Report.

Connecting vessels to shoreside electricity in Sweden

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Svensk sammanfattning

Syftet med projektet ”Kaj-El” var att utveckla beslutsstöd vid implementering och användning av landström när fartyg ligger vid kaj. Målgruppen för resultaten är svenska hamnar och rederier. För att uppnå syftet har bland annat följande områden undersökts:

- Drivkrafter för att erbjuda eller använda landström bland hamnar och rederier
- Processen att erbjuda eller använda landström, såsom vilka beslut och steg som behöver tas, samt vilka aktörer som är inblandade
- Affärsmodeller vid installation och drift av landströmsanslutningar
- Utmaningar vid installation och drift av landström
- Tekniska lösningar för landström som används i svenska hamnar och ombord på fartyg
- Förutsättningar och åtgärder för att erbjuda och använda landström bland hamnar och rederier i större utsträckning än idag

I projektgruppen ingick forskare och experter inom sjöfart, transport, logistik, ekonomi och human factors från SSPA och Göteborgs universitet samt Svensk Sjöfart och Sveriges Hamnar. Industrin var även representerade i en referensgrupp med deltagare från rederier, hamnar och elbolag. Intervjuer genomfördes med hamnar i Sverige, en hamn i Norge (Kristiansand) och två hamnar i USA (Long Beach och Seattle) för att kunna jämföra perspektiv och erfarenheter, samt med rederier, teknikleverantörer, nationella nätoperatörer och elleverantörer. Dessutom genomfördes två workshops och ett avslutande resultatseminarium.

Denna rapport ger en översikt över situationen i Sverige när det gäller erbjudandet och fartygs användning av landström i hamnar. Principer för affärsmodeller har identifierats samt rekommendationer för hamnar och rederier vid implementering och nyttjande av landström när fartyg ligger vid kaj. Det kan noteras att Sverige ligger i europeisk framkant genom att nio svenska hamnar erbjuder landström, med fokus på ro-pax och färjesegmenten. Aktörer, i synnerhet hamnar, upplever dock att trycket från regelverk ökar för att erbjuda landström i större utsträckning och kunskapen bland icke erfarna hamnar är låg. Ytterligare vägledning om landström-installationer behövs, där det finns ekonomiska, affärsmässiga, tekniska och driftsrelaterade frågor att hantera. En viktig fråga är hur man säkrar elförsörjningen i hamnarna. Samarbete mellan aktörer är nyckeln till framgångsrik implementering av landström och en högre standardiseringsnivå för att underlätta tekniska val kan spela en viktig roll. Flera områden i behov av ytterligare forskning lyfts fram, som att undersöka möjliga scenarier för effektbehov från användning av landström och försörjningsstrategier för hamnar.

Projektet har fått finansiering av Trafikverkets sjöfartsportfölj.

Summary in English

The purpose of the KAJ-EL project was to offer decision support to ports and shipping companies about the implementation and use of shoreside electricity in Swedish ports. More specifically, this project investigated the following, among other questions related to shore power:

- the driving forces and barriers among ports and shipping companies to offer or use shore power;
- the decision making, steps and actors involved in the process of adopting shore power;
- the costs and business arrangements for installing and operating shore power;
- the challenges in the installation and operation of shore power;
- the different shore power equipment used in Swedish ports and on board vessels;
- the actions and condition to realise OPS adoption to a larger extent.

The project group included researchers and experts in shipping, transport, logistics, economics, and human factors from SSPA and the University of Gothenburg, and included industry partners Svensk Sjöfart (Swedish Ship Owners' Association) and Sveriges Hamnar (Ports of Sweden). In addition, industry and authorities were involved in a reference group with representatives from shipping companies, ports and electricity providers. Interviews were performed with various ports in Sweden, a port in Norway (Kristiansand) as well as the US ports of Long Beach and Seattle to compare the perspectives. Shipping companies were interviewed, as were a number of OPS equipment manufacturers, national grid operators and electricity providers. Two workshops and a final seminar were also conducted.

This report presents an overview of the OPS situation in Sweden and provides principles for business models as well as recommendations for ports' and shipping companies' OPS work. It can be noted that Sweden is at the European forefront of OPS in the sense that it currently has nine cities offering OPS, with main focus so far on the ro-pax and ferry segment. Actors, in particular ports, perceive that the regulatory pressure to offer OPS is increasing and the knowledge about OPS, especially among non-experienced ports, is still limited. Further guidance on OPS installations and operations is therefore needed, in terms of the financial, business, technical and operational issues that the actors must deal with. One major question is how to secure the electricity supply to the ports. Collaboration between actors is key to successful OPS implementation and a higher level of standardisation can facilitate technical choices. Several areas in need of further research are highlighted in this report, such as investigating possible future power demand scenarios from using OPS, and supply strategies for ports.

The project received funding from Trafikverket (The Swedish Transport Administration).

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List of Acronyms and Units

A	Ampere
AC	Alternating current
AMP	Alternative maritime power
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CSI	Clean Shipping Index
DC	Direct current
ECA	Emission control area
EEDI	Energy Efficiency Design Index
EMSA	European Maritime Safety Agency
ESI	Environmental Ship Index
EU	European Union
GHG	Greenhouse gas
HFO	Heavy fuel oil
HV	High voltage
HVSC	High-voltage shore connection
Hz	Hertz
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kV	Kilovolt
kVA	Kilovolt ampere
kWh	Kilowatt-hour
LNG	Liquified natural gas
LV	Low voltage
MARPOL	International Convention for the Prevention of Pollution from Ships
MD	Marine distillate
MDO	Marine diesel oil
MGO	Marine gas oil
MVA	Megavolt ampere
MW	Megawatt
MWh	Megawatt-hour
N2O	Nitrous oxide
NOx	Nitrogen oxide
O_3	Ozone
OPS	Onshore power supply
PAH	Polycyclic aromatic hydrocarbon
PM	Particulate matter
PM_{10}	Particles less than 10µm (micrometre)
RES	Renewable energy sources
RO	Residual oil
ROI	Return on investment
Ro-pax	Roll-on roll-off passenger vessel
Ro-ro	Roll-on roll-off vessel

SECA	Sulphur emission control area
SEEMP	Ship energy efficiency management plan
SO_2	Sulphur dioxide
SOx	Sulphur oxide
TWh	Terawatt-hour
UNCTAD	United Nations Conference on Trade and Development
V	Volt
VOC	Volatile organic compound
W	Watt
WPCI	World Ports Climate Initiative

1 Introduction

The maritime sector is under pressure to find solutions that alleviate its environmental footprint, due to its contribution to global greenhouse gas (GHG) emissions (Zis, 2019). Shoreside electricity has been identified by both the European Union (EU) and Swedish authorities as one important component in achieving a fossil-free maritime sector. By using shoreside electricity, the sea transport sector may both reduce emissions while in port and utilise renewable sources of electricity. Thus, depending on the source of electricity used, both the local and global environmental impact of vessels at berth can be reduced. The degree of electrification in ports is increasing, but only a minority of vessels currently makes use of shoreside electricity in Swedish ports. For reasons that will be described in detail in this report, the use of shoreside electricity by vessels in port is an important topic for shipping companies and ports, as well as for technology providers, grid operators and electricity providers, the institutions that establish the technical standards for this sort of solution, and the policy makers that establish environmental policies.

The purpose of the KAJ-EL project was to offer decision support to ports and shipping companies about the implementation and use of shoreside electricity in Swedish ports. This is done by identifying the driving forces and barriers, actions and conditions to realise viable business arrangements in shoreside power. The work included a large number of interviews, three workshops, and the development of decision support and principles for business models. More specifically, this project investigated the following, among other related questions:

- The motivations to offer or use shore power;
- The decision making, conditions, steps and actors involved in the process of adopting shore power capability;
- The costs and business arrangements for installing and operating shore power connections;
- The challenges to the installation and operation of shore power;
- The different shore power equipment used in Swedish ports and on board vessels; and
- The benefits of and barriers to further expansion of the solution.

The project group included researchers and experts in shipping, transport, business, economics, and human factors from SSPA and the University of Gothenburg and industry partners Svensk Sjöfart (Swedish Ship Owners' Association) and Sveriges Hamnar (Ports of Sweden). In addition, representatives from shipping companies, ports, and electricity companies were involved in a reference group. The project took its starting point in industry needs and involved key actors to explore the problem from both theoretical and practical perspectives. The project built upon international research on shoreside electricity. The results therefore contribute to research and have a large potential for immediate use in the industry.

