	Gross Tonnage
HFO	Heavy Fuel Oil
HVSC	High-Voltage Shore Connection
LNGC	Liquefied Natural Gas Carriers
LVSC	Low-Voltage Shore Connection
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
ME	Main Engine
MEPA	Marine Exchange/Port Authority
MGO	Marine Gasoil
OGV	Ocean-Going Vessel
OPS	On-shore Power Supply
PIC	Person in Charge
PM_x	Particulate Matter
PoLA	Port of Los Angeles
PoLB	Port of Long Beach
Ro/Ro	Roll-on/Roll-off
RSZ	Reduced Speed Zone
SECA	Sulphur Oxide Emission Control Areas
SFOC	Specific Fuel Oil Consumption

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1. INTRODUCTION

The current project has been carried out during the months of **April and May of 2019**, in the offices of the Port of Gävle. This thesis is the front-end part of a broader project in collaboration with the University of Gävle (HiG). The basis of the investigation has to be settled somehow on it as there are many questions to be examined.

1.1. Background

Freight traffic is strongly rising worldwide despite the economic stagnation. Globalization together with the growing trade and economic relations have led to an increase in the number of ships, namely cargo ships and large ferry vessels [1] [2] [3]. This implies greater air pollution and becomes of paramount importance for the port cities, as far as ship’s mooring is concerned. Local **air and water pollution** as long as **noise and vibrations** pose a threat for persons, plants and the environment [4] [5] [6]. Shore-to-ship power supply systems have the potential to limit all that negative impact, by means of connecting the vessels to the on-land electricity grid, which electricity is expected to be generated in a sustainable manner [7]. An **On-shore Power Supply (OPS)** system may contribute to **sustainable development** as long as overall emissions are reduced [8]. Energy efficiency increases because primary energy sources are not mainly based on fossil fuels and also the power demand is reduced as a result. However, there are many aspects to be examined because each case involves specific aspects. General concerns have still to be deeply studied as well.

1.2. Aim

As this project is barely a preliminary study, all sort of information may be useful for it or for further studies. A potential On-shore Power Supply system in the Port of Gävle is determined by the energy costs and fuel savings, which obviously depend on the ship’s parameters and type of activity. That OPS system is intended to be installed only and for the moment **in the *Container terminal* and in the *Energy terminal*** [9]. Consequently, results shown in this report are related to these two terminals and the vessels that ever stay alongside their quays. The purpose of this thesis requires several tasks to be undertaken, and they are described in the following bullet points.

a. Literature review about other existing OPS systems that have been carried out in relevant ports, including a review of regulations and international standards to be applied in the Port of Gävle.
b. Statistics of vessels calling at the Port of Gävle: number of calls and time at berth.
c. Review of on-board power systems, fuel consumption and emissions of container ships and tankers calling at the Port of Gävle.
d. Brief review of main technical issues and factors that must be taken into account.
e. Brief review of energy prices: shore-side electricity and fuels.
f. Estimation of energy costs, fuel saving and emission reduction based on the above tasks.
g. Recommendation of a shore-ship connection configuration.

2. METHOD

In this section, how each of the tasks shortlisted in the previous chapter and carried out is described. Although the time dedicated to collect information takes longer than calculations, final **estimations** are paramount and the key purpose of this thesis. On-shore power supply systems have not been widely investigated, therefore to support **recommendations** and a design configuration for the Port of Gävle is not easy. Not a lot of papers on this matter have been published; hence, this report cannot be based on a pure literature study. Peer-reviewed papers comprise not only general issues about on-shore power supply systems, but also technical problems approaching fuel consumption and emissions calculation, or ship-to-shore power synchronisation. In fact, International Standards relied upon some of these papers. Conversely, **reports, personal interviews and practical and real installations** are instead even more meaningful for this project [10] [11] [12] [13] [14] [15] [16]. To receive **first-hand information** boosts the accuracy of calculations and supports any further suggestions strongly.

Literature review has been conducted through interviews and conversations with port managers and authorities, who also provided additional information consisting of internal studies and reports. Most of them were relevant for the project, and so have they been included in the current report; however, some were discarded. At the same time, an own questionnaire surveying several ships that called at the Port of Gävle is used to reinforce the input data (so-called *Technical Survey*); it is based on [17]. This survey is key for the calculations and estimations, since they consist of direct values and opinions from on-board engineers that are closely familiarised with operational issues (*APPENDIX*).

In order to carry out estimations, average data are considered to be accurate enough. For instance, average time at berth and average power demand at berth for vessels are significant values and core elements in the report. The timeframe taken ranges **from January 2017 to March 2019**. However, there are many vessels calling at the Port of Gävle, and to gather all the information for each one of them is neither easy nor quick. Other sources of information, consisting of case studies, technical equivalencies between vessels and the results found in the literature, are thereby used to support the calculations and to allow the project to be finished within the scheduled time.

The **economic analysis** is quite simple due to a lack of detailed data. Shore-side electricity prices and fuel cost for vessels are considered constant. Looking over the past, it makes no sense to discuss future prices because trends do not have a clear correlation. Hence, costs are estimated using average data.

3. RESULTS AND DISCUSSION

This chapter presents the core part of the thesis, where each one of the tasks described above as purposes of the project is examined and discussed. In order to organise the work and to make the report easily understandable, there are several parts that compose the chapter. The literature review is described mainly from section 3.1. to 3.4. From 3.5. to 3.7., issues concerning the Port of Gävle and the vessels therein are analysed. Finally, last sections present the final values and calculations for a potential OPS system in the Port of Gävle.

3.1. Existing installations: a market review

This section describes current installations that may be meaningful for the Port of Gävle and a worldwide reference for potential OPS systems. Practically all types of ships are likely to be plugged into the on-land power systems, e.g. container-, Ro/Ro-, cruise- or tanker- vessels.

The fact that the ships plug through a **High-Voltage Supply Connection (HVSC)** or a **Low-Voltage Supply Connection (LVSC)** is heavily dependent on the existing on-board electricity system (i.e. voltage), and the peak power demand, which is increasing hand in hand with the vessels’ size and tonnage. To supply the same power output, high-voltage cables allow to transfer more power than low-voltage cables. Therefore, HVSC standards have developed sooner than LVSC standards. However, the quays at the Port of Gävle restrict the vessels’ size, which means that only a few vessels are expected to be supplied with high-voltage. Information available in prior studies and reinforced afterwards by the *Technical Survey* supports it. Although HVSC are regarded as the most efficient, most ships calling at the Port of Gävle would need an additional on-board power transformer whereby voltage levels are matched. This would entail higher costs as a result of this additional retrofitting that ships should carry out. What has been done in other ports can help clarify how to approach it in the Port of Gävle.

3.1.1. Port of Gothenburg

The first LVSC was installed in 1989, supplying 400 V at 50 Hz. A fixed transformer kiosk includes the crane to connect the cables to the vessel. A cable reel is included in the kiosk; they are released to be plugged in the socket-outlet of the ship [18].

In 2000, the world’s first HVSC was implemented, supplying 1250 kVA, at 6,6 kV or 10 kV and 50 Hz. The transformer and switchgears are placed in the main substation (away from the quay), whereas the control equipment and the cable arrangement equipment is enclosed in a small 9-ft container at the quay. Due to the high-voltage, only a single main cable is enough to supply the rated power. No crane is needed because a cable reel is mounted on-board. The socket-outlet is placed inside the 9-ft container [18] [19].

A mixed solution was developed in 2006. While the on-shore was a HVSC, the ferries operate at low-voltage. In this case, the power transformer is mounted on-board to supply from 10 kV to 400 V at 50 Hz.

In 2012, the Port of Gothenburg conducted a study to evaluate the feasibility of an OPS in each of the terminals [19]. The study assesses the costs and benefit on alternative solutions: partial and full development of the OPS, and their comparison with the current situation. Partial development comprises OPS for ships with the highest berthing frequency. Power requirements for ships range from 1,5 MVA for Ro/Ro ships to 15 MVA for cruise ships. Every ship call among 2010 and forecasted berthing for 2011, organised by terminal, is taken into account to justify the calculations. Costs included are the following: running costs for electricity generation on-board and on-shore, investment costs for OPS, environmental costs (air pollution and CO_2), and costs of retrofitting. There is not any OPS for the container, cruise, or tanker segments

Provided the estimations, results delivered show that only a couple of terminals seem profitable if an OPS is installed (partially and fully). Namely, the Ro/Ro- and the Car transport ships terminal. These results may not be appealing for the Port of Gävle, considering the primary OPS system would be installed in the *Energy terminal* (tankers) and the *Container terminal* (container ships). However, an analysis needs to be undertaken with calculations for a practical case. Existing installations have arisen due to single co-operation between ports and shipping companies. If a broader OPS installation takes place, how the costs are to be distributed (between ports and shipping companies) needs to be clarified. Moreover, flexible equipment to supply at both 50 Hz and 60 Hz has not been considered in the study, which can open up the range of vessels using the OPS.

3.1.2. Port of Stockholm

The first LVSC was installed in 1985, consisting of 9 cables that are connected in parallel to supply up to 2500 kVA with 400 V at 50 Hz. The cable arrangement is specific for the Aland Island vessels, as the regulations therein were not consistent [18]. A different LVSC was implemented in other terminal in 2006, consisting of 12 cables that are connected in parallel to supply with 690 V at 50 Hz. A power transformer placed at the quay supplies electricity to ferries from the 10 kV voltage level of the *Frihamnen terminal*. The rated power capacity is also 2500 kVA. Both LVSC avoid the ship black-out, by synchronising the on-board generators with the shore-side electricity grid in a process that lasts around 5 minutes [15].

3.1.3. Port of Los Angeles

California is a regulatory forerunner on OPS systems owing to ships which are equipped with a socket-outlet are required to connect to shore-side supply. The on-land power grid frequency is 60 Hz in the United States, so that more vessels are likely to be directly plugged into the on-land power system. Most connections at quay supply with 6,6 kV, but many ships require LVSC. A power transformer needs to lie between. First solution consists of a barge where the cable reel and the transformer are sited, thus supplying the ships with 440 V at 60 Hz. Typically, 9 low-voltage cables are connected to the vessel. Second solution consists of an on-board transformer and cable reel. The vessel lowers one or two high-voltage cables onto the dock, where they are connected to shore socket-outlets [20] [21].

3.1.4. Port of Bergen

In 2015, the Port of Bergen installed an integrated solution developed by *Schneider Electric*, which is called *Shorebox*. This solution consists of a flexible LVSC, as far as it can supply up to 1000 kVA with either 440 V or 690 V at either 50 Hz or 60 Hz. The voltage level can be selected by switching the taps of the transformer and a motorised cable reel is also included. In addition, this solution complies with IEC/ISO/IEEE 80005-3. On site civil work is minimised by means of a fully automated ship connection procedure, which allows a standardised plug and play. The whole solution is enclosed in a container and does not require fixed building works [22] [23].

3.1.5. Other ports

In addition to the mentioned SHOREBOX, there are two main companies that have developed d flexible solutions, consisting of the ability of supplying power at both 50 Hz and 60 Hz, i.e. they use power electronics converters.

SIEMENS SIHARBOR is a solution where all the electrical equipment is enclosed in a container erected at a height of 8 m. It can supply up to 1000 kVA with different voltages: 400 V at 50 Hz, and 440 V or 690 V at 60 Hz. SIEMENS also offers the same concept for HVSC and it has been implemented in several ports (Port of Lübeck, Port of Cuxhaven [23], Port of Flensburg…) [24].

ABB delivered the world's first HVSC in 2000, in the Port of Gothenburg. ABB's Static Frequency Converter system has also been installed in the Port of Rotterdam (2013) and in the Port of Ystad (2013), delivering a HVSC in compliance with IEC/ISO/IEEE 80005-1. The Port of Ystad was the world's largest plant, supplying up to 6 MVA with 11 kV at either 50 Hz or 60 Hz to Polish ferries [25] [26].

STENA LINE, as part of STENA AB, is leading the change from several points of view. It is responsible of many HVSC for cruises in the Ports of Gothenburg, Trelleborg and Rotterdam. SCHNEIDER ELECTRIC has been responsible of the retrofitting of, at least, five ferries. STENA LINE is also boosting district heating for cruises at berth, and other renewable energy projects as part of its sustainability strategy. For instance, the installation of solar panels to supply its terminal at the Port of Holyhead, or the installation of a 1 MWh battery on a ferry in operation [27].

Many ports have conducted feasibility studies with regard to OPS systems, although most of them comprise cruise ships, which are vessels that not call at the Port of Gävle [28] [29]. In any case, general conclusions might be meaningful for this project [19] [30] [31] [32] [33] [34] [35]. The Port of Rotterdam feasibility study addresses however container ships [20].

3.2. Other matters of interests

3.2.1. Alternative Marine Power program

Alternative Maritime Power is a unique air quality program that focuses on reducing emissions from container vessels docked at the Port of Los Angeles (PoLA). This port is the world reference in OPS systems since they have undertaken successful pioneer projects and have contributed to the development of the IEC/ISO/IEEE 80005 International Standard [26].