The purpose of the present report was to assemble knowledge from existing academic literature and recent public reports on the topic of shore power, and describe the results of the interviews and workshops to bring together a set of examples, recommendations and decision support for actors involved in shore power.

1.1 Reading instructions

In this report, the ‘Background’ chapter provides a context and definition to OPS based on published academic literature and recent public reports. The ‘Methods’ chapter describes the methods used in the KAJ-EL project to gather empirical data from various relevant actors involved in OPS in Sweden and abroad. Thereafter, the findings from the collected data are presented in chapters 4-7, with each section representing a different aspect of OPS, for example technical aspects or business models. In chapter , the recommendations to ports and shipping companies are summarised. Relevant information from the published literature can also be found in sections 4-8, complementing the primary data gathered in this project. Finally, the ‘Conclusions’ chapter offers an overview of the main takeaways from this report and research project, including suggestions for further research.

2 Background to Onshore Power Supply

OPS refers to vessels connecting to shoreside electrical power while in port to minimise or eliminate the use of fuel for the internal combustion engines (ICEs) (auxiliary engines) commonly used to produce onboard electricity to maintain basic onboard functions while at berth (Bellone, Lundh, Wahde, & MacKinnon, 2019; Kumar, Kumpulainen, & Kauhaniemi, 2019). OPS can also be referred to as cold ironing, shore-to-ship power, shore-to-ship electrification, shore-to-ship connection, ship-to-shore connection, shoreside power supply, shore connection, shore power, alternative maritime power (AMP), etc. (Kumar et al., 2019). The electricity is typically provided by a power infrastructure mounted within port grounds; hence, the port must have this infrastructure installed or fitted and available, and the vessel must be fitted or equipped with the necessary power socket or cable and plug. There are different technologies and ways to mount the required equipment in port and on board (see section 5.2, p.36). OPS can also be transferred to hybrid and electric vessels and transformed to recharge their batteries (Bellone et al., 2019; Kumar et al., 2019; Letafat et al., 2020).

2.1 Benefits of OPS

Utilising OPS should allow for a reduction or even the elimination of local emissions from running ships' auxiliary engines while in port (Kumar et al., 2019; Prousalidis, Antonopoulos, Patsios, Greig, & Bucknall, 2014; Zis, North, Angeloudis, Ochieng, & Harrison Bell, 2014). Research by Jivén (2004) reported that turning off auxiliary engines while at berth resulted in onboard staff being exposed to less noise and fewer emissions on deck, the engine room environment being quieter during port calls, stevedores being exposed to fewer emissions from the ship (Jivén, 2004), and a reduced need for maintenance of such engines (Zanetti, 2013) (see Table 1 for a summary of the benefits). Zis et al. (2014) found that the use of OPS by container vessels at berth could lead to reductions of in-port emissions of 48–70%, 3–60%, 40–60% and 57–70% for carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NOx) and black carbon (BC), respectively, with increased benefits seen for non-sulphur emission control area (SECA) ports with long vessel berth durations and a larger proportion of larger ships (see also Yu, Voß, and Tang (2019)). A report by Jonge, Hugi, and Cooper (2005) made for the Directorate General Environment of the European Commission showed that the estimated mid-range values of emission reduction efficiencies per vessel connecting to shore power compared to using 2.7% sulphur residual oil (RO) were 97% NOx, 96% SO_2 and particulate matter (PM), and 94% volatile organic compounds (VOCs), and compared to using 0.1% sulphur marine distillate (MD) the values were 97% NOx, 94% VOCs, 89% PM and 0% SO_2 (for the reduction of SO_2, shore power and 0.1% sulphur MD are equivalent measures) (see also Kotrikla, Lilas, and Nikitakos (2017)). Shoreside electricity is beneficial in the simultaneous reduction of all air pollutants emitted by shipping at ports. The findings of Winkel, Weddige, Johnsen, Hoen, and Papaefthimiou (2016) indicate that the total anticipated health benefits of using shoreside electricity in EU ports were estimated at €2.94 billion for 2020, while the potential for reduction of carbon emissions reached 800,000 tonne of CO_2. Yet, power provision in ports varies regionally and internationally, and the effectiveness of OPS globally is governed by this variation (Sciberras, Zahawi, & Atkinson, 2015; Zis et al., 2014). The policies of a country and the potential for renewable energy sources (RES) determine the amount of savings made by using OPS, both now and in the future, since the energy source mix will change over time. The unique characteristics of each port play a decisive role in the efficiency of each policy. In addition, the distribution of ship sizes is important, with larger vessels offering greater potential for emissions reduction (Yu et al., 2019; Zis et al., 2014). Time spent at berth is also important and varies depending on ship type, cargo and port efficiency (Khersonsky, Islam, & Peterson, 2007). With the increased adoption of methods such as speed reduction and provision of OPS while at berth, it is essential that ports are able to make informed management decisions using representative vessel activity information to assess the costs and benefits of alternative policies (Zis et al., 2014). An inventory of the emissions and a cost-benefit analysis should be performed as a basis for further measures and the effective reduction of ships' emissions at berth (López-Aparicio, Tønnesen, Thanh, & Neilson, 2017).

Table 1. List of benefits of OPS.

Benefits of OPS
Reduction or even elimination of emissions
- Less exposure to emissions for both staff on board and stevedores
Quieter engine room environment during port calls
- Less exposure to noise for staff on board
Reduced need for maintenance of the auxiliary engines

Emissions related to the use of OPS depend on the energy mix used by the port (Sciberras et al., 2015; Zis et al., 2014). Consequently, in order to assess the real potential benefits of providing OPS, it is necessary to calculate the resulting emissions of the use of auxiliary engines (Khersonsky et al., 2007) and type of fuel burned from the ships as reference values (Winkel et al., 2016), then compare these with OPS on both the local and global levels (Khersonsky et al., 2007) and the energy mix used for the electricity generation on shore (Winkel et al., 2016). As Sciberras et al. (2015) observe, 'reducing airborne pollution must not come at the expense of increased electrical pollution' (p.43). In some cases, shore power would generate more pollutants on a global level, especially when applied in countries with a poor-quality energy mixture; moreover, the potential additional exposure of the population near power stations must also be weighed in (Zis et al., 2014). EU Directive 2018/2001/EC (The European Parliament and the Council of the European Union, 2018) urges Member States to increase their use of clean energy sources in their energy mixture (see also Zis et al. (2014)). Electricity provision in Sweden is principally based on clean energy sources, providing an opportunity for emissions reductions on a larger than the purely local scale (Zis et al., 2014).

Installing a harbour grid for OPS might not only offer the advantages of fuel consumption reduction, cost reduction and environmental benefits, but, as the appearance of hybrid and electric vessels is expected to become ever more frequent (Kumar et al., 2019), it might also become a good strategic driver for harbour grid investments. OPS can also progress in the future to involve more automation, along with distributed energy generation and battery energy storage systems for peak shaving (Kumar et al., 2019). Energy management of such combined systems could help to reduce the electricity costs of a ship (Tang, Wu, & Li, 2018).

2.2 OPS history and usage

Provision of electrical power to ships at berth is a fully developed concept that has been known and used by military vessels for many years (Zis et al., 2014), as well as archipelago ferries, coastguard vessels, pilot boats, tugboats and ice breakers have been connecting to low-voltage (LV) power in some ports for a couple of decades. High-voltage (HV) connections and related international standards, however, are relatively recent. Moreover, their diffusion to ports and retrofitted ships has been low (Zis, 2019) over the past decade, including in Sweden (Lighthouse, 2018; SVT Nyheter, 2015), since, to date, few ports and vessels (and few segments) have OPS capability or have been interested in connecting to port electricity. Globally, OPS is typically only used commercially, for example by cruise ships, where regulatory mechanisms specifically require companies to use this technology (Ballini, 2013). In recent years, however, shoreside electricity has been gaining exponential traction, mainly due to environmental regulations and trends. As part of the World Ports Climate Initiative (WPCI) project, port authorities planned that all new quays would have the infrastructure necessary to provide OPS already in place (Dutt, 2009).