The California Air Resources Board (CARB) approved the "Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port" Regulation, commonly referred to as the At-Berth Regulation. This regulation applies to multiple ports in California and requires vessel fleet operators visiting these ports to reduce at-berth emissions from Auxiliary Engines (AE) [36].

3.2.2. OPS Master Plan in Spanish Ports

This project is part of the National Action Framework for the development of infrastructures in compliance with Directive 2014/94/EU, on the deployment of alternative fuels infrastructure, and following the recommendation 2006/339/EC, on the promotion of shore-side electricity. Pilot cases will be carried out and the project aims to release regulatory, technical and environmental studies in order to identify existing barriers and outline solutions [37]. In its database, many relevant references are accessible for the general public, including technical and real life solutions.

3.3. Standards and regulations

The current section involves main regulations for shore-side power supply or *cold ironing*. *IEC, ISO,* and *IEEE* jointly have agreed on developing a full standard with the purpose of promoting OPS over their areas of influence. The *IEC* and *ISO* standards apply in European countries, and the *IEEE* standards have the biggest influence in the US. The *ISO* standard handles mechanical aspects, and the *IEC* and *IEEE* cover electrical aspects of the connection. The co-operation usually leads to world standards. Several drafts have been released over the past 20 years, thereby attempting standardization. However, most of them have been embodied to put together the *IEC/ISO/IEEE 80005: Utility connections in port* [38].

3.3.1. Reference International Standards

International Standards represent the technical agreement between Authorities and companies. As trade and shipping are global, to comply with the same regulations worldwide makes them easier.

IEC/ISO/IEEE 80005-1:2019 – *Utility Connections in Port. Part 1: High Voltage Shore Connection (HVSC) systems. General requirements* [39].

It comprises the design, installation and testing of HVSC systems and addresses: HV shore distribution systems, shore-to-ship connection and interface equipment, transformers/reactors, semiconductor/rotating frequency converters, ship distribution systems, and control, monitoring, interlocking and power management systems.

IEC/ISO/IEEE 80005-2:2016 – *Utility Connections in Port. Part 2: High and Low Voltage Shore Connection systems. Data communication for monitoring and control* [40].

It deals with the non-safety related communication. It 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. It also specifies the interface description, addresses and data type.

IEC/ISO/IEEE 80005-3:2016 – *Utility Connections in Port. Part 3: Low Voltage Shore Connection (LVSC) systems. General requirements* [41].

It is applicable to the design, installation and testing of HVSC systems and addresses: LV shore distribution systems, shore-to-ship connection and interface equipment, transformers/reactors, semiconductor/rotating frequency converters, ship distribution systems, and protection, control, monitoring, interlocking and power management systems.

3.3.2. Complementary regulations

IEC 62613-1:2018 – *Plugs, socket-outlets and ship couplers for high-voltage shore connection systems (HVSC-Systems) - Part 1: General requirements*. [42]

IEC 62613-2:2018 - *Socket outlets and ship plugs for high-voltage shore connection systems (HVSC systems). Part 2: Requirements for dimensional compliance and interchangeability of products intended for use by different types of ships*. [42]

IEC 62613 addresses the needs in terms of plugs, socket-outlets and ship couplers (ship connectors and inlets), of the IEC/ISO/IEEE 80005-1:2016, therein referred to as "accessories". This standard specifies requirements that allow compliant ships to connect to compliant high voltage power systems through a compatible shore-to-ship connection.

IEC 60092-101:2018 – *Electrical installations in ships. Part 101: Definitions and general requirements.* [43]

IEC 60092-503:2007 – *Electrical installations in ships - Part 503: Special features* - AC supply systems with voltages in the range of above 1 kV up to and including 15 kV. [44]

3.3.3. Directives and recommendations

As environmental issues concern society, high-level authorities from all over the world are pushing through reforms thereon. The following directives are not official regulations, but set general guidelines and environmental driving forces for competent authorities in each field [45].

EU directive 2012/33/EC, the sulphur content of marine fuels

« The Community's environmental policy aims to achieve levels of air quality that do not give rise to unacceptable impacts on, and risks to, human health and the environment. » [46]

EU Directive 2016/802/EU, a reduction in the sulphur content of certain liquid fuels

« The purpose of this Directive is to reduce the emissions of sulphur dioxide resulting from the combustion of certain types of liquid fuels and thereby to reduce the harmful effects of such emissions on man and the environment. » [47]

Both Directives 2012/33/EC and 2016/802/EC boost the environmental concerns within the EU Member States' territory, territorial seas and exclusive economic zones or pollution control zones.

IMO MARPOL Annex VI – Regulations for the prevention of air pollution from ships

Entered into force on May 2005, it makes provision for certain areas to be designated as Sulphur Oxide Emission Control Areas (SECA). These areas include the North Sea and the Baltic Sea. The maximum limit of sulphur content is 0,1% sulphur by weight for marine fuels used by inland waterway vessels and ships at berth in Community ports [48]. The International Maritime Organization has set new rules that will prohibit ships from using fuels with a sulphur content above 0.5 percent from Jan. 1 2020, compared with 3.5 % now, unless they are equipped with so-called *scrubbers* to clean up sulphur emissions. IMO MARPOL stands as a reference for the Authorities, and regulations mentioned above are wherein related. The sulphur limits timeline is explained in *Figure 1*.

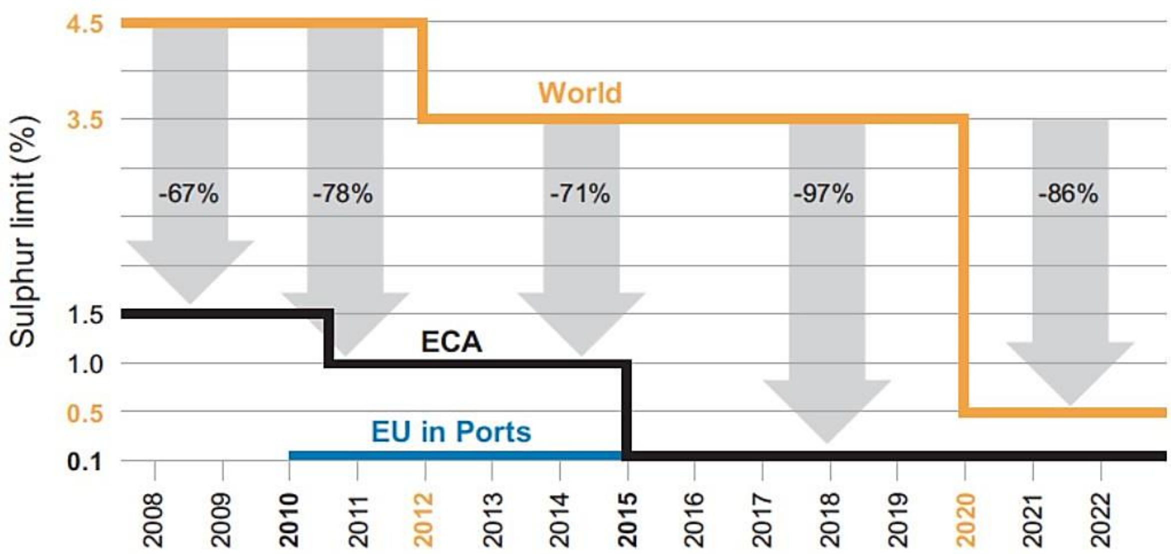


Figure 1. Sulphur limits timeline [48].

EU Directive 2014/94/EU, on the deployment of alternative fuels infrastructure

« In its Communication entitled "Europe 2020: A strategy for smart, sustainable and inclusive growth", the Commission aims at enhancing competitiveness and energy security by a more efficient use of resources and energy. » [49]

This directive refers to electricity supply as an "alternative fuel" because serves as a substitute for fossil oil sources and has the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector. Moreover, "shore-side electricity supply" has to be provided through a standardised interface to seagoing ships, therein encouraging authorities to comply with international standards.

EU recommendation 2006/339/EC, on the promotion of shore-side electricity

« (...) a European Union strategy to reduce atmospheric emissions from seagoing ships, which urged port authorities to require, incentivise or facilitate ships' use of land-based electricity while in port. »

This recommendation encourages the most those ports where air quality limit values rate above the average but also those where high levels of noise cause discomfort in the surrounding neighbourhood [50].

Council Implementing Decisions, on authorising Member States to apply a reduced rate of taxation on electricity provided to vessels at berth in a port

The European Commission helps thus to promote shore-to-ship supply systems. Countries such as Denmark, Sweden or Spain have already been authorized to this day [51] [52] [53].

3.3.4. Discussion

Taking into account the new LVSC standards [41], it is not recommendable to have more than 5 cables and sockets in LVSC, and that poses a problem when supplying high power is required. As a result, a solution suggested by environmental managers and electricity technicians in the ports contacted consists of having the power station on board the vessels. That would be theoretically easy to apply in container vessels, as the installation would be integrated in a single container and the two HV socket-outlets would be accessible at the lar- or starboard of the vessel. Container vessels seldom carry their maximum capacity, thereby this solution is likely to be implemented.

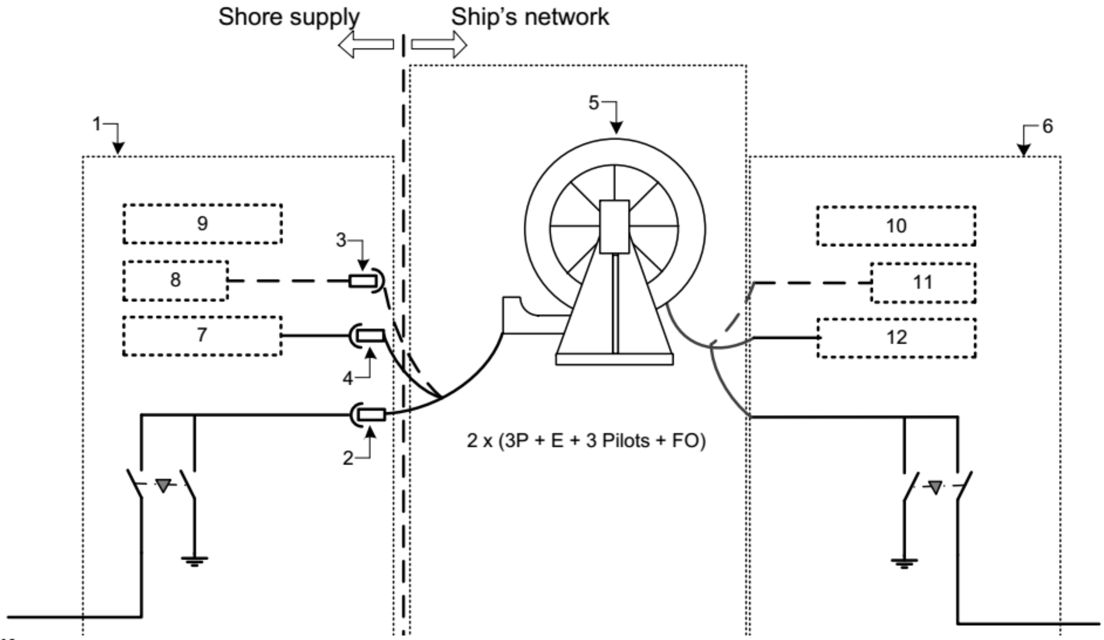
Standards push forward HVSC, and having an **on-board power station** seems the most reasonable solution to turn a LVSC into a HVSC. Most current vessels are not equipped with any socket-outlet for shore connection, thus leading inevitably to some kind of retrofitting. It seems easier to develop a standardised solution for the mentioned integrated power station on board container ships, than trying to plug them in LV. Once a vessel carries its own power station, the connection procedure is quicker and safer [54].

With regard to tankers, an analogous procedure is often hindered by problems of space, i.e. the vessels need to be retrofitted case by case. Moreover, the standards suggest **specific requirements for tankers and Liquefied Natural Gas Carriers (LNGC)** due to security issues. The control and monitoring cable management system must be separated from the plug (shore-side) and socket-outlet (on-board), which means separated cable arrangements are needed for each vessel. Three cables are to be plugged in tankers, but only one in LNGC [39]. If an area contains electrical equipment that is not of safe type, certified or approved by a competent authority for the gases or combustible dust encountered, the such equipment may have to be isolated by the time the tanker is at the quay [39] [41].

One aspect of major concern for the standard is the issue of human safety. Both port authorities and ship-owners are concerned with the possibility of injuries or deaths related to power connection. Strict shore connections and technical solutions must allow smooth dockside operations and safe cable handling. The standard requires the use of a mechanical securing device that locks the connection in the engaged position. This plug and socket-outlet is sometimes called as a *Kirk key interlock* device, and the power plug/socket contacts sequence shall be as specified in [55]. To comply with the regulations, each port must have its **own written procedures and training** for operators undertaking safe cold-ironing operation. For instance, PoLA unveiled its connection procedures in 2014 [21].

3.4. Design configuration

Many installations described before consist of pilot projects (especially those LVSC) that do not comply with the International Standards. In order to boost shore-side electricity for seagoing ships, all parties involved should come to an agreement on how to do it. According to the Standards, HVSC are mandatory when supplying high power is required. However, there are specific requirements depending on the type of vessel. Mainly, the number of HV cables allowed and on which side (shore or ship) the connection between the *interlock device* and the socket-outlet takes place. *Figure 2* shows the diagram for container ships. Other ships' diagrams are described in [39].