According to a recent report by the European Maritime Safety Agency and European Environment Agency (2021), 8.8% of the world's container ships, 8.9% of cruise ships and 1.1% of roll-on roll-off passenger vessel (ro-pax) ships are currently equipped with HV OPS. In the EU, 9.6% of container ships, 15.1% of cruise ships and 10.1% of ro-pax ships are equipped with HV OPS. The same report states that at least 31 ports in EU Member States have implemented HV OPS to date (e.g., Finland, Denmark, Germany, France, Spain, and Italy), with at least 36 available shore connection facilities.

2.2.1 OPS in Sweden

Sweden currently has the most ports with HV OPS and the highest number of OPS facilities of all the countries within the European economic area (European Maritime Safety Agency & European Environment Agency, 2021), namely in Stockholm, Gothenburg, Karlskrona, Trelleborg, Ystad, Piteå, Helsingborg and Visby (Transportstyrelsen, 2021). Luleå offers LV OPS, as do the Ports of Stockholm, Gothenburg, Visby, and Helsingborg (see Table 2 below, which lists all existing LV and HV OPS stations in Swedish ports).

Table 2. Existing OPS in Swedish ports (working reference by Transportstyrelsen (2021)).

Port	Terminal	Voltage	Frequency (Hz)	Vessel type
Gothenburg	Älvsborg quay 700 and 712	6.6 kV	50 Hz	Ro-ro
	Stena berth 21	11 kV	60 Hz	Ro-pax
	Stena berths 11-12-13	11 kV	50 Hz	Ro-pax
	Stena	400 V	60 Hz	High speed boats
	Stigbergskajen	400 V	50 Hz	Yachts
Helsingborg	ForSea-lines Berth 208	400 V	50 Hz	Ro-pax 2 connection points for ferries
	ForSea-lines Berth 301	400 V	50 Hz	Ro-pax 2 connection points for ferries
	ForSea-lines Berth 302	400 V	50 Hz	Ro-pax 2 connection points for ferries
	ForSea-lines Berth 301	10 kV	50 Hz	Connections for ferries
	ForSea-lines Berth 302	10 kV	50 Hz	Connections for ferries
	Quay 700	400 V/200 A	50 Hz	Ro-pax 4 connection points for ferries
	Helsingør quay 119	400 V/125 A	50 Hz	4 connection points for yachts
Karlskrona	Stena, Verkö	11 kV	50 Hz	Ro-pax
Luleå	Svartekajen	400 V	50 Hz	Icebreakers
Piteå	Port hub	6 kV	50 Hz	Ro-ro (Ships must carry their own cable. Working current is also available for 400 V/125 A/50 Hz)
Stockholm	Masthamnen	690 V	50 Hz	Ro-pax
	Masthamnen	690 V	50 Hz	Ro-pax
	Skeppsbron	400 V	50 Hz	Archipelago ferries
	Ström-/Nybrokajer	400 V	50 Hz	Archipelago ferries
	Skeppsbron	400 V	50 Hz	Pax
	Innerstadskajer	400 V	50 Hz	Yachts, military vessels
	Värtahamnen	11 kV	50 Hz	Ferries
	Värtahamnen berth 3	11 kV	50 Hz	Ferries
	Värtahamnen berth 4	11 kV	50 Hz	Ferries
	Värtahamnen berth 1**	11 kV	50 Hz	Ferries will be brought into use in the near future (2023)
	Värtahamnen berth 2**	11 kV	50 Hz	Ferries will be brought into use in the near future (2022)
	Norvik	11 kV	50 Hz	Connections ready for container ships
	Norvik	11 kV	50 Hz	Connections ready for container ships
	Norvik	11 kV	50 Hz	Ro-ro
	Kapellskär	11 kV	50 Hz	Ro-ro
	Värtan Fortum quay 504	6,6 kV	50/60 Hz	Bulk carriers
	Nynäshamn	6,6 kV	60 Hz	Ro-pax
Trelleborg	Berths 2* and 3*	11 kV	50 Hz	Ro-pax
	Berths 4* and 5*	11 kV	50 Hz	Ro-pax
	Berths 8* and 9	11 kV	50 Hz	Ro-pax, railway
Ystad	Berths 1, 3, 4, 6	11 kV	50/60 Hz	Ro-pax
	Berth 7	11 kV	50/60 Hz	Ro-pax
	Berth 8	11 kV	50/60 Hz	Ro-pax
Visby	Skeppsbron Holmen, N:a the breakwater	400 V	50 Hz	Ferries, cargo ships, military vessels
	Ferry berths 5, 6 and 7	11 kV	50/60 Hz	Ro-pax ferries

** Trelleborg only has a crane and sockets in position 9; other cranes and sockets are not available.*

Swedish port authorities are required to hold an environmental permit from Länsstyrelsen (County Administrative Board) in order to run their activities. In these permits, the Environmental Court states that OPS is a mandatory consideration when port updates and extensions are undertaken, as a means of reducing local air emissions from vessels at berth to improve air quality for nearby residents (Zanetti, 2013).

Several individual shipping companies and ports have invested heavily in technology for electricity connection at the quay (see e.g., Göteborgs Hamn (2019); Sjöfartstidningen (2019b); Stena Line (2017); Stockholms Hamnar (2021)). This trend is especially evident in the active participation of several major players in ongoing initiatives and collaborations, for example within the Baltic Ports Organization and the World's Ports Action Program. Initiatives have also received funding from "Klimatklivet", which is a governmental support program for climate investments managed by Naturvårdsverket, the Swedish Environmental Protection Agency (Sjöfartstidningen, 2019a). Yet, investments and knowledge of what is required to enable electricity connection at the quay are still concentrated in specific segments, among a few large players and within certain regions. The majority of electricity-connected vessels are visible in the ferry segment in scheduled traffic. Other segments have low distribution; for example, no electricity-connected container vessels are visible in the container terminals in Gothenburg or Stockholm. On the other hand, there are Swedish tanker companies now pioneering HV OPS for tankers (e.g., Terntank, Donsötank), and the cruise ship segment has started buying into this technological solution as well.

Examples of Swedish OPS installations

Stena Line and the Port of Gothenburg have used LV connections for the German ro-pax ferry lines Stena Germanica and Scandinavica since 1989 (e.g., Zanetti (2013)). Since that date, more vessels have been retrofitted or built with shore electricity capability, and more connection points have been built. As an example, in the year 2000, an HV shoreside connection was implemented at the request of and in collaboration with Stora Enso, making the Port of Gothenburg the first port worldwide to offer shoreside electricity to cargo vessels (Dutt, 2009; Zanetti, 2013).

Examples of international of OPS installations

In Oslo, Norway, infrastructure for ferries and cruise ships is currently awaiting funding for investment in shore power for container vessels (Oslo Havn, 2021).

The Port of Rotterdam, in the Netherlands, where OPS has been mandatory for inland shipping for over a decade (Port of Rotterdam, 2019), is in ongoing negotiations for shore power for tankers where Swedish Donsötank vessels plan to connect. OPS has also been successful in Juneau, Alaska and California (Arduino, Murillo, & Ferrari, 2011; Khersonsky et al., 2007).

In 2002, the City of Los Angeles signed a memorandum of understanding (MOU) with six shipping lines to collaborate in the port's development of OPS (Khersonsky et al., 2007). The use of OPS became compulsory for ship operators in Californian ports and, as a consequence, terminals and ship owners have had to buy into this technology, further increasing uptake and utilisation (Innes & Monios, 2018; Zis, 2019).

In the Port of Oakland (San Francisco), an increase from 68% to 75% in the share of electricity connections was reported in 2018 (Safety4Sea, 2019) (see, e.g.. WPSP (n.d) for other shore power examples around the world).

2.3 Emissions from vessels

The interest in OPS from a regulatory perspective stems from the fact that while maritime transport is expected to grow, its use of fossil fuels can be harmful to the environment as well as human health. Indeed, maritime transport is the medium for over 90% of global trade (International Chamber of Shipping, 2020; Kollamthodi et al., 2013; Kumar et al., 2019) and is considered the most fuel-efficient mode of transport (Zis, 2019). The demand for shipping is expected to continue to grow (Kumar et al., 2019; UNCTAD, 2020; Viana et al., 2014; Winkel et al., 2016) at an average annual growth rate of 3.5% over the 2019–2024 period, driven in particular by growth in containerised, dry bulk and gas cargoes (UNCTAD, 2020). It should triple from 2008 to 2025 (Kumar et al., 2019). Yet, ships today run mostly on fossil fuels, whose impact includes GHG emissions from CO_2, NOx, other air pollutants such as sulphur oxides (SOx), PM, VOCs, ozone (O_3) coming mostly from the main engines, auxiliary engines and boilers, and the noise of ships at berth using their auxiliary engines (Kumar et al., 2019; Winkel et al., 2016). Air pollutants are harmful for the environment and for human health (Kumar et al., 2019). The air pollutants from heavy fuel oil (HFO, 1% sulphur) and marine diesel oil (MDO, 0.1% sulphur) have even been tested for impact in the indoor environment on board, and it was shown that VOCs, polycyclic aromatic hydrocarbons (PAHs), nanoparticles, NOx and, in the case of HFO, SO_2 could spread to the engine control room as well as the accommodation area through the ventilation system during operation, affecting the indoor environment on board for seafarers, even if at low levels (Langer, Österman, Strandberg, Moldanová, & Fridén, 2020).

The third IMO GHG study, from 2015, estimated that in the period 2007–2012, on average, shipping as a whole accounted for approximately 3.1% of annual global CO_2 emissions (1,015 million tonnes) and approximately 2.8% of annual GHG emissions combining CO_2, methane (CH_4) and nitrous oxide (N_2O), expressed as carbon dioxide equivalent (CO_2e) (approx. 1,036 million tonnes CO_2e). There was an average annual total of 20.9 million of NOx (as NO_2) emissions from shipping as a whole during the same period, representing about 15% of global NOx emissions from anthropogenic causes, and 11.3 million tonnes of SOx (as SO_2), representing around 13% of global anthropogenic SOx emissions (IMO, 2015) (see also Winkel et al. (2016)). The fourth IMO GHG study, from 2020, stated that general shipping emissions in 2018 represented 2.89% of global anthropogenic emissions, compared to 2.76% in 2012 (IMO, 2020b). According to the 2020 shipping review report by the United Nations Conference on Trade and Development (UNCTAD), ships continue to generate around 3% of the world's total GHG emissions, such as CO_2 (UNCTAD, 2020) (see also Kollamthodi et al. (2013); Winkel et al. (2016)).

As port emissions occur closer to communities, they have been seen as a growing cause for concern, making initiatives such as OPS increasingly important. Possible sources of emissions in ports include seagoing vessels, domestic vessels (fireboats, pilot boats, police boats, push-boats, tugboats), cargo-handling equipment, heavy- and light-duty vehicles, locomotives, electrical grids, power plants, industrial and manufacturing facilities, administrative offices and logistics infrastructure or warehouses (Safety4Sea, 2019). López-Aparicio et al. (2017) revealed, in an emissions inventory study for the Port of Oslo, that oceangoing vessels were the main contributors of air pollutants in port, causing 63–78% of the total NOx, PM_{10}, SO_2 and CO_2e emissions, and that 70% of all shipping emissions occurred within 400 km of land, with the highest volume emitted during vessels' time at berth, followed by that emitted during the period of vessel manoeuvres.

Vessels at berth typically need to have their auxiliary engines running (on fossil fuels) in order to produce electrical power to maintain the basic functions of the vessel, such as lighting, ventilation, heating, onboard systems and communications (Winkel et al., 2016). A study by Kotrikla et al. (2017) estimating ship emissions at the Port of Mytilene, Greece, from all ships during the study period, when manoeuvring and when at berth, showed that the latter was responsible for 77% (216.2 metric tonnes) of the total CO_2 and 63% (277 kg) of the total PM_{10} emissions.

2.4 Regulations influencing the use of OPS

Globally, air pollution from shipping is regulated by the IMO through the International Convention for the Prevention of Pollution from Ships (MARPOL), adopted in 1973. Annex VI of MARPOL entered into force in 2005, aiming, among other things, to minimise airborne emissions from ships. Several amendments have since been made to MARPOL, including:

- Lowering the limit of sulphur content to up to 0.1% in marine fuels used by ships in emission control areas (ECAs) and EU inland waterways and at berth for more than two hours in EU ports (EMSA, 2020; European Commission, 2018; The European Parliament and the Council of the European Union, 2016; UNCTAD, 2020) (see also Kumar et al. (2019); Zis (2019); Zis et al. (2014)) and to up to 0.5% outside ECAs (European Commission, 2018; IMO, 2020c; UNCTAD, 2020);
- The Ship Energy Efficiency Management Plan (SEEMP) is a mandatory measure requiring all vessels to monitor emissions over time via monitoring tools based on a ship and fleet efficiency performance approach for shipping companies; and the

Energy Efficiency Design Index (EEDI) which requires that all new vessels have a minimum energy efficiency reference level per capacity mile (IMO, 2020a) (see also Newman (2020));
- Prohibiting the carriage of non-compliant fuel oil for combustion for propulsion or operation purposes on board ships unless they have an exhaust gas cleaning system (scrubber) on board (IMO, 2020c).

The IMO's strategy is to have a 50% reduction of the total annual GHG emissions from shipping by 2050, relative to 2008 levels (UNCTAD, 2020), consistent with the targets set by the 2015 Paris Agreement which aim at maintaining global warming below 1.5°C (UNCTAD, 2020). Having said that, ways to reduce shipping emissions, including those occurring close to communities, are important to consider and can include:

- The adoption of emission abatement technologies, such as shore power used by vessels while at berth to replace the use of the auxiliary engines, as encouraged by the European Commission (European Commission, 2018)
- The use of cleaner fuels, such as marine gas oil (MGO), and/or the use of scrubber systems on board to remove SOx and PM emissions, thus allowing the use of HFO (Christodoulou, Gonzalez-Aregall, Linde, Vierth, & Cullinane, 2019; Kumar et al., 2019; Zis, 2019);
- Efficient hull and propeller design, route optimisation and wind energy as a means of propulsion (Newman, 2020; Zis et al., 2014);
- The establishment of reduced speed zones in ports (UNCTAD, 2020; Winkel et al., 2016).

Directive 2014/94/EU mandates that Member States must assess the need for OPS for seagoing and inland waterway vessels as part of each national policy and that TEN-T Core Network ports shall have OPS installed by December 31st 2025, with the exception of those ports that do not identify a demand or environmental benefits that justify the costs (The European Parliament & The Council of the European Union, 2014) (see also Zis (2019)). The list of TEN-T maritime ports can be found in the report 'Ports: Gateways for the Trans European Transport Network 2030' by the European Commission (2013). More recently, in July 2021, the European Commission announced the 'Fit for 55' package of proposals, expected to be under negotiation into 2022, a programme which will impose strict regulations on EU's transport sector, aiming at the reduction of the EU's GHG emissions by 55% by 2030, compared with 1990 levels, and full EU decarbonisation by 2050 (DNV, 2021; UK P&I, 2021). For carbon neutrality by 2050, a 90% emissions reduction on all transport is required. Proposals that affect shipping include:

a) a revision of the EU's Emission Trading System, to come into effect in 2023;
b) a tax exemption applied to alternative fuels for a period of ten years and removed for common fuels between EU ports as of 2023;

c) a FuelEU Maritime regulation, to be implemented in 2025, focused on the production and use of low-carbon fuels or, for example, wind power on board;
d) an increase of liquified natural gas (LNG) availability at EU Member States by 2025 (DNV, 2021).

These proposals specify OPS as a mandatory measure for core EU ports and for passenger ships and container ships that stay at berth for a minimum of two hours by 2030 (DNV, 2021), unless they choose to use another sustainable technology (UK P&I, 2021).

Generally, addressing environmental regulations requires ship owners and ports to pay to acquire abatement technology and/or increase their operating costs by using cleaner but pricier fuel. Which option is most cost-effective for the ship owner might depend on various factors, including ship type, ship size, regulations affecting the waters in which the ship sails and the ports of call.