Key

1	Shore supply system	6	Onboard shore connection switchboard
2	Socket-outlet (shore-side) and plug (onboard)	7.	Interlocks with pilot wires shore-side
3	Fibre optic communication for control and monitoring (integrated in power cable); plug (shore-side) and socket-outlet (onboard)	8	Control shore-side
		9	Protection relaying shore-side
		10	Protection relaying onboard
4	Pilot wires (integrated in plug and socket-outlet)	11	Control onboard
5	Cable management system	12	Interlocks with pilot wires onboard

Figure 2. General system diagram for Container ships [39].

3.4.1. Docking patterns

With regard to the *Container terminal*, the dock is equipped with cranes to load/unload containers. In many ports, rails are placed very close to the quay-side and require the full range of the quay and the cranes may restrict the arrangement of the electrical connection. Conversely, as *Figure 3* illustrates, there is more than 4 meter of free space, which is expected to be enough to place the required infrastructure.

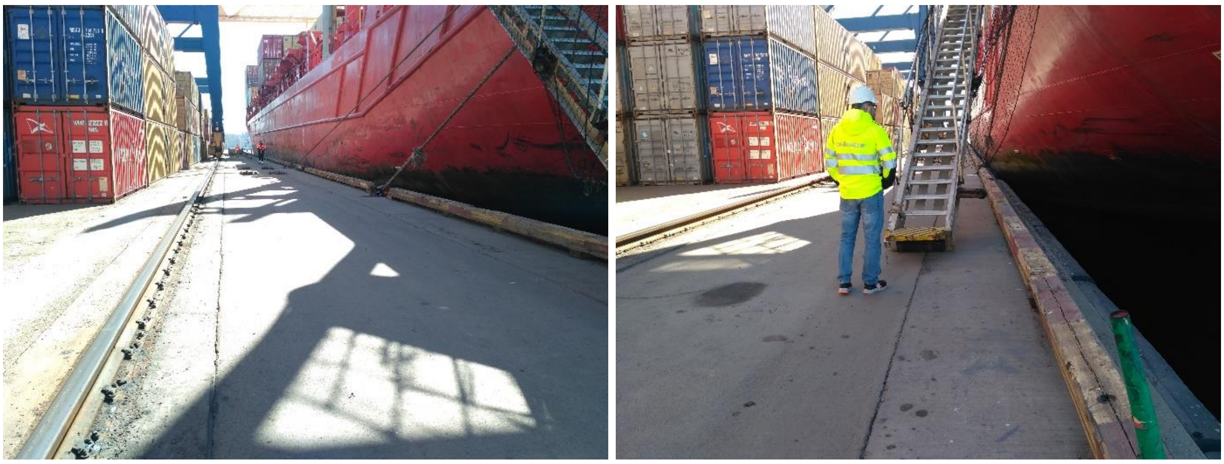


Figure 3. Docking patterns in the current Container terminal in the Port of Gävle.

3.4.2. Possible shore-side configurations

The on-shore infrastructure can be addressed in several ways, depending on where the power converter is placed (where the frequency conversion occurs). The cable arrangement is determined by the International Standards for each type of vessel; however, the docking patterns may be particularly unlikely to affect in the Port of Gävle. According to the European Commission Recommendation, voltage level ranges are limited [50]; however, the final configuration is open to distribute the cables either in AC or DC and the place to install the power converter is also flexible (*Figure 4*).

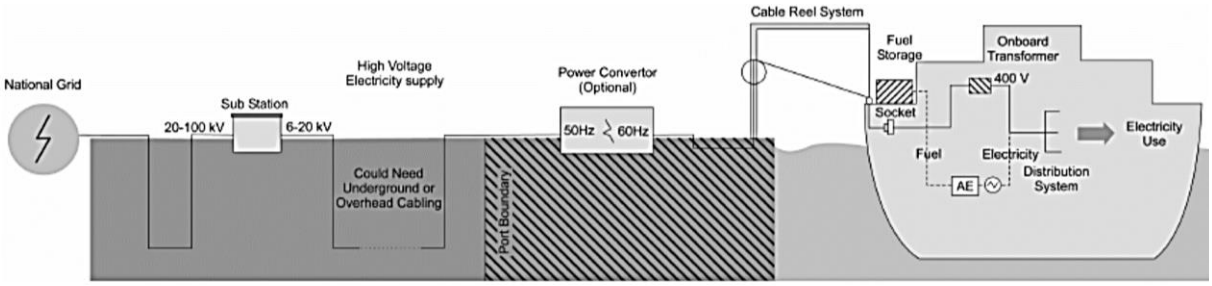


Figure 4. General shore-to-ship installation according to 2006/339/EC [50].

Three main possible topologies are widely discussed in the study carried out by I. Fazlagic and P. Ericsson [18], and the summary of advantages and disadvantages is shown in *Table 1*. In that report, the *Configuration 2* is recommended to be implemented in a whole big port. However, the Port of Gävle has only a few berths and the project will start out in the *Container terminal* and the *Energy terminal*. Therefore, the ***Configuration 1*** **seems more likely** in this case.

Table 1. Summary of advantages and disadvantages for different configurations [18].

	Advantages	Disadvantages
Configuration 1 Frequency converter located at berth	+ Free-standing system at each berth. + Fault in one converter and service maintains will not influence other berths.	- Big footprint needed at every single berth. - The frequency converter must be dimensioned according to the highest power demand on the present berth. - The frequency converter is in use even if a 50 Hz vessel is connected. - Large amount of transformers required, due to the need of a step-down and a step-up transformer for each frequency converter.
Configuration 2 Centrally placed frequency converter(s)	+ Small footprint needed at every single berth. + Frequency converter is only used for converting 50 Hz to 60 Hz, so the converter is not burdened by the 50 Hz vessels, resulting in higher efficiency and the frequency converter can be dimensioned after the total power demand of the harbour for 60 Hz vessels.	- More vulnerable. If a fault occurs in a frequency converter, all connected berths will not be able to serve 60 Hz to the vessels. - The use of double-busbar switchgears instead of standard switchgears will increase the price.
Configuration 3 DC distribution with alternators	+ Small footprint needed both at berth and for the centrally placed converter. + Easier to build a modular-based system. + Low transmission losses.	- No products available today to be applied for this application. - If a fault occurs in the centrally placed rectifier building or in the DC-link, no berth will be able to serve their vessels with on-shore power supply.

3.5. Vessels register

This chapter involves ship and port activities and knowledge thereof in general and about the Port of Gävle.

3.5.1. Vessels activities in the Port of Gävle

Depending on ship type, vessels have different operating speeds and generating capacity. Despite quite a few studies break out vessel types differently, it is more common and useful to classify vessels by the cargo they carry. However, some vessels may carry different cargo and cannot be classified clearly. A detailed analysis on vessel ship types can be found in [56]. The current project involves tankers and container vessels, as far as **the potential OPS system will start out from the *Oil terminal* and the *Container terminal***.

Vessel's movements are broken down into sections according to its speed. Four distinct time-in-modes make up a call: Cruise, Reduced Speed Zone (RSZ), Manoeuvring, and Ship alongside (at the quay, hoteling). Each time-in-mode is associated with a speed and thereby with an engine load and emission factors. Time-in-modes are used in studies to estimate fuel consumption, power demand, engine load and emission factors and so on. Further information with regard to vessels movements is described in the ICF Consulting report [56]. For purposes of this report, only what concerns to the **vessels at the quay** is described as follows. Ship berthed alongside the quay (*hoteling*), expressed in hours per call, represents the time at quay when the vessel is operating only its AE. These AE have variable levels of load, but peak loads occur before and after the propulsion engines are started up or shut down, respectively. The AE generate all on-board power and are used to power loading/unloading equipment, if applicable.

Not every type of vessel calls at the Port of Gävle. The Port of Gävle consists of terminals for specific purpose, where ships berth according to their cargo, as *Figure 5* illustrates. The *Oil terminal* comprises the first dock of the port, where berthed tankers load and off-load the gas/oil products, and the storage area. The products flow through an above- and underground long pipeline to be stored in the storage tanks inland. However, the berth where tankers stay alongside is called *Energy terminal*. This project focuses namely on the ***Container terminal*** and the ***Energy terminal***. The size and type of ship that can call at the Port of Gävle is restricted. The port can accommodate ships of up to 42 m of breadth, with a draft of 12,20 m (waterway depth). Besides dredging activities that are currently ongoing, the ***Container terminal* is being expanded**, thereby allowing two large container ships berth at the same time. The existing *Container terminal* can accommodate vessels up to 190 m in length and 1500 containers. The new container terminal will be able to handle ships with a length of 366 m and a loading capacity of 14000 containers.

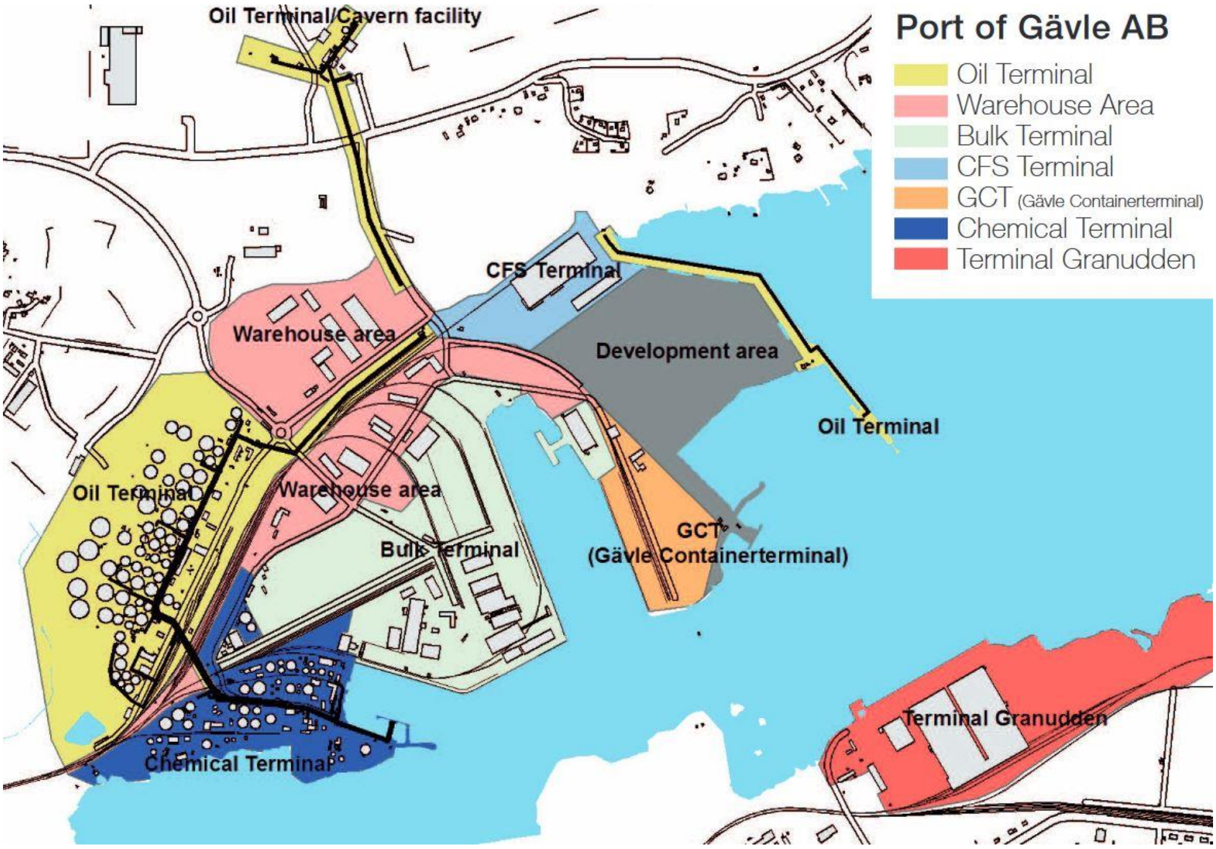


Figure 5. Terminals layout of the Port of Gävle [28].

Every vessel calling at the Port of Gävle is recorded. In this report, vessels berthing in the *Container terminal* and in the *Energy terminal* **from January 2017 to March 2019** are considered. Ships often change their names, which means the same vessel is visiting the same port but is not clearly registered. This has been considered and the following results are proper. Every vessel has associated a unique **IMO number** that allow them to be tracked. The number of container ships and time they are berthed varies significantly from year to year, as *Figure 6* illustrates.