3 Methods

The project used a qualitative research approach. As part of the research, a systematic review of the available literature was performed, followed by extensive data collection, primarily through interviews (36), three workshops, and attendance at five available webinars on the topic of OPS (see Appendix, p.73, for a full list of the data collection events). Interviews and a workshop were performed with various maritime ports in Sweden, as well as with a port in Norway and with American organisations regarding the use of OPS in the Ports of Long Beach and Seattle in the US. Shipping companies and maritime transport managers were interviewed, as were a number of OPS equipment suppliers and national grid operators and electricity providers. Regarding the second and third workshops, see section 3.2 (p.21) for a description.

The study relies on a sample of respondents from organisations that have been or were, during the project, involved in OPS in various capacities. The organisations approached for the study were thus selected based on factors such as their prominence in relation to historical investments in OPS, their expressed interest in OPS-related issues, and their ability to represent some specific aspect of the logistical value chain that would be affected by the introduction of OPS.

3.1 Interviews

The interviews were semi-structured, being initially based on prepared questions and then open for other relevant, more organic, follow-up. The interviews were performed by at least one researcher, but normally more than one and of different backgrounds (i.e., human factors, technical expertise, business, logistics) to promote more detailed notetaking and subsequent internal discussion. Normally, there was only one interviewee, but at times a panel of subject-matter experts were interviewed. Interviews were scheduled for 1–1.5 hours each. Thirty-six interviews were performed, of which eight were follow-ups of prior interviews.

Topics of interest during the interviews with ports and shipping companies included:

- History and status of OPS implementation and usage at/by the organisation thus far;
- Ship segments involved in OPS usage;
- Motivations behind implementation;
- Decision processes and stakeholders that needed to be involved;
- The business case and models for OPS adoption;
- The types of equipment chosen, power requirements, voltage, frequency, maintenance, training and certification, and associated costs;
- Aspects of OPS equipment standardisation;
- The main challenges encountered in implementation and usage;
- Recommendations for others in the maritime sector considering OPS.

With equipment suppliers, the focus was on their history of working with OPS equipment, standards, differences between different equipment choices and associated costs. With grid and electricity companies, on the other hand, the focus was on the power needs for OPS and the upcoming challenges of and solutions for electricity scarcity.

3.2 Workshops

The workshops were used to disseminate and discuss preliminary results but also to learn the industry's combined views on new issues that built on the results of the previously-held interviews. A selected group of people was invited to participate, based on their specific backgrounds, to share and discuss their expertise/perceptions on the topics at hand. The workshops were set for two hours each and moderated by SSPA and Gothenburg University researchers. Three workshops were held. The first workshop looked at business models for OPS for ports and ship owners. This workshop was kicked off with two guest presentations – one by Ports of Stockholm and the other by the Port of Kristiansand in Norway, introducing their current business models and those under consideration – followed by a more theoretical presentation by the project team. Then, the attendees were divided into two mixed groups based on their professions/areas of expertise to allow for a richer discussion and better coverage of the different perspectives within each group. The groups were asked the same pre-determined questions regarding best practices of business models for OPS and the main challenges in setting them up and standardising them. Finally, the results of both groups were discussed *in plenum* before the workshop was closed.

The second workshop consisted of a meeting with the Port of Norrköping at which preliminary project results and recommendations were presented and discussed with the port's board of directors. This workshop allowed us to learn the perspective of a port that has not yet implemented OPS and whose traffic is mainly cargo-related and irregular.

The third and final workshop consisted of a dissemination seminar presenting general project results and the main identified issues and recommendations, at which there was a panel discussion with five invited guests, representing each of the main stakeholder groups (Sveriges Hamnar, Stena Teknik, Göteborg Energi, Transportstyrelsen (the Swedish Transport Agency), ABB). The audience had the opportunity to ask questions and provide input. The input from each of the workshops was of value to the finalisation of the written report.

3.3 Data analysis

The qualitative analysis was initiated by transcribing the interview recordings and sorting the data into a thematic matrix (Charmaz, 2014) categorised on the basis of the initial interests and research questions of the project, as well as based on the interviews and the themes/categories identified throughout the data collection process. The thematic matrix provided an overview of the different experiences of the different interviewees per theme/category; it also facilitated comparative analyses between them and the listing of alternatives and examples of OPS. The results are presented in the following sections in the form of diagrams and tables and described extensively in the body of text.

4 Stakeholder perspectives on OPS implementation

The adoption of OPS can be broken down into three steps (see Figure 1 below). First, a decision is made to consider and install OPS. This decision can be made as a result of an initiative from the port and/or ship owner or pressures or requests from different actors. Then, the preparation process begins, where decisions are made on what to install and how (including the procurement process), followed by installation. Finally, the OPS installations can be put into operation.

In the next section, an overview of which stakeholders are involved in OPS adoption is given, followed by a description of the identified driving forces mentioned by ports and shipping companies, based on their experiences of OPS adoption.

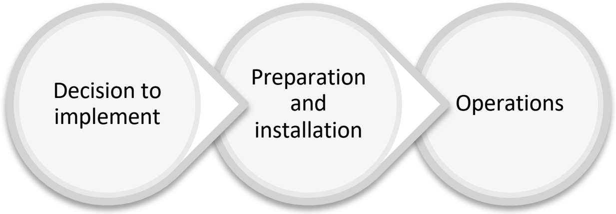

Figure 1. Steps in the implementation of OPS.

4.1 Stakeholders involved in OPS adoption

The decisions surrounding the adoption, installation and operation of OPS can involve and be affected by many actors. During this project, a number of actors with a direct or an indirect link to the specific decision maker were identified. Based on comparisons with stakeholder models found in the research literature (e.g., Olesen (2015)), the stakeholders involved in the process of implementing and operating OPS are categorised and listed as per Table 3. Involved in OPS are regulators and standard setters, infrastructure and resource providers, and port-, vessel-, OPS- and cargo-related actors. See Table 3 below for the actors which play a role in each of the three stages of OPS implementation.

In this project, the focus is on the port and shipping companies. In the case of ports, the port authority is most often the party responsible for OPS infrastructure investments. Shipping companies involve both ship owners and operators. The decision to implement OPS is the concern of the ship owner. However, the operator (which is a role that can also be taken by the ship owner) is important both when initiating and operating the OPS.

Table 3. Stakeholder categories involved at different points of OPS adoption.

	Decision to adopt OPS	Preparing the OPS installation	Operating OPS
Regulators & standard setters	• EU or national government • Local or regional government	• (Ashore – Elsäkerhetsverket (National Electrical Safety Board) / On board – Transportstyrelsen (the Swedish Transport Agency) and classification societies) (standardisation organisations and work groups, etc.)	
Infrastructure & resource suppliers	• Grid operator • Electricity provider	• Grid operator • Electricity provider	• Electricity provider
Port-related actors	• Port authority & port owner • Port & terminal operator (e.g., APM & Stena) (can be the same)	• Port & terminal operator (e.g., APM & Stena) (can be the same)	• Port & terminal operator (e.g., APM & Stena) (can be the same)
Vessel-related actors	• Ship owner • Ship operator (can be the same as ship owner)	• Ship owner	• Ship operator (can be the same as ship owner)
OPS-related actors		• Technological consultant • Equipment manufacturer	• Installation and maintenance provider
Cargo-related actors	• Cargo owner (includes consignee, consigner, etc.)		

4.2 Driving forces to install OPS

A number of common driving forces, motivations, or reasons to adopt OPS today were identified from the interviews. The motivations of ports and ship owners differ slightly. A few OPS installations in Swedish ports and vessels have already been in operation for over a decade; hence, detailed information about the reasons why those installations were made at that time, other than the environmental concerns, was difficult to determine. In

Table 4, the drivers from both the ports' and shipping companies' perspectives are summarised.

There are four main forces driving the implementation of OPS: a more political and environmental push, as well as a concern to address requests from municipalities to improve air quality for residents; a business-oriented motivation to answer customer requests for OPS facilities in order to maintain competitive advantage and follow new technological trends; a financial driver for those who expect to be able to reduce costs by using OPS rather than meeting today's fuel prices; and, finally, the improvement of the work environment for crew and terminal operators (in reducing noise, pollution and vibrations).