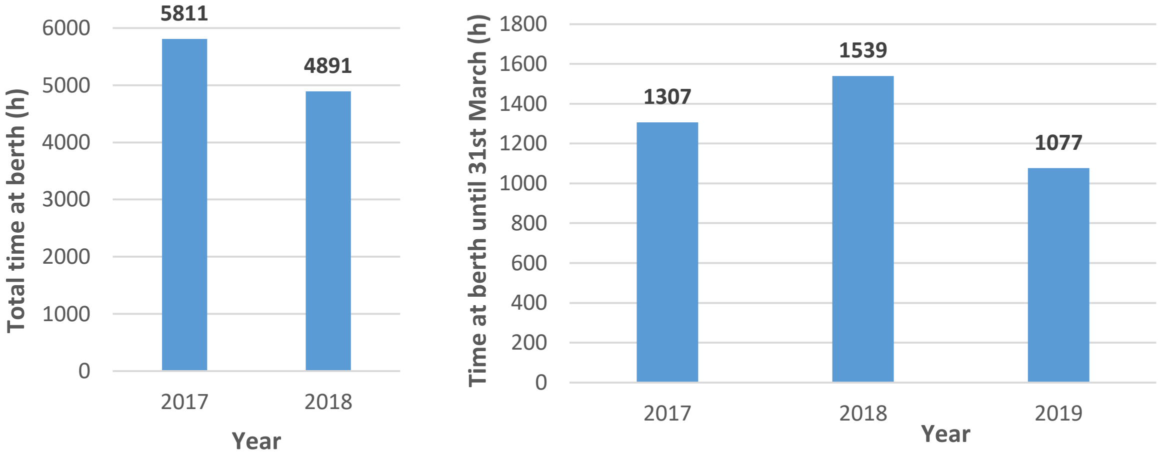


Figure 6. Total time at berth, left. Time at berth until March 31st, right (Container terminal).

3.5.2. Container terminal

Raw data show the time the vessels stay alongside the quay, at each berth (B17 and B19 for the *Container terminal*). Some vessels are not going to call at the Port of Gävle in the near future; however, they are going to be replaced by very similar ones. Shipping companies often charter the ships for 3 or 4 years to sail the same route and then change them to others. Size and type of ship remains the same, although new generation of ships are to be included in the fleet, i.e. bigger but more efficient vessels [6] [57] [58].

37 container ships are included in the register of this report. However, many ships call less than five times, thereby the total time berthed is negligible compared the rest of vessels. Therefore, only those vessels that have been berthed alongside more than 2,5% of the total time (from January 2017 to March 2019) are considered in the calculations. *Table 2* shows the vessel register for the period considered. The full register is property of the Port of Gävle Authorities and it is not included in this report.

Table 2. Summary of main container vessels calling at the Port of Gävle.

VESSEL	COMPANY	Calls (num)	AVG (h)	TOTAL (h)	% total register
ADELINA D	MAERSK	54	25,2	1363,1	11,6%
ANNABA	MAERSK	56	25,1	1405,5	11,9%
HELUAN	MSC	58	24,6	1426,5	12,1%
HARRISON	MSC	45	25,9	1165,8	9,9%
AMERDIJK	MSC	16	28,9	463,0	3,9%
BALTIC PETREL	UNIFEEDER	25	44,7	1117,8	9,5%
BALTIC TERN	UNIFEEDER	16	49,1	785,7	6,7%
OOCL RAUMA	UNIFEEDER	27	40,8	1101,6	9,3%
VERA RAMBOW	UNIFEEDER	14	45,5	637,0	5,4%
THETIS D	UNIFEEDER	14	36,6	511,9	4,3%
HEINRICH EHLER	UNIFEEDER	9	40,4	364,0	3,1%
EVOLUTION	-	10	28,1	280,9	2,4%
TOTAL		**344**	**30,9**	**10622,7**	**90,1%**

In short, only **12 vessels** are berthed alongside the port during more than 90% of the time, with an average time at berth of **30,9 h**. Data dispersion throughout time berthed for each vessel is narrow, as most of calls range from 20 to 40 hours. For instance, the following figures illustrate the time at berth per call for the vessels ANNABA, OOCL RAUMA and VERA RAMBOW (*Figure 7*, *Figure 8*, *Figure 9*).

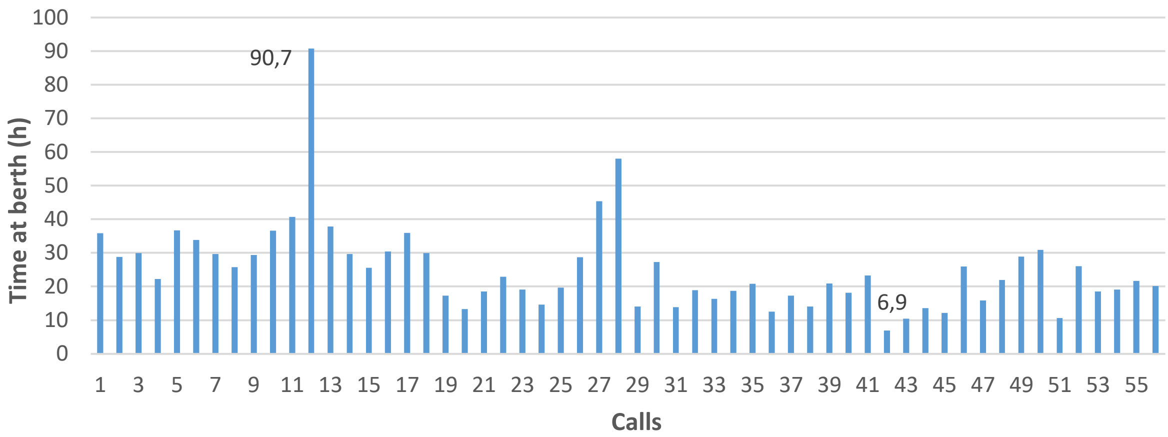


Figure 7. Time at berth per call for ANNABA vessel.

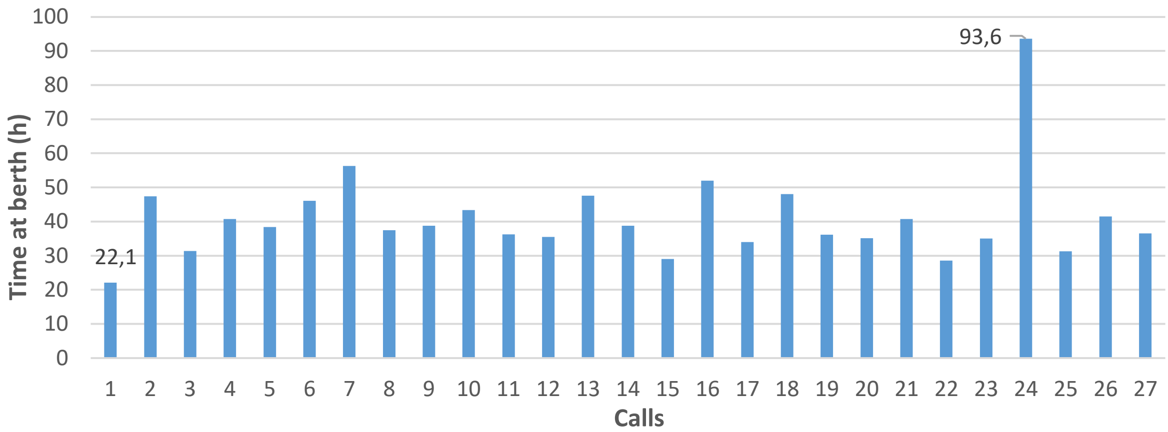


Figure 8. Time at berth per call for OOCL RAUMA vessel.

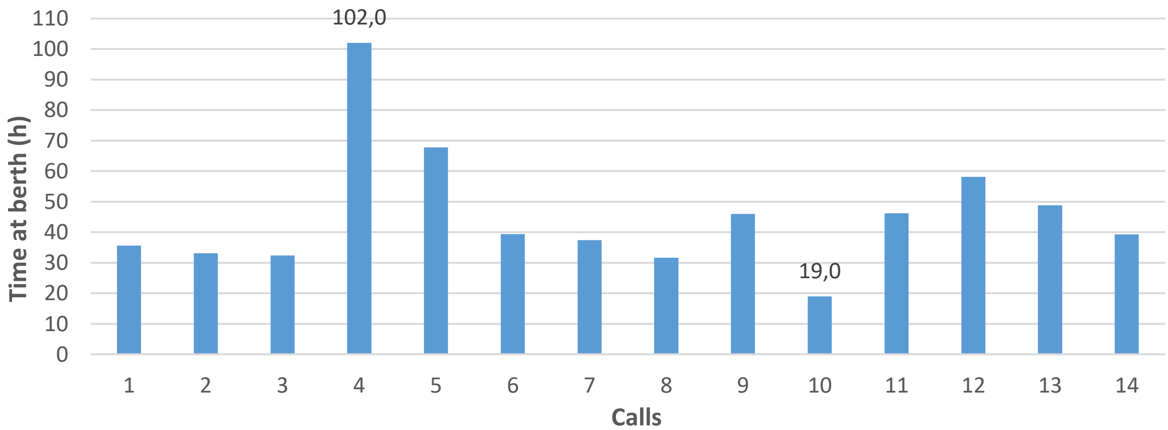


Figure 9. Time at berth per call for VERA RAMBOW vessel.

3.5.3. Energy terminal

The vessel register for the *Energy terminal* is completely different than for the *Container terminal* because there are many more vessels that call just a few times over the period considered and the time at berth is also disparate. Only 11 out of 120 ships make at least 5 calls at the Port of Gävle.

However, the total time at berth for these vessels does not represent a significant percentage, as illustrated in *Figure 10* and *Figure 11*.

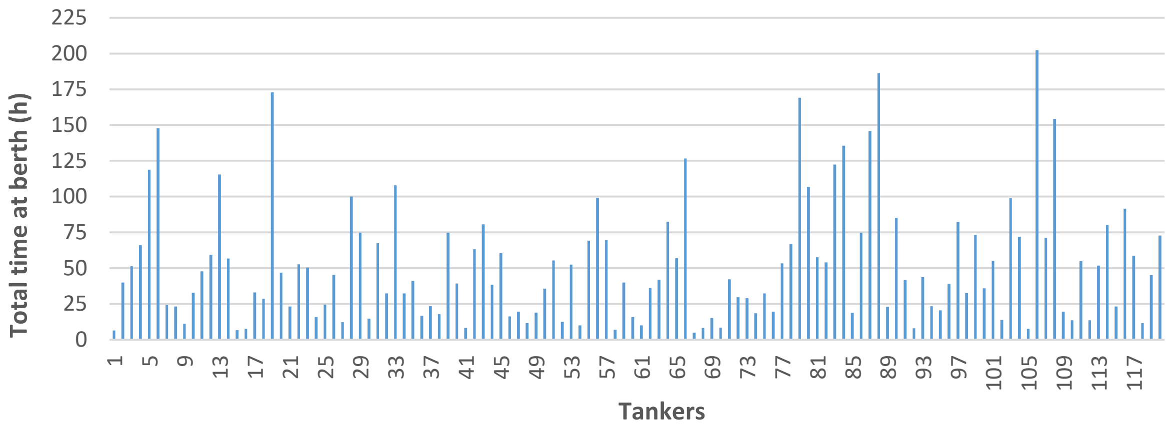


Figure 10. Total time at berth per vessel in Energy terminal.

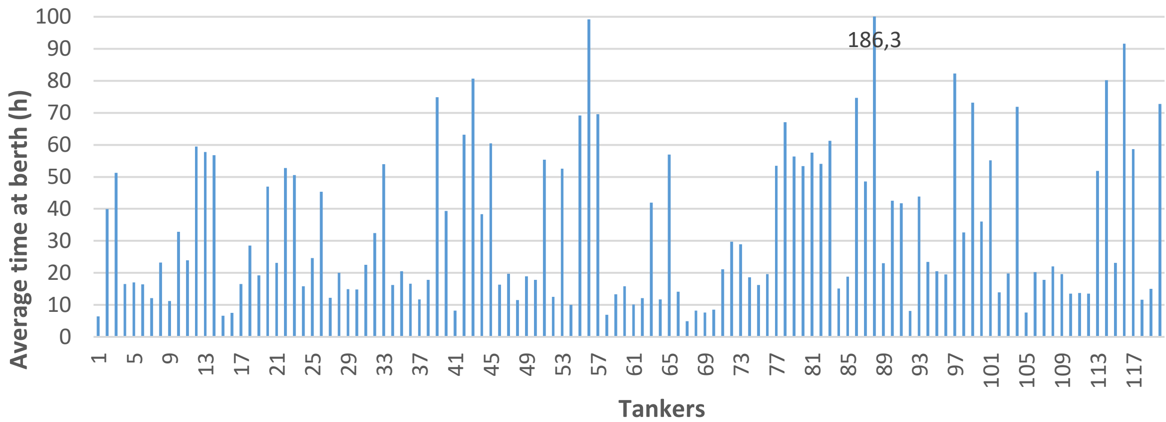


Figure 11. Average time at berth per vessel in Energy terminal.

3.6. On-board power systems

First, vessels' typical on-board power systems are presented; then, fuel consumption and emissions are discussed by means of a literature review on reports, articles and case studies. Afterwards, problems and technical issues that arise in OPS systems are briefly discussed.

3.6.1. On-board generation and distribution

Marine vessel power systems have evolved over time and may be different depending on the type of ship, frequency, voltage level, system analysis, power generation, electrical distances and load flow, system's size and extent, load profile, single line faults and environmental effects [58]. Ships are an isolated electrical system themselves, because they include the power generation, distribution and demand. Power demand can be split by the energy purpose: to supply electricity to all the on-board electrical-driven equipment, and to drive the propellers. here are two main groups of power generation systems in which most of the vessels can be classified. This classification is based on how the ship's propulsion is undertaken. Apart from what it is stated below, every vessel includes at least one Emergency Generator to supply a minimum load.

a. Conventional propulsion vessels

In a conventional power system, a mechanical-drive system with reduction gears couples the prime movers to propeller shafts. A Main Engine (ME) is used to propel the vessel at sea and while manoeuvring. Sometimes, the ME is coupled to a shaft generator, thereby supplying electricity to the on-board equipment while the ME is running. There are always several AE, which are also coupled to their own electric generators. The AE supply electricity mainly at the quay, but also at sea and while manoeuvring, if necessary. As a result, conventional power systems can be separated or integrated, connected to the same switchboard and with or without shaft generator (*Figure 12*). Shore-side interlock must be connected to the main switchboard, by means of its own electric switchgear and protection devices.

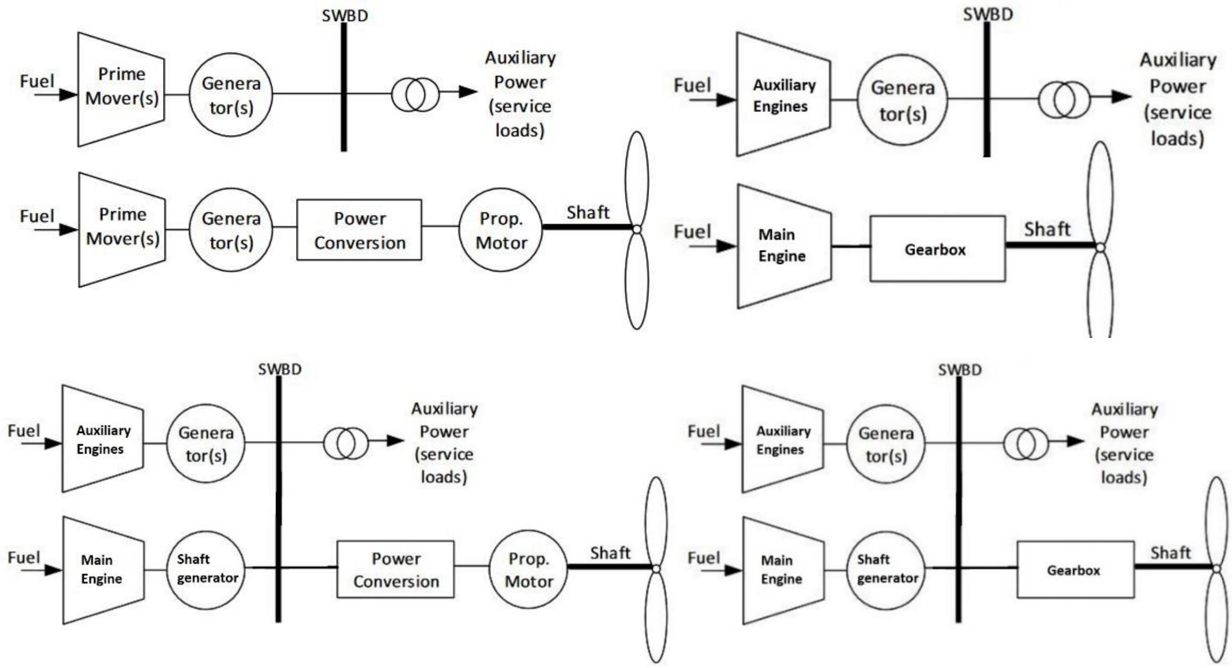


Figure 12. On-board power systems for conventional propulsion vessels [58].

b. Diesel-electric propulsion vessels

Cruise ships and big vessels which operate with high-voltage use diesel-electric propulsion systems. Electric propulsion by means of a power electronics device allows faster response for manoeuvring and at the quay. Several engines are coupled to their own electric generator and the whole package is connected in parallel to the main switchboard. The switchboard feeds the on-board electrical-driven equipment and the Drive, which is coupled to the propeller. As a result, there is no distinction between ME and AE, as *Figure 13* illustrates.

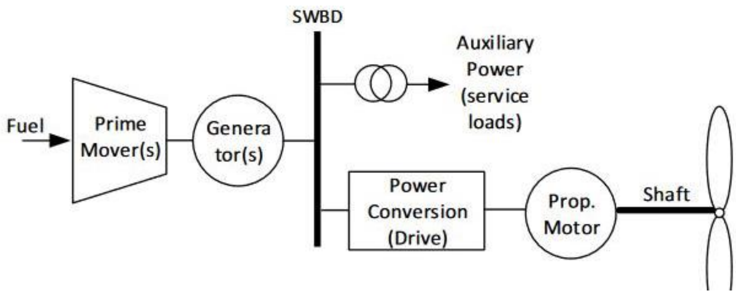


Figure 13. On-board power systems for Diesel-electric propulsion vessels [58].

In view of the changes of the market (bigger ships and development of power electronics), new vessels are increasingly using diesel-electric propulsion systems [7] [34] [59]. The vessels calling at the Port of Gävle are expected to include conventional electric-drive power systems. In any case, issues concerning an OPS and the socket-outlet on board are only practical, i.e. the OPS associated switchgear only has to supply electricity to the Service Loads of the AE while the ships are berthed alongside the quay.

3.6.2. Other ports statistics: a literature review

An OPS system shall provide the vessels with the appropriate power; moreover, voltage and frequency must match. For the time being, there is not an available database that contains all this kind of information. Whereas the voltage level and frequency can be, in principle, easy to determine from a ship database, the average and peak power demand are certainly dependent on each vessel. The operating life and the load cycle (number and intensify) of the engines pose a challenge in checking the power demand but also other aspects, e.g. emission factors or fuel consumption sorted by time-in-modes [56]. In order to collect this information, just a few studies have been conducted, namely concerning vessels that call frequently at European ports. Ocean-Going Vessels (OGV) are expected to behave similarly worldwide, especially in controlled areas (SECAs). However, ships sailing within European countries may show different data. These studies consist of surveys randomly delivered to shipping companies and vessels. Technical departments and on-board chief engineers answered them.

The Port of Rotterdam conducted a study in 2006 in which 53 randomly selected container ships (from 100 m to 350 m length) were surveyed in order to know about their electric systems and power requirements while they were berthed alongside the quay [20]. The survey split the vessels into 19 Feeders (less than 140 m length container vessels) and 34 Deep-sea container vessels (more than 140 m length). However, as vessels are increasing their size over time, current feeders can be larger than 140 m. This classification is relevant for the purpose of the project, as the typical container ship that call at the Port of Gävle ranges 140-180 m. Due to practical restrictions (already mentioned), the Port of Gävle cannot accommodate ships of more than 250 m in length. However, it is more important to know the average and peak power demand, voltage level and frequency. Voltage levels ranged from 380 V to 6600 V, while most vessels used 440 V at 60 Hz and only 8% of ships used 6,6 kV [20]. An own survey was carried out in [18] for 30 oil- and product tankers (from 100 m to 250 m length) that called at the Port of Gothenburg with the same purpose. Results from both sources are shown in *Table 3*.

Table 3. On-board power systems and demand [18] [20].

Power demand	Average power demand (kW)	Peak power demand (kW)	Peak power demand (kW) for 95% vessels
Container vessels (< 140 m)	170	1000	800
Container vessels (> 140 m)	1200	8000	5000
Container vessels (total)	800	8000	4000
Oil- and product tankers	1400	2700	2500

System voltage	380 V	400 V	440 V	450 V	6,6 kV
Container vessels (< 140 m)	42 %	16 %	42 %	-	-
Container vessels (> 140 m)	6 %	79 %	-	3 %	12 %
Container vessels (total)	19 %	6 %	64 %	2 %	9 %
Oil- and product tankers	13 %	-	40 %	47 %	-

System frequency	50 Hz	60 Hz
Container vessels (< 140 m)	63 %	37 %
Container vessels (> 140 m)	6 %	94 %
Container vessels (total)	26 %	74 %
Oil- and product tankers	20 %	80 %

System frequency in the vessels is mainly 60 Hz, but the amount of vessels using 50 Hz is not negligible. The idea of creating an OPS exclusive on-land power plant to supply electricity at a different frequency from the one that the existing in-land grid has, has not been reported yet. Therefore, supplying electricity to vessels at both frequencies implies the **use of a power electronics converter**.

3.6.3. Power demand at the quay in the event of an OPS system

When vessels carry **refrigerated containers (*reefers*)**, the on-board power demand is great and then occurs the peak power demand. Typical refrigerated containers demand from 3 to 8 kW, but transient peak demands are up to 10 kW. AE are operated then at high loads to supply electricity to the cooling systems. Depending on how many reefers the vessel is carrying, the average and peak demand will be higher or lower. Container ships surveyed usually carry 30 containers at most. However, sometimes one ship carries many reefers, which can lead to a peak power demand of 10 times the average power demand [11]. Power demand values found in the literature are shown in *Table 3* above.

The average power demand for AE operating at the quay is used to calculate the energy demand that can be supplied by means of an OPS, which is one of the objectives of the project. However, there are a few points that need to be taken into account. It cannot be assumed that the same average power demand obtained from studies and surveys is needed to be shore-side supplied. Around 40 % of the base load for AE operating at the quay is required to feed the pumps and fans of the engines' cooling system. That is, the **base load at the quay on an OPS system** would drop to **60 %** [11] [12].Waste heat from engines and boilers is partially used to keep areas comfortable, and on-board mechanical ventilation operates non-stop. In an OPS system, AE are shut down, which means there is **no waste heat available** to heat up spaces. This is an important issue that needs to be solved. Remaining power demand corresponds to auxiliary loads and stand-by pumps that control fuel viscosity.

3.6.4. Synchronisation

The shore-to-ship connection must be controlled at every time. According to the International Standards, the **transition from ship-side to shore-side supply** must be smooth, which means that power tripping, voltage dips, surges and overloads should be avoided [39] [40] [41]. If any of these events occurs, the threat of a *blackout* might happen [60]. The ground system becomes therefore a critical part of the design, as discussed below.

a. The blackout problem

A ***blackout*** is an unexpected power disconnection that **may damage some electronic devices**, which would need to be replace, taking up time and money. This situation may be due to a malfunctioning of protection relays, transient overcurrent and short-circuits, unpredictable transient surges, or failure in shore-to-ship power synchronisation. On-board chief engineers are very concerned about this problem, and the best way to solve it consists of the development of a plug-and-play solution [11] [12]. When the power required in LV is high (greater than 750 kVA), up to 5 single cables are needed according to [41]. A limit of 5 cables is recommended for supplying LV power, 2 cables for HV containers, 3 cables for HV LNGC and 1 cable for HV tankers [39] [41]. Cables have standardised cross section and their current rating depend on the type of cable, its operating conditions and its working environment. Aluminium or copper cables can be used, being **aluminium cables** more suitable in this case because they are lighter and expected to be winded and unwinded quite often [61].

b. Ground system and other issues of concern

In order to avoid a *blackout*, several considerations must be addressed. In LVSC, phase-ground faults are limited by using a **neutral grounding resistor**, which is continuously monitored and the protection relays automatically trip shore-side supply in case the monitoring is lost. High-resistance grounded (HRG) systems prevent high fault currents and the neutral resistor may be sized as a 5 A continuous, as it is recommended in [41] and discussed in [60]. Although an ungrounded power system is not recommended (IT configuration), the International Standards allow it. In [60], a sized 2 A continuous neutral resistor is recommended. Furthermore, Port Authorities may require vessels to equip on-board isolation transformers instead of a neutral disconnect switch. In HVSC, ungrounded power system is not allowed. In any case, a phase-ground fault can create a touch voltage exceeding 25 V in LVSC and 30 V in HVSC [39] [41]. Finally, safety loop controls must be tested in order to assure the safety of the operators during the shore-to-ship connection procedure [62].

According to the International Standards, the HVSC system design should also consider harmonic distortion and line voltage drops, among others. Magnitudes of these issues are evaluated and discussed in [61]. On the one hand, voltage drops increase with the power demand and the length of cables. Likewise, voltage drops decrease when the power factor (*cos phi*) and the cable cross section are increased, as it is expected looking over the theory. Results included in this paper provide candidates of power cables for HVSC systems that comply with the International Standards, depending on the cable length requirements.

3.7. Technical survey

In order to focus in the Port of Gävle, a comprehensive questionnaire was prepared, as part of this project, in accordance with the steps followed by prior studies. The results included in this report were obtained during the months of April and May, 2019, and are detailed in the *APPENDIX*. Although the survey was sent to many vessels and companies, only a few of them showed willingness to fill it out. In fact, it was possible to get on board some vessels and to discuss all kind of issues related to an OPS system in person [10] [11] [12]. Some blanks remain empty because the vessels could not provide the information (not available). The following sections include that relevant information with regard to operational data at the quay: **electrical system**, **fuel consumption** and **power demand**.