With regards to environmental and political forces, the ports mention that environmental permits from Länsstyrelsen (County Administrative Board) stipulate the need to investigate the possibility of OPS in terminal modifications or new terminals. That Länsstyrelsen pressurise ports to undertake such investigations was mentioned by the majority of the interviewed ports and encourages those ports which have not yet investigated installing OPS to prioritise doing so. This pressure also applies to those shipping companies which manage their own terminals. Further, municipalities, which are often owners of the port, and their residents, also put pressure on ports to reduce local air pollution and noise, which is experienced as a driver among the ports. Shipping companies also mention reduction of emissions as a main driver as well as achieving improved environmental ratings – whether current or anticipated – due to national environmental goals, policy and/or EU directives. Improving environmental ratings as well as reacting to and preparing for current and upcoming regulations is also mentioned as a driver for the ports. The push from the environmental permits and feedback from municipalities have also previously played key roles in the transition to shore power in the ports, as suggested by Zanetti (2013).

In the area of business and competition, it is evident that one of the main drivers for the ports is related to requests from customers, that is, shipping companies and/or cargo owners. Mention was also made of the fact that the ports see a competitive advantage and branding possibility in the implementation of OPS, due to the concern that customers will expect to be offered OPS and that other ports will be offering it. For shipping companies, similarly, competitive advantage and branding are drivers to install OPS. There might be expectations and concerns that OPS will be available on other vessels in the segment or become required in the future. Furthermore, some shipping companies mention a push from cargo owners to install OPS.

In the financial area, receiving external funding to cover a portion of the costs of the infrastructure is an important driver for both ports and shipping companies to take the step of installing OPS technology. As regards the shipping companies, the potential cost savings made by connecting to electricity rather than using fuel is another key driver, as is the reduced need for auxiliary engine maintenance and corresponding costs. The savings from not using the auxiliary engines can amount to 20 Swedish *öre* per kWh according to a local ro-pax company.

Finally, with regards to social forces, the ports and shipping companies both mentioned the driver of increasing the comfort of operators in the port as well as the crew on board with respect to engine noise and vibrations.

Examples of drivers among ports

In accordance with Port of Norrköping's current Länsstyrelsen environmental permit, the company is required to follow the development in OPS and regularly report on what measures are possible to implement. The Port of Norrköping is in a strong development phase, with an ongoing expansion of the port facility. In connection with this development project, OPS is also being prepared. In parallel, the company has a long-term strategy for a shift towards increased electrification for land and sea transport.

At the Port of Gothenburg, a close dialogue with 'Donsörederierna' (agglomerate of shipping companies located on the Donsö island, in Gothenburg, Sweden) took place, which showed a strong interest in OPS. The Port of Gothenburg will offer OPS for the tanker segment from 2023, and several newbuilt vessels will be prepared to use OPS in the port. Financial funding from “Klimatklivet” made the investment possible (Göteborgs Hamn, 2019; mynewsdesk.com, 2021).

At the Port of Piteå, an OPS installation was initiated at the request of a goods owner who transports cargo on the ro-ro vessels of a regular customer at the port. The installation was adapted exactly to the needs of the ro-ro vessels in question.

Table 4. Driving forces for ports and ship owners.

Driving forces	Ports	Ship owners
Environmental performance/Political	Environmental permits	Environmental permits applying to shipping companies that manage own terminals
	Local air pollution and noise affecting municipalities and residents	
	Reduction of emissions (in response to policies and own initiatives) and improved environmental ratings	Reduction of emissions (in response to policies and own initiatives) and improved environmental ratings
	Preparation for expected future policies	Preparation for expected future policies
Business/Competition	Requests from ship owners	Agreement with port(s); Push from cargo owners
	Competitive advantage and branding, following the trend	Competitive advantage and branding, following the trend
Financial		Lower operational and maintenance costs
	External funding for infrastructure	External funding for infrastructure
Social	Comfort of terminal operators	Comfort of onboard crew

The environmental permits and cost factor are, seemingly, the main differences between ports and ship owners in terms of drivers for OPS. OPS on ships is not typically imposed by environmental permits (except for those shipping companies that manage their own terminals), and some ship segments see the connection to electricity at berth as an opportunity to reduce energy costs (e.g., an interviewee from a technology provider suggested that a ro-ro ship might save around 1.7 million SEK/year on fuel, even if the port increases their port fees with OPS). Ports, on the other hand, have generally experienced OPS as a financial burden for which it is difficult to calculate financial return on investment (ROI), even with external funding for a portion of the infrastructure cost. In such a case, the value of OPS becomes other than financial, but, due to this issue, the business models for OPS at ports and decisions about how to charge ships for OPS connections are vital (see chapter 6, p.41). In terms of costs and benefits of shoreside electricity, these are also dependent on regional characteristics such as electricity price, port size, grid conditions, and vicinity to urban areas. Furthermore, conditions vary for different seaports and inland ports, which are typically visited by different ship types (type, size, cargo, etc.) (Winkel et al., 2016). Moreover, port authorities are not the ones to benefit most from the reduction of harmful emissions (Winkel et al., 2016). For some ship segments, the cost-benefit of connecting to electricity at berth can be less evident than for others, depending on how accessible their common fuels are. Among those who may derive fewer benefits, the willingness to install OPS either fades or is treated as an environmental initiative and long-term company strategy instead.

5 Technical aspects of OPS

A number of technical aspects must be considered before installing and using OPS, from the perspective of both the port and the shipping company. Table 5 lists the main technical aspects, which are described in more detail in the sections that follow.

Table 5. Main technical aspects to be considered by ports and ship owners before installing and operating OPS.

Process step	Technical aspect to consider	Ports	Ship owners
Preparing for OPS installation	**Power demand and electricity availability**	• General study of power needs for the port's expected calls • Grid expansions	• Estimated power need from the ship for desired activities
	Voltage (standards)	• Consider standard voltages based on power needs and voltage of vessels; whether voltage transformer is needed	• Check voltage on shore; consider having transformer aboard
	Frequency (standards)	• Consider generic local frequency and offering converter based on the expected port calls and frequencies on board	• Check the frequency offered by the ports and whether a converter is available; consider having a converter on board
	Plugs and cables (standards)	• Consider plug standards and cable types and lengths depending on expected port calls	• Check plugs at port and whether port has cables available; consider having cables on board and check inlet type at terminal
	OPS infrastructure and connection stations/points	• No. of quays to be connected • Possible combinations, e.g., what the crane with cable on the quay should look like and where it should be placed, where the transformer station can fit on the terminal • Energy storage, etc.	• E.g., where the hatch and inlet for shore power should be on board • Whether current conversion for recharging batteries is needed
Before first connection and onwards	**Certification, inspection (with safety check)**	• Port staff goes on board to inspect OPS compatibility and maintenance • Safety check of equipment	• Ship owner to request a certification of the installation from the classification societies • Safety check equipment
Maintenance after installation and onwards	**Contractual maintenance and equipment replacement**	• Plugs to be replaced every five years, for example; check for cable damage, etc.	• Onboard system to be maintained regularly even if OPS has not been in use for a long time

A case-by-case cost-benefit and feasibility analysis should be performed (Prousalidis et al., 2014), considering:

- The state and power capacity of the grid at the port and, if grid extensions might be needed, the ship and its power demands at berth;
- The port's electric infrastructure and power substation capabilities; the number of quays to be connected; the new port infrastructure that might be needed; whether there is space ashore to retrofit substation equipment, energy storage, etc.;
- The ship's electrical system specifications, such as voltage, frequency, earthing system, etc.; whether the existing ship-to-shore switchboard meets the power demands at berth; whether there is space to retrofit the solution on board (Prousalidis et al., 2014).

5.1 Current international standards

The following international technical standards are available for alternating current (AC) shore-to-ship connections:

- IEC/IEEE 80005-1:2019 Utility connections in port — Part 1: High-voltage shore connection (HVSC) systems — General requirements;
- IEC/IEEE 80005-2:2016 Utility connections in port — Part 2: HVSC and low-voltage shore connection (LVSC) systems — Data communication for monitoring and control;
- IEC/PAS 80005-3:2014 Utility connections in port — Part 3: LVSC systems — General requirements (Pre-standard, to be replaced by IEC/IEEE DIS 80005-3 Utility connections in port — Part 3: LVSC systems — General requirements (under development));
- IEC also have additional standards for HV and LV plugs, socket outlets and ship couplers for shore connection systems.