3.7.1. Container terminal

Taking into account the vessels register's features, acceptable assumptions can be made. Only 4 container vessels sent the Technical Survey back: OOCL RAUMA, ESSENCE, BALTIC PETREL and VERA RAMBOW. The ESSENCE is a sister vessel of AMERDIJK[1]. However, she was not included in the register (she will be calling frequently the following months) but it was possible to get the Technical Survey back fulfilled by the on-board Chief Engineer. Data for AMERDIJK are assumed to be the same. According to Gross Tonnage (GT), Length and Date Built values, there are more sister vessels, which allows to extend results because technical data are expected to be similar.

Table 4. Container ships characteristics and power system.

VESSEL	Data	GT	Length (m)	Date built	IMO	Voltage (V)	Frequency (Hz)
ADELINA D	*Inferred*	15487	168	2006	9306079	400	50
ANNABA	*Inferred*	15487	168	2006	9306201	400	50
HELUAN	*Inferred*	15633	161	2007	9358905	440	60
HARRISON	*Inferred*	14290	159	2002	9220079	440	60
AMERDIJK	ESSENCE	17368	168	2011	9491472	440	60
BALTIC PETREL	Survey	16324	169	2005	9313216	400	50
BALTIC TERN	*Inferred*	16324	169	2005	9313199	400	50
OOCL RAUMA	Survey	17488	168	2009	9462794	440	60
VERA RAMBOW	Survey	17488	168	2008	9432220	440	60
THETIS D	*Inferred*	17488	168	2009	9372274	440	60
HEINRICH EHLER	*Inferred*	17488	168	2008	9372200	440	60
EVOLUTION	*Inferred*	9191	146	1996	9136228	440	60

The operating life and the load cycle of the engines make a little difference, although these data are acceptable in this case [63]. **Average data** within surveyed sister vessels have been used to extend results to their non-surveyed sister vessels. Blanks for those vessels whose data are not available have been inferred by calculating the average values from the rest of vessels. As it has been mentioned before, the **average power** at the quay in the case of a potential OPS system has been calculated by multiplying the average power at the quay for each vessel by a 0,60 coefficient.

[1] OOCL RAUMA, BALTIC PETREL and VERA RAMBOW: chartered by *Unifeeder*.
ESSENCE and AMERDIJK: chartered by *MSC*.

The **peak power** at the quay depends mostly on the reefers carried, and the peak power in a potential OPS system would not be so high, due to the same arguments stated. However, this drop would not be so significant in that event and, therefore, any reduction coefficient has been considered. Parameters and power demand are shown in *Table 4* and *Table 5*.

Table 5. Container ships fuel consumption and power demand at the quay.

VESSEL	Data	Average fuel cons. at quay (kg/h)	Average power at quay (kW)	Average power at quay (kW) OPS	Peak power at quay (kW)
ADELINA D	*Inferred*	134,5	310	186	771
ANNABA	*Inferred*	134,5	310	186	771
HELUAN	*Inferred*	134,5	310	186	771
HARRISON	*Inferred*	134,5	311	187	771
AMERDIJK	ESSENCE	116,7	300	180	800
BALTIC PETREL	Survey	152,1	410	246	850
BALTIC TERN	*Inferred*	152,1	410	246	850
OOCL RAUMA	Survey	150,0	300	180	750
VERA RAMBOW	Survey	110,4	225	135	700
THETIS D	*Inferred*	130,2	263	158	725
HEINRICH EHLER	*Inferred*	130,2	263	158	725
EVOLUTION	*Inferred*	134,5	310	186	771
TOTAL AVERAGE		**129,0**	**310**	**186**	

3.7.2. Energy terminal

The many vessels included in the register make the Technical Survey very difficult to carry out. In fact, only *Terntank*[2] filled it out for one vessel who was not included in the register (she will be calling frequently the following months). Although she is a sister vessel of others and some information could be inferred, there are not yet enough data to calculate power demand and fuel consumption in the same way as it has been done for the *Container terminal*. From now on, calculations are referred to the *Container terminal* and container ships.

3.8. Energy prices

In order to accomplish with the energy and costs analysis in the next section, prices for both OPS system and fuel need to be briefly examined, as follows.

3.8.1. On-shore electricity prices

Electricity prices in Sweden are among the cheapest in the EU. Swedish power system is divided into four areas, and the Port of Gävle is located in the SE2. According to the trend (avoiding the crisis period), electricity prices are increasing steadily, as *Figure 14* illustrates [64]. The European Commission have released some documents for certain countries in order to promote shore-to-ship supply systems [51] [52] [53]. As a result, electricity taxes are slightly symbolic (only a minimum of 0,05 SEK/kWh is required by Swedish authorities). Network charges also include power and annual charges, which stand at approximately 30 SEK/kW per month and 9000 SEK, respectively [19]. In the event of an OPS system, it is not yet clear which entities would be accounted for the

[2] Shipping Company based in Gothenburg.

fixed charges. For the calculations made in this report, an **electricity price of 0,70 SEK/kWh** is considered.

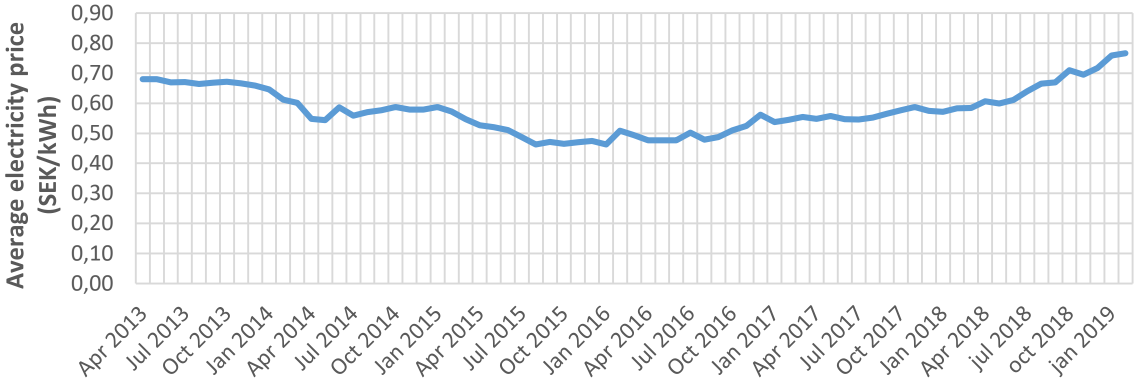


Figure 14. Electricity prices for industry in area SE2.

3.8.2. Fuel types and prices

Due to sulphur content limits and other regulations with regard to fuel composition, ships may use different type of fuel depending on the time-in-mode and its position at sea. To run the ME and the AE, different types of fuel are used: Heavy Fuel Oil (HFO, residual or distillate), Marine Gasoil (MGO) and Marine Distillate Oil (MDO) [65]. These products can be mixed on board to get the desired composition in order to comply with the regulations. Oil usually needs certain physical conditions to be efficiently burned out in the engines. Therefore, some vessels are equipped with boilers that heat up the fuel to be burnt in the engines at the desired levels of viscosity. At the quay, ships only use the AE, thereby using either only one type of fuel or two types (for the AE and for the boiler) [66].

In the same report reviewed in the previous section, the type and amount of fuel burnt in AE and boilers at the quay is shown [20]. 90% of feeders (container vessels < 140 m) use MGO, whereas 85% of deep sea container vessels (container vessels > 140 m) use HFO. Fuel consumption ranges from 0,8 m^3/day to 22 m^3/day for 95% of the vessels. However, these figures need to be updated. Sulphur content regulations have led ships to burn only MGO (<0,1%) at berth [48]. As a result, overall fuel consumption and cost are easier to estimate due to all ships use MGO at berth.

MGO prices have been very variable worldwide over the last decade and there may exist differences in price between ports and also between companies, depending on the purchasing contracts [67]. In April 2019, MGO 0,1% price for the Port of Gothenburg stood around 500 $/ton, while around 600 $/ton for the Port of Rotterdam. Prices continue upward trend; however, it is still far from 1200 $ average peak, that persisted over an extended period of time in 2011 and 2012. All in all, MGO 0,1% prices go hand in hand with Brent barrel trends [67]. For the calculations made in this report, a **MGO 0,1% price of 500 $/ton** has been considered, with an exchange rate of 0,1 $/SEK.

The IVL Swedish Environmental Research Institute released a report with regard to emissions from traffic to and from the Port of Gävle in 2017 [68]. They estimated the fuel consumption on average of the oil-fired boilers, based on the vessel's carrying capacity. Nowadays, most of vessels do not need to use the boilers because they burn MGO [69] [70]. In case of boilers be operating, they use around 50% of the total fuel burnt at berth [12]. The report expresses this consumption in terms of the GT value. *Table 6* provides the IVL report values and those obtained through the *Technical Survey*, which match reasonably well.

Table 6. Fuel consumption in comparison to IVL report values.

	Vessel	Fuel consumption $\left(\frac{kg}{1000GT \cdot h}\right)$
IVL report	Container ships	2,9 to 5,4
	Tankers	4,0
Technical Survey	Container ships and tankers	4,2 (on average)

3.9. Design parameters for an OPS system

In order to design both on-shore and shore-side installations, which at first entail investment costs but eventually operational costs, the rated capacity must be defined. That implies that the peak power demand must be lower than the rated capacity. The *Technical Survey* shows a peak demand of **850 kW** for BALTIC PETREL and BALTIC TERN. Interviews held with on-board Chief Engineers state this peak power demand is a common value. However, there are a few times throughout the year when this peak power demand can be much higher, i.e. up to 2500 kW. In any case, vessels demand higher power than the peak surveyed in less than 3 calls per year. As a result, to retrofit each vessel for its typical peak power demand seems to be a reasonable option. Of course, in the event of high power demand, a ship-to-shore connection is not possible, and the AE would work as usual. As the peak power demand depends directly on the amount of reefers, the feasibility of the ship-to-shore connection is known beforehand. There is no way for the vessel to demand an unpredictable peak power. It is the choice of ships owners the capacity of the on-board installation, but bigger equipment takes up space, weight and money.

Likewise, shore-side rated capacity should be able to supply the highest peak power demand. On-board electrical-driven loads are mostly pumps and fans, i.e. *inductive* loads, which absorb *reactive power*. Typical *cos phi* values range from 0,8 to 0,95 [58] [61] [59]. Therefore, apparent power for shore-side transformers, converters, cables and complementary equipment must be designed to withstand a *cos phi = 0,8* value at the highest power demand. Accordingly, a design load for each coupling point of **1000 kW** is suggested, which leads to a design apparent power of **1250 kVA**. Every item of the electrical installation is distributed from the main substation to the *interlock device* that is to be plugged in the ship socket-outlet.

Some of the vessels surveyed **already have an OPS system**, but the switch-breaker is in all cases 400 A, which makes the shore-side connection unfeasible. This installation is only used in dry dock, i.e. when the power demand is very low and the AE are usually shut down. That means that every vessel would need some kind of retrofitting to adapt the vessel to an OPS system. The *Technical Survey* shows that all container ships use low-voltage (400 V or 440 V) at 50 Hz and 60 Hz respectively, which may lead to design a LVSC instead of a HVSC. However, design power requirements in a LVSC require many cables (more than recommended, indeed [41]). As long as vessels need to be retrofitted and adapted to be shore-side supplied, **a HVSC is highly recommended**, which only implies to carry the power transformer on board in comparison to a LVSC. In [39] it is stated that the voltage level at the coupling point shall be **6,6 kV**. Final requirements for an OPS in the *Container terminal* are collected in *Table 7* below.

Table 7. OPS system requirements in the Container terminal.

Rated power (kVA)	Frequency (Hz)	Voltage level (V)
1250	50 or 60	6600

3.10. Energy costs and savings

Investment costs on shore and on board vary substantially depending on the configuration. On one hand, the shore-side installation requires the following items: power transformers, frequency converters, switchboards and control panels, cable reel system, connection box, cable conduits and canalisation. On the other hand, on-board items consist of: power transformer, switchboards and control panels, cable reel system and electrical distribution system. Most of items need to be on both sides to guarantee safety. The purpose of this report is to provide an approximate account on costs in general. Therefore, investment costs have not been particularly detailed. The *Calculation Model OPS* is a calculation tool developed by the *International Association of Ports and Harbours* (*IAPH*), that promote OPS systems through their *World Ports Climate Initiative* [71]. *Table 8* shows total investment costs for a 1500 kVA on-board installation for a HVSC, which suits in most container ships calling at the Port of Gävle. Considering an interest rate of 6% and a depreciation of 10 years, yearly costs result in **620.000 SEK/year** for a typical vessel. Costs of the main switchboard and the cable arrangement barely vary with the rated power of the installation, whereas the transformer makes the difference. Those ships that may require higher power in other ports would need to install a bigger transformer on board.

Table 8. Total investment costs for a 1500 kVA 6,6 kV on-board installation [71].

Item	Cost (SEK)
Transformer 1500 kVA	2.000.000
Main switchboard and control panel	1.000.000
Cabling	30.000
Cable reel system	1.520.000
TOTAL	**4.550.000**

Provided the information obtained from previous sections, it is possible to estimate fuel costs for an average container ship calling at the Port of Gävle and the electricity costs for a potential shore-side supply. As *Table 9* shows, these values only comprise operational costs for the *Container terminal*. Results are expressed in *per call*, which make overall calculations easier, due to the fact that the number of vessels and time they are berthed varies significantly from year to year. Using the OPS system, energy costs decrease by 71% at berth (from 19919 SEK to 4022 SEK). Additionally, **3984 kg of MGO are saved** per call on average, thereby eliminating associated noise and emissions, which are estimated further on. Vessels navigate different routes, but they usually call at the same ports during a few years. This implies a different number of calls and average time at the quay for each vessel. There is no doubt that profitability is higher for ships if they use the OPS system as many times as possible, and also energy prices are different in each port. Consequently, this report does not carry out any payback calculations for the vessels.

Table 9. Fuel consumption and electricity costs for an OPS system in the Container terminal.

Average fuel cons. at quay (kg/h)	Average power at quay (kW) OPS	Average call (h)	Fuel at quay (kg/call)	Fuel cost (SEK/call)	OPS cost (SEK/call)
129,0	186	30,9	3984	19919	4022

3.11. Emissions

In this final section, ship's emissions are addressed.

3.11.1. Emission reduction estimation

Ships represent significant sources of the exhaust gas emission in the form of NO_x, SO_x, PM_x, CO and CO_2, and AE emit mainly NO_x, SO_x and PM_x [72]. Ship emissions are expected to exceed the land based source emissions by 2020 and still remain uncontrolled for most vessels [7]. Nunes et. al examined ship emissions through the activity-based methodology in four of the main ports of Portugal, and dividing the analysis into ship types and operational modes [9]. They found that **tankers and container ships were the largest emitters**, with CO_2, NO_x and SO_2 being responsible of more than 95% of the cruising and in-port emissions. A comparison between their calculations and other foreign ports emissions have been carried out with varied results. Incidentally, the preliminary OPS project in the Port of Gävle is considering to start it out from the *Oil terminal* and the *Container terminal*, where tankers and container ships berth.

A ship's life cycle is usually longer than 20 years, and so do the on-board engines [36]. Ship engines are able to burn fuel from different qualities, i.e. to comply with the regulations in and out the ECAs, which means ships are controlled somehow through inspections [73] [74]. While the ship is berthed alongside the quay, HFO combustion is not permitted (and also in specific areas at sea). As a result, ME are shut off and the AE, which use MGO due to sulphur regulations, are coupled to electric generators to provide power to the on-board equipment [48] [65] [75]. Some generators are powered by diesel fuel which is burned up in oil boilers, thereby adding other source of pollution.

In the study conducted by IVL Swedish Environmental Research Institute, ship traffic emissions were included and many references were taken for calculations [68]. Only the associated emissions at the quay are presented in *Table 10*. As a matter of fact, the highest emissions occur at the quay due to the time the ships are berthed, although the emission factors [g/kWh] are higher while manoeuvring and sailing through the fairway. In addition, *Table 11* presents the emissions of main substances, sorted in this case by vessel categories, according to [68].

Table 10. Estimated emissions in the Port of Gävle in 2017 (ex. Tugboats) [68].

	Operating mode	CO_2 (t)	NO_x (t)	PM_x (t)	SO_x (t)
Auxiliary engines	At the quay	10200	155	0,58	6,40
	Tankers using cargo pumps	610	8,6	0,035	0,38
Boilers	At the quay	2100	0,06	0,006	0,04
TOTAL	**Quay location**	**12910**	**163,66**	**0,621**	**6,82**

Table 11. Summary of the total estimated emissions in the Port of Gävle in 2017.

	CO_2 (t)	NO_x (t)	PM_x (t)	SO_x (t)	Calls
Container ships	6400	93	0,44	4,0	202
Tankers	5000	57	0,34	3,1	194
Cargo ships	3100	44	0,20	2,0	457
Subtotal vessels	14500	194	0,97	9,1	853
Tugs	400	8	0,06	0,3	-
Total at quay location	12910	163,66	0,621	6,82	-
% at quay location	89,0%	84,4%	64,0%	74,9%	-
TOTAL	**14900**	**202**	**1,04**	**9,4**	**853**

Data obtained from the *Technical Survey* are not comprehensive enough to carry out an accurate calculation on emissions. As it has been described before, most container ships are quite similar. As long as all the vessels considered above (90% of the time at the quay) undertake the necessary retrofitting, a significant reduction in the associated emissions is expected. To multiply 90% by the % of emissions above the total at the quay, an acceptable estimation on emissions is obtained. Results included above in *Table 11* are used and compared in *Table 12* below. To summarise, a potential OPS installed in the *Container terminal* and connected to 90% of container ships at the quay **avoids emissions** that are estimated in: **5126 tonnes of CO_2, 72 tonnes of NO_x, 0,36 tonnes of PM_x and 2,7 tonnes of SO_x each year**.

Table 12. Estimated emissions on an OPS system in the Container terminal.

	CO_2 (t)	NO_x (t)	PM_x (t)	SO_x (t)
Currently	6400	93	0,44	4,0
OPS estimated	1274	22	0,08	1,3

3.11.2. Emission factors

Emission factors (EF) represent the amount of gas or pollutant per base energy unit (g/kWh). However, emissions are greatly dependent on engine loads. Emission factors are considered to be constant down to about 20 % load. AE are generally operated in banks, i.e. when low loads are needed, one or more engines are shut down. The remaining engines operate at higher loads, thereby running at a more efficient level. The environmental and engineering consultancy firm *ENTEC* conducted a study in 2005 on emissions due to electricity generation by using the on-board auxiliary engines and by land-based electricity generation [76]. *Table 13* shows the average emission factors of the study in comparison with the average emission factor calculated from the T*echnical Survey*. In the ICF report [56], AE emission factors are given for different fuels (RO, MDO and MGO). Two factors turn out to be decisive in order to quantify the accuracy for the energetic consumption and the emission in maritime transport: engine's Load Factor and the Specific Fuel Oil Consumption (SFOC) in main and auxiliary engines [77] [78]. However, engine's maintenance condition can influence on the NO_x and CO emissions formation and it should be introduced as an uncertainty factor as a result.

Table 13. Emission Factors for Auxiliary Engines.

Source		NO_x (g/kWh)	SO_x (g/kWh)
EF for electricity production in Europe		0,35	0,46
EF from AE (0,1% S fuel)		11,80	0,46
At the quay (on average, *Technical Survey*)		8,06	-
ICF 2006	RO	14,70	11,10
	MDO	13,90	6,16
	MGO	13,90	2,05

4. CONCLUSIONS

Looking back to the tasks that were intended to be carried out at the beginning of the project, most of them have been addressed with satisfaction. As the project goes on, the tasks and the schedule may undergo changes. Due to a lack of information but namely time, a design configuration has not been recommended. It is expected that further studies within the project undertake an in-depth analysis on the shore-side configurations.

The current thesis has analysed input data with regard to vessels calling at the Port of Gävle: power systems, fuel consumption and emissions, among others. According to available input data, the OPS system and the estimations have only been considered in the ***Container terminal***, putting the *Energy terminal* on the back burner. **12 container ships stay alongside the quay during 90,1%** of the time; therefore, a reasonable decision for a potential OPS system would be to retrofit only these vessels. A **typical call lasts 30,9 h on average**, seldom less than 20 h, which means that the time required to carry out the connection procedure is negligible. The *Energy terminal* is an EX-classified area and handles large amounts of liquid bulk with fire hazards that require to be carefully addressed in further projects. Furthermore, the International Standards do not include very detailed procedures for *HazLocs* in ports, that need to be further developed.

Existing HVSC in other ports have proven to be useful, mainly those that have been installed recently and according to the International Standards. Most LVSC were carried out as pilot projects, thereby evincing LVSC cannot become very widespread due to practical issues. Moreover, HVSC have been studied deeper than LVSC, in line with the needs of the market. In the Port of Gävle, container ships' power demand is such that **a HVSC is highly recommended**. This is a big decision because it affects both technical and practical issues of the shore-side installation. A connection point on the quay in the *Container terminal* shall **supply 1250 kVA at a voltage level of 6600 V**, which means the vessels shall carry their own power transformer. The electricity shall be supplied at either 50 Hz or 60 Hz, according to the vessels' electrical systems. Therefore, the installation of a **power converter** somewhere is mandatory (obviously shore-side). A few configurations have been discussed but none of them is suggested as the design configuration because of the need of a more comprehensive analysis of the shore-side installation.

With regard to the *Technical Survey*, the own questionnaire was expected to be filled out by more vessels. Estimations of power demand and fuel consumption at the quay have been carried out taking data from sister vessels and other studies conducted by other port authorities. As a result, calculations cannot be more accurate and average data have been used instead. An interesting result of an OPS system is the **reduction of the power demand at berth** due to the AE shut down, which has been **estimated in a 40%**. The problem of a *blackout*, of big concern for the on-board Chief Engineers, is yet sorted out as long as the installations are built in compliance with the International Standards.

3984 kg of MGO (<0,1% S) are saved per call on average, which implies that energy costs decrease by 71% at berth (from 19919 SEK to 4022 SEK) in an OPS system. MGO and electricity prices are constant for those calculations: **500 $/ton** and **0,70 SEK/kWh**, respectively; a trend for future prices could not be found due to high variations during the past years. Looking over the investment costs, yearly costs result in **620.000 SEK/year** for a typical container ship calling at the Port of Gävle (1500 kVA), considering an interest rate of 6% and a depreciation of 10 years.

The OPS system likeability depends on energy prices and investments, but namely on the vessels' willingness to undergo changes. There are **two complementary arguments** that stand for and against in that regard. On the one hand, the Port of Gävle requires a minimum number of vessels to be willing to be plugged at berth to carry out any investments on a shore-side installation. On the other hand, vessels require to be connected to shore power in as many ports as possible. Therein lies the main hindrance to the project. Port Authorities and shipping companies need to strive and **work hand in hand** to make steps forward. Moreover, governments and competent authorities should encourage all the parties involved to boost OPS systems, by means of collaboration agreements or new regulations on the field.

Finally, a potential OPS system installed in the *Container terminal* and connected 90% of the time at the quay **avoids emissions** that are estimated in: **5126 tonnes of CO_2, 72 tonnes of NO_x, 0,36 tonnes of PM_x and 2,7 tonnes of SO_x each year**. Noise and vibrations are also directly reduced, although they have not been quantitative identified. The emission reduction estimation is significant, which encourages other ships, i.e. tankers and cargo ships, to be shore-side supplied. They are expected to be more difficult to retrofit, though, and also the shore-side facility. The highest emissions occur at the quay due to the time the ships are berthed; however, emissions while manoeuvring and sailing through the fairway are not negligible and need to be addressed.

In conclusion, an OPS system in the Port of Gävle has proven to be committed to sustainable development and inclusive growth, due to a more efficient use of resources and energy. The Port of Gävle expect to carry on with the project in order to start out their first OPS system in the near future. Hopefully, this thesis can serve to undertake that further project as soon as possible.

Future outlook

Several research projects may be addressed to follow up, since this report is a first approach to the installation of a potential OPS system in the Port of Gävle. One interesting starting point is to strike up conversations with shipping companies and ship owners in order to come up to agreements with regard to their willingness to carry out the vessels' required retrofit. Likewise, other Port Authorities may be looking forward to know about OPS systems as well and they might study the shore-to-ship power supply feasibility in their berths. The Baltic Sea is indeed an intensive shipping area and ships usually sail routes within Baltic ports. On account of that, collaboration agreements seem reasonably easy to reach. Focusing on the Port of Gävle, a more comprehensive study on fuel savings at berth might be useful in relevant ships, as part of the collaboration, leading to case studies. Not only container ships, but also tankers and cargo ships, which have not been examined in this thesis. Moreover, challenges related to the *Energy terminal* need to be discussed, since this area is EX-classified because it handles large amounts of liquid bulk with fire hazards.

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APPENDIX

Table A 1. Container terminal vessel register (Jan 17' – Mar 19').