Standard 80005-1 for HV has been compulsory within the EU since 2014, according to Directive 2014/94/EU and TSFS 2016:917. The remaining standards are not prescriptive, yet they serve as important recommendations to ascertain compatibility between vessels and ports worldwide and regulate the development of technical solutions. The standards define requirements that promote the efficiency and safety of connections by compliant ships to compliant ports through a compatible shore-to-ship connection point. The content of the standards was inspired by equipment used in comparable activities/purposes in other sectors, for example the OPS plugs used in the mining industry. Moreover, innovative OPS solutions chosen at specific ports have influenced other ports that followed and resulted in standard recommendations.

The standards include a set of generic voltages, at low and high levels. As concerns frequency, the standards state that this should match between ship and shore; otherwise, a frequency converter is to be used. Ship type-specific annexes in the standards include additional requirements for compliant vessels and ports to achieve compatibility and address ship type-specific safety issues.

The standards do not currently cover details such as location of the onboard receiving equipment or where the onboard connection point should be located; neither do they cover detailed design and dimensioning of the installation based on power requirements, electricity distribution means (e.g., cable reel, mobile crane, etc.) or which specific voltage is to be used. It is also worth mentioning that the standards do not currently cover direct current (DC) connections, which are typically associated with the recharging of battery-powered ships.[1] See Figure 2 below for a summary of what the standards currently cover and do not cover, as well as what is under consideration.

The interviewed ports and shipping companies were aware of the standards and, in most situations, the standards are followed. Among the ports with OPS in Sweden at the moment, one can find a few exceptions where, for example, the port does not offer frequency conversion or cables, sharing this responsibility with the connecting vessels.

In addition to the international standards, national standards, rules and regulations, together with classification society standards, must be met, both on board and ashore. Classification societies typically follow the IEC standards, while national standards are mainly for shoreside electrical installations, where there are associated laws. The Maritime Safety Committee (MSC) at the IMO is also working on 'Interim Guidelines' consisting of global safety standards for the provision of shore power to ships (IMO, 2020d).

A joint working group from IEC aimed to develop standards for shore connection, comprised of various organisations (e.g., ISO, IEEE, electrical system suppliers such as ABB, cable management system suppliers, port authorities, shipping companies and classification societies) is further developing the standards for the various shipping segments that are not yet covered (e.g., tankers, LNG carriers, vehicle carriers) and/or that have only recently started to plan for and integrate OPS. Specifically, the location of the shore connection point on board tankers is under discussion as well as a dedicated annex of the standard for pure vehicle carriers (see Figure 2). Standards are also in the making for DC charging to ascertain interoperability between ports. This will be an important topic in the future as many short-route ferries and inland waterway vessels are converting to become battery-operated.

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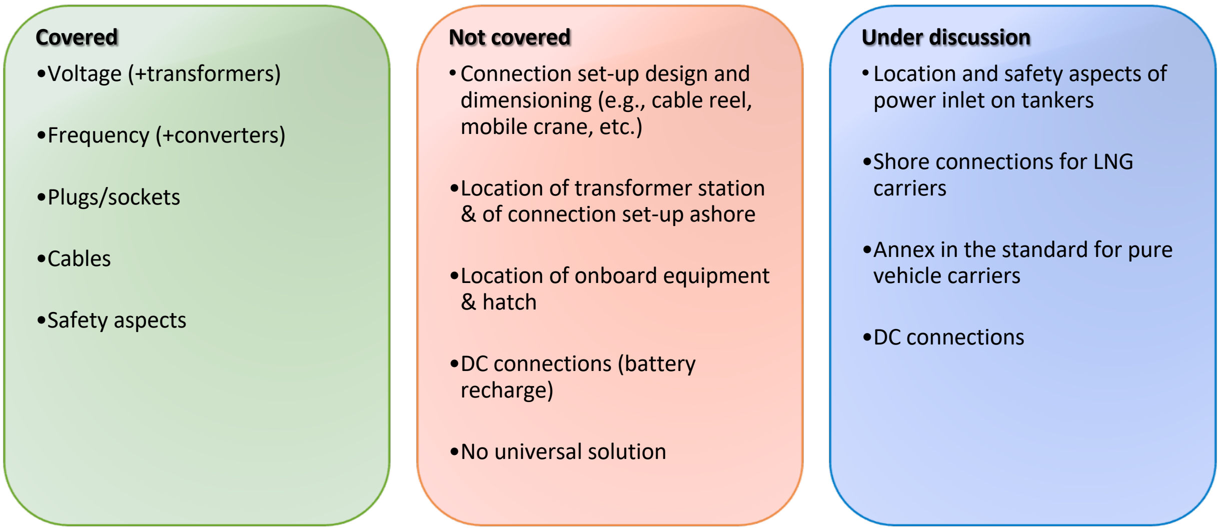
[1] OPS infrastructure ashore typically offers an AC connection and would hence be unusable for recharging batteries on board, which require a DC connection. Vessels that wish to charge onboard batteries using OPS facilities (Bellone et al., 2019; Kumar et al., 2019; Letafat et al., 2020) need to have an AC-to-DC converter on board or on shore. The Ports of Helsingborg (Sweden) and Helsingør (Denmark) have such a solution for two electric ForSea ferries to charge their batteries while at berth.



Covered

- Voltage (+transformers)
- Frequency (+converters)
- Plugs/sockets
- Cables
- Safety aspects

Not covered

- Connection set-up design and dimensioning (e.g., cable reel, mobile crane, etc.)
- Location of transformer station & of connection set-up ashore
- Location of onboard equipment & hatch
- DC connections (battery recharge)
- No universal solution

Under discussion

- Location and safety aspects of power inlet on tankers
- Shore connections for LNG carriers
- Annex in the standard for pure vehicle carriers
- DC connections

Figure 2. Summary of what current international standards do and do not cover and what issues are under discussion.

Standards are crucial in providing guidance to the decision maker by delimiting the range of technical options. As one interviewee from an equipment provider said, standards are the most important factor in ensuring the wide acceptance of OPS. Yet, there are still several possible technical combinations and types of equipment that can make up a complete OPS installation. It can be said that, to a degree, the current standards answer how OPS is to be realised to be safe and controllable, but they do not say how the actual relative geometry between ship and shore OPS connection points should be designed. Ports and ship owners expressed a wish for OPS standards to provide further guidance, making their decision process more straightforward and guaranteeing OPS compatibility between ports and ships while simultaneously reducing their need to check with each other what equipment and standards are preferred by their counterparty before implementing a new installation. On the other hand, this gap in the standards has allowed different equipment providers, in conjunction with ports and ships, to develop alternatives that answer specific problems (though still complying with the standards), such as integrating OPS in a movable container. The standards have been evolving incrementally as such solutions are discovered and disseminated. A downside of developing different standards for each vessel segment, as pointed out by an equipment provider, is reduced flexibility of use by other segments. The possibility for a universal solution, even if remote in the case of OPS due to disparate vessel needs, tends to weaken over time as ports and ship owners/segments devise their own custom solutions. Moreover, the probability that novel disruptive solutions, i.e., outside the standards, can be employed (e.g., induction charging) might diminish as more ports and ships invest in standard solutions. Figure 3 summarises strengths, weaknesses, opportunities, and threats of OPS standards, which have been identified in this study.