VESSEL	COMPANY	Calls (num)	AVG (h)	TOTAL (h)	%
ADELINA D	MAERSK	54	25,2	1363,1	11,6%
AKERDIJK		2	18,2	36,4	0,3%
ALANA	UNIFEEDER	5	13,3	66,3	0,6%
ALDEBARAN J		1	51,6	51,6	0,4%
AMERDIJK	MSC	16	28,9	463,0	3,9%
ANNABA	MAERSK	56	25,1	1405,5	11,9%
BALTIC		1	39,3	39,3	0,3%
BALTIC FULMAR		1	10,4	10,4	0,1%
BALTIC PETREL	UNIFEEDER	17	42,7	726,7	6,2%
BALTIC TERN	UNIFEEDER	9	50,3	452,3	3,8%
BARMBEK		5	51,5	257,7	2,2%
CONGER		1	12,8	12,8	0,1%
CONMAR GULF		2	4,1	8,1	0,1%
DELPHIS BOTHNIA		1	51,3	51,3	0,4%
EILBEK		7	47,6	333,4	2,8%
EVOLUTION		10	28,1	280,9	2,4%
FLOTTBEK		8	48,9	391,1	3,3%
GRETE SIBUM		8	13,9	111,2	0,9%
HARRISON	MSC	14	24,3	340,2	2,9%
HEINRICH EHLER	UNIFEEDER	9	40,4	364,0	3,1%
HEINRICH SCHEPERS	UNIFEEDER	2	15,1	30,1	0,3%
HELUAN	MSC	58	24,6	1426,5	12,1%
IDA RAMBOW	UNIFEEDER	4	12,2	48,7	0,4%
KATHARINA SCHEPERS	UNIFEEDER	1	6,5	6,5	0,1%
LANTAU ARROW	UNIFEEDER	1	11,6	11,6	0,1%
LINDAUNIS		1	13,9	13,9	0,1%
MARIELYST		5	13,9	69,4	0,6%
NORDIC BREMEN		1	8,0	8,0	0,1%
OLAND		1	4,9	4,9	0,0%
OOCL RAUMA	UNIFEEDER	27	40,8	1101,6	9,3%
PEGASUS		1	51,6	51,6	0,4%
PETKUM		1	6,7	6,7	0,1%
PICTOR J		1	20,0	20,0	0,2%
POLLUX		1	23,1	23,1	0,2%
SANDY RICKMERS	MSC	31	26,6	825,6	7,0%
THETIS D	UNIFEEDER	14	36,6	511,9	4,3%
VALDIVIA	MSC	2	23,2	46,4	0,4%
VERA RAMBOW	UNIFEEDER	14	45,5	637,0	5,4%
VIKING EAGLE		2	35,1	70,2	0,6%
VIOLETTA	MSC	3	13,7	41,1	0,3%
VIONA	MSC	1	24,6	24,6	0,2%
WES AMELIE		1	36,1	36,1	0,3%
X-PRESS MULHACEN		2	3,9	7,8	0,1%
TOTAL		**402**		**11788,5**	

PORT OF GÄVLE – BOARD SHIP SURVEY
PART I: COMPANY AND CONTACT INFORMATION

☐ Confidential

Company Name:			
Division Name:			
Mailing Address:			**City:**
State/Province:	**Zip Code:**		**Country:**
Contact Person:		**Title/position:**	
Phone 1:	**Phone 2:**		**Fax:**
Email Address:			

Do you consider any part of this survey to be confidential? ☐ Yes ☐ No

Type of Business: ☐ Auto Carrier/Ro-Ro ☐ Bulk Carrier/General Cargo ☐ Container Ship ☐ Motor Ship/Container
☐ Passenger ☐ Product Carrier ☐ Reefer ☐ Tanker

Print Name:	**Title:**
Signature:	**Date:**

* If submitting by e-mail, please type your name in the signature box.

PORT OF GÄVLE – BOARD SHIP SURVEY
PART II: SHIP AND ENGINE INFORMATION

(Please complete one form per vessel that visited Port of Gävle from January 2017 to March 2019) ☐ Confidential

SHIP INFORMATION

Vessel Name		**Lloyds/IMO #**		**Country Flag**		**Voltage (V)**	
Vessel Type		**Date Built**		**Ship Electrical Power (kVA)**		**Frequency (Hz)**	
Gross Tonnage (GT)		**Net Tonnage (GT)**		**Deadweight Tonnage (GT)**			(metric tons)
Average Daily Fuel Consumption at Normal Cruise Speed at Sea							(metric tons)
Average Daily Fuel Consumption from ship berthed alongside the quay (hoteling)							(metric tons)
Average Daily Fuel Costs from ship berthed alongside the quay (hoteling)							

Direct Drive Main Engine/s (Note: for diesel-electric/generator-set engines on cruise ships, etc. pleas list under "auxiliary engines" below)

Number of ME	**Engine Type:** ☐ Diesel piston ☐ Gas turbine ☐ Steam turbine		**If diesel engine, type?** ☐ 2-stroke ☐ 4-stroke		
Make			**Date Built**		
Model	**Rated Power at MCR** ☐ kW ☐ hp		**RPM at MCR**		
Fuel Used #1 ☐ Residual ☐ Distillate	______ %S		**Fuel Used #2** ☐ Residual ☐ Distillate	______ %S	
Average cruise power at sea ☐ kW ☐ hp			**Average cruise speed at sea** (Knots)		
Please describe any engine modifications completed to either improve fuel efficiency or reduce emissions (e.g., slide valves, fuel injectors):					

AUXILIARY ENGINES (and all diesel-electric engines, whether for ship propulsion or on-board power). Exclude emergency/standby engines.

	Engine #1	Engine #2	Engine #3	Engine #4	Engine #5	Engine #6
Make						
Model						
Date Built						
Rated Power at MCR	☐ kW ☐ hp	☐ kW ☐ hp	☐ kW ☐ hp	☐ kW ☐ hp	☐ kW ☐ hp	☐ kW ☐ hp
Engine Type	☐ Turbine ☐ Diesel piston ☐ 2-stroke ☐ 4-stroke	☐ Turbine ☐ Diesel piston ☐ 2-stroke ☐ 4-stroke	☐ Turbine ☐ Diesel piston ☐ 2-stroke ☐ 4-stroke	☐ Turbine ☐ Diesel piston ☐ 2-stroke ☐ 4-stroke	☐ Turbine ☐ Diesel piston ☐ 2-stroke ☐ 4-stroke	☐ Turbine ☐ Diesel piston ☐ 2-stroke ☐ 4-stroke
Fuel type used within Port of Gävle SECA	☐ MGO ___ % S ☐ MDO ___ % S	☐ MGO ___ % S ☐ MDO ___ % S	☐ MGO ___ % S ☐ MDO ___ % S	☐ MGO ___ % S ☐ MDO ___ % S	☐ MGO ___ % S ☐ MDO ___ % S	☐ MGO ___ % S ☐ MDO ___ % S

Average total ship power generated from engines #1-6 above	At sea ☐ kW ☐ hp	Manoeuvring ☐ kW ☐ hp	Ship alongside the quay (hoteling) ☐ kW ☐ hp
Time the ship is berthed alongside the quay (hoteling)	hours	Maximum power generated from engines **#1-6 above, alongside the quay (hoteling)**	☐ kW ☐ hp

Auxiliary Engine QUESTIONS

Did you make vessel modifications to comply with the Directive (EU) 2016/802? ☐ Yes ☐ No If Yes, what modifications did you make?
Date modifications completed
Cost of modifications
Where were the modifications performed?

Main Engine QUESTIONS

Would requiring low sulphur MGO use in main engines while operating out of the SECA require modification of the vessel? ☐ Yes ☐ No If Yes, please comment below.
Check boxes for modifications required and estimate cost (if unable to provide individual cost estimates, please estimate total modification cost): ☐ Fuel tank(s) ☐ Cylinder lube oil system ☐ Fuel valves ☐ Engine fuel pumps ☐ Engine fuel injectors ☐ Fuel piping and pumps ☐ Other, please explain other modifications that will be required and estimate the associated costs:
Would requiring low sulphur MGO use in main engines while operating within the SECA require modification of the vessel? ☐ Yes ☐ No If Yes, please comment below.
Check boxes for modifications required and estimate cost (if unable to provide individual cost estimates, please estimate total modification cost): ☐ Fuel tank(s) ☐ Cylinder lube oil system ☐ Fuel valves ☐ Engine fuel pumps ☐ Engine fuel injectors ☐ Fuel piping and pumps ☐ Other, please explain other modifications that will be required and estimate the associated costs:

Vessels that Transport Refrigerated Containers

What power is required during loading and unloading of refrigerated containers?	kW	What power is required while the ship is berthed alongside the quay (hoteling)?	kW
Time required for <u>loading</u> refrigerated containers	hours	Time required for <u>unloading</u> refrigerated containers	hours
Please comment on any seasonal impacts on refrigerated container volume in the comments section.			

EXHAUST EMISSION FACTORS for electricity production

Average total exhaust emissions [g/kWh]	CO_2	NO_x	SO_2	VOC	PM
At sea					
Manoeuvring					
Ship alongside the quay (hoteling)					

* Please specify whether the information is expressed in other stated unit of measurement.

Other general questions

Has the company conducted any study on implementing a shore-side power supply system?
Is it possible/feasible to carry out any retrofit on board of existing vessels?
Is the company willing/reluctant to change to a shore-side power supply?
Hazardous areas (“HazLocs”): Which safety issues concern you most with regard to a shore-side power supply?

Comments (please use extra sheets if necessary):

Table A 2. Ship information (I).

Name	Length (m)	IMO	Country Flag	Vessel type	Date Built	Ship Electrical Power (kVA)	Voltage (V)	Frequency (Hz)
OOCL RAUMA	168	9462794	NETHERLANDS	Container ship	2009	2500	440	60
ESSENCE	168	9491496	NETHERLANDS	Container ship	2011	6000	440	60
BALTIC PETREL	169	9313216	CYPRUS	Container ship	2005	3625	400	50
TERNSUND	147	9722390	DENMARK	Tanker	2016	3989	440	60
VERA RAMBOW	168	9432220	GERMANY	Container ship	2008	6700	440	60

Table A 3. Ship information (II).

Name	Gross Tonnage (GT)	Net Tonnage (NT)	Deadweight Tonnage (DT)	AVG/d FC Cruise Speed Diesel (kg/h)	AVG/d FC alongside (kg/h)
OOCL RAUMA	17488	8125	17861	1125	150
ESSENCE	17368	7822	21232	1600	116,7
BALTIC PETREL	16324	6450	15952	1166,7	152,1
TERNSUND	11374	4780	15000	9800 LNG (11,7knot)	116,7
VERA RAMBOW	17488	8125	17861	1529,167	110,4

Table A 4. Main Engines (I).

Name	Number of ME	Engine type	Date Built	Make	Model	Rated power at MCR (kW)	RPM at MCR
OOCL RAUMA	1	Diesel piston 4-S	2009	MAN B&W	8L58x64	11200	430
ESSENCE	1	Diesel piston 2-S	2010	WÄRTSILÄ	6RT FLEX 60	14520	-
BALTIC PETREL	1	Diesel piston 2-S	2004	MAN B&W	8S50MC-C	12640	-
TERNSUND	1	Diesel piston 2-S	2015	YCMP-WÄRSTSILÄ	RT-flex 50DF	5850	102
VERA RAMBOW	1	Diesel piston 4-S	2008	MAN B&W	8L58x64	11200	427

Table A 5. Main Engines (II).

Name	Fuel type #1	% S	Fuel type #2	% S	Average power at sea (kW)	Average Cruise Speed (knots)
OOCL RAUMA	Residual	0,100%			9500	17,0
ESSENCE	Residual	0,096%	Distillate	0,030%	10164	-
BALTIC PETREL	Distillate	0,090%			6500	15,5
TERNSUND	LNG	-	Distillate	0,020%	2600	11,7
VERA RAMBOW	Residual	0,100%			7800	15,8

Table A 6. Auxiliary Engines (I)

Name	Number of AE	Engine type	Date Built	Make	Model	Rated power at MCR (kWe)	Fuel type	% S
OOCL RAUMA	3	Diesel piston 4-S	2009	CATERPILLAR	3508B	900	MGO	0,100%
ESSENCE	4	Diesel piston 4-S	2009	WÄRTSILÄ	A8L20	1200	MGO	0,030%
BALTIC PETREL	3	Diesel piston 4-S	2004	CUMMINS	KTA 38 M	880	MGO	0,080%
TERNSUND	3	Diesel piston 4-S	2015	MITSUBISHI	S12A2-MPTAW-4	790	MGO	0,020%
VERA RAMBOW	3	Diesel piston 4-S	2009	CATERPILLAR	3508B	968	MGO	0,010%

Table A 7. Auxiliary Engines (II)

Name	Average power at sea (kWe)	Average power manoeuvring (kWe)	Average power alongside (kWe)	Peak power alongside (kWe)	Time ship alongside (h)
OOCL RAUMA	0	150 to 700	300	750	30 to 36
ESSENCE	480	1500	300	800	8 to 30
BALTIC PETREL	0	480 to 560	410	850	2 to 40
TERNSUND	450	600	350	700	24
VERA RAMBOW	0	220 to 250	225	700	30 to 50

Table A 8. Emergency Engines.

Name	Number of EE	Engine type	Date Built	Make	Model	Rated power at MCR (kWe)	Fuel type	% S
OOCL RAUMA	1	Diesel piston 4S	2009	MAN B&W	D2866TE	156	Distillate	0,100%
ESSENCE								
BALTIC PETREL	1	Diesel piston 4S	2004	CUMMINS	VTA 28 DM	500	Distillate	0,080%
TERNSUND								
VERA RAMBOW								

Table A 9. Emission factors or emission amount.

	At sea			Manoeuvring			Alongside the quay (hoteling)		
Name	CO_2 (g/kWh)	NOx (g/kWh)	SO_2 (g/kWh)	CO_2 (g/kWh)	NOx (g/kWh)	SO_2 (g/kWh)	CO_2 (g/kWh)	NOx (g/kWh)	SO_2 (g/kWh)
OOCL RAUMA									
ESSENCE		10,12			11,21			9,26	
BALTIC PETREL	572,1	16,18	0,142	606,8	15,05	0,151	-	7,9	-
TERNSUND	450	1,79	0	670	3,76	4,18	700	1,96	4,36
VERA RAMBOW		11,8		274,8 kg/h	7,03		274,8 kg/h	7,03	