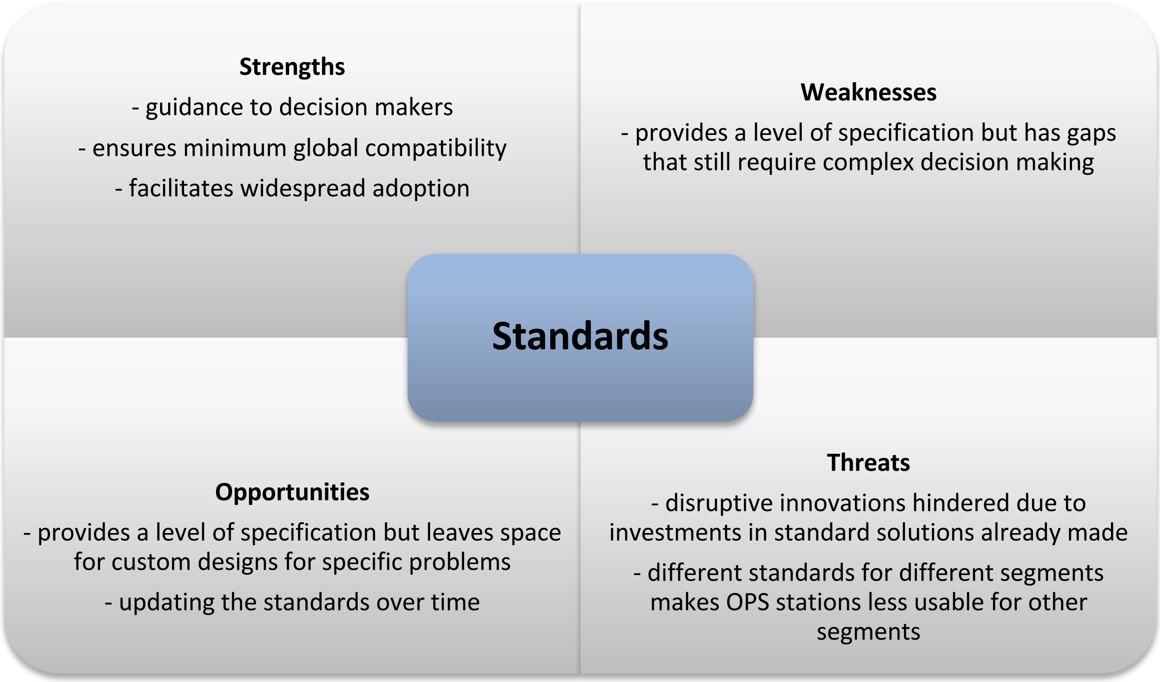


Figure 3. Strengths, weaknesses, opportunities, and threats of OPS standards identified in this study.

5.1.1 Voltage levels

The HV standard IEC/IEEE 80005-1 presents two possible voltage levels, 11 kV and 6.6 kV, and the LV standard IEC/IEEE 80005-3 presents three possible voltage levels, 690 V, 440 V and 400 V, to be used as nominal voltage from shore to ship. A transformer might be needed to convert the shore voltage to the ship's nominal voltage unless the ship's network is designed for the shore supply voltage and the neutral point treatment is in line with the ship's systems. The electrical shore supply must be galvanically isolated from the ship's electrical system if the international standards are to be followed. For HV connection, this transformer can be placed ashore or on board, but for LV connection it should be ashore.

If ports and connecting vessels have the same voltage, there is no need for the vessels to purchase and carry a voltage transformer on board. This will make the design of the OPS installations easier and less costly. However, it is not only the voltages of the vessel and the port that matter; the voltage distributed from the local grid to the port must also be transformed before reaching the OPS connection point which the vessels will connect to. Normally, the voltage from the grid will be reduced to lower levels at the port. Hence, the Port of Gothenburg suggested that a 6.6 kV-voltage might be easier to meet at ports around the world than 11 kV or higher voltages. The 6.6 kV-voltage level is suitable for e.g., product tankers. On the other hand, 11 kV might be more suitable for cruise ships due to the high-power demand in port. There might also be other reasons for choosing a certain voltage level, e.g., ForSea ferries, which run between Helsingborg (Sweden) and Helsingør (Denmark), have chosen the 11 kV standard to distribute power onboard for charging their batteries while in port. This is because high charging power needs to be transferred in a very short time. The voltage is then transformed and converted to DC on board to match the battery voltage. This energy transfer is made via a robotic arm which connects to the ferries automatically to be able to minimise connecting time in port.

The choice of nominal voltage (low or high) from the shore is based on the estimated power need of connecting ships. High power demands imply HV connections. Hence, communication between a port and a specific shipping company is important to confirm the power need, or – in the case of a port installation for unspecified shipping companies – a general study needs to be performed (which might be supported by consultancy services or equipment suppliers) and simultaneous communication with the grid operator and electricity provider should be established.

The increasing need for power on existing vessels and even greater need on newer ships calls for HV rather than LV connections to avoid the larger number of parallel cables and thicker cable size required by LV as well as the longer time it takes to connect. With an HV connection, one is able to transfer the same amount of power with fewer and thinner cables, which makes the connection process easier. An HV cable of 11 kV makes it possible to transfer 25 times more power than a 400 V cable of the same dimension (Ericsson & Fazlagic´, 2008). It is commonly understood that 1 MVA of electrical power-need for a vessel using OPS is the divider between LV and HV connection (IEC/IEEE, 2019) (see Table 6 for the pros and cons of LV and HV connections). Table 7 below shows the maximum power each cable connector (i.e., plug and inlet) can supply.

Table 6. Pros and cons of low vs. high voltage OPS for ship owners and ports.

Voltage levels	Pros	Cons
Low	• Cheaper equipment • Appropriate for low power demands (below 1 MVA). Less strict safety rules and regulations to follow • Onboard transformer not required if vessel's voltage is the same	• For high power demands (above 1 MVA), requires more and thicker cables, increasing the time needed to connect. • Onboard transformer required if vessel's voltage is not the same
High	• Covers both low and high-power demands • More flexible for future demands (future-proof) • Fewer and thinner cables required. Faster to connect • Onboard transformer not required if vessel's voltage is the same	• More expensive equipment • Stricter safety rules and regulations to follow, including operator certification • Onboard transformer required if vessel's voltage is not the same

Table 7. Maximum power each cable and voltage can provide (calculated based on power formula).

Voltage	Max Current/Connector as per IEC standard	Max Power
400 V (low)	350 A	240 kVA
440 V (low)	350 A	265 kVA
690 V (low)	350 A	415 kVA
6.6 kV (high)	500 A	5.7 MVA
11 kV (high)	500 A	9.5 MVA

An example from a shipping company

Terntank and the tanker companies on Donsö Island in Sweden are pioneering OPS for tankers. Terntank considered an LV connection due to the lower cost and the requirements of their onboard 440 V system but ultimately opted for a 6.6 kV HV due to their power needs when operating pumps and ballast water treatment. With their power needs, an LV connection would have been less practical due to the higher number of cables required. An HV connection costs more and requires a transformer on board to convert the shore's 6.6 kV to the 440 V on board, but it is more practical to operate. The company also chose to buy a plug adapter in case they need it to connect at different ports and did not consider it a significant added cost.

5.1.1.1 Power demand from different ships

The choice of amount of energy sourced by the OPS distribution system in the harbour to the ship depends on the power needed on board and the cost of using OPS at that time of day or night. The decision of how much power the ship receives can be based on an onboard energy management system based on need and cost (Letafat et al., 2020). The power demand of each vessel can depend on ship type (see Table 8 for examples), ship size, activities on board and time at berth. Some ships use only hotel load when using the port facilities for offloading, while others need power for the loading/discharging of cargo (e.g., tankers require around 400 kW for loading and 1500 kW for discharging). Cruise ferries have the highest power consumption while hotelling of any vessel type (they use almost the same hotel power in port as they do in transit, whereas container vessels, for example, at berth use around 10% of the power that they would use in transit). An energy company mentioned an approximate 10–16 MW or more per cruise ship (Sweco Energy AB, 2020), similar to the power demand of 10,000–15,000 households, which represents up to 5% of the electricity provider's maximum capacity. Different power capacities will have different impacts on the business case for shoreside electricity installations, the size of the installations and, for instance, the impacts on the (local) power grid (Winkel et al., 2016).

Table 8. Power demand indicators per vessel type (Ericsson & Fazlagic´, 2008) and approximate time-at-berth indicators (from interviews).

Type of ship	Power demand for OPS (kW)	Examples of time at berth
Commuter vessels	5–85 kW	Overnight
Commuter vessels with fast charging of batteries	150–600 kW	At berth and overnight
Feeder container ships	100–400 kW	8–12+ hours
Deep sea container ships	250–1500 kW	24+ hours
Ro-ro ships	250–1500 kW	6–48 hours
Tankers	500–1500 kW	10+ hours
Cruise ships	2000–20000 kW	10–48 hours

Different vessels stay in port for different durations, depending on, among other things, the cargo and availability of handling capability. Due to the environmental effects and mechanical stress of stopping and starting the onboard generators, a too-short port stay will not be beneficial in reducing emissions. Khersonsky et al. (2007) note that, for the Port of Gothenburg, it takes approximately 10 minutes to complete the process of connection, suggesting that for very brief calls, it would not be efficient to use shore power. A minimum of two–four hours in port is commonly referred to in the interviews, although this might be calculated case by case as part of the shipping companies' business models. Other studies refer to four hours as a minimum reference time to connect to OPS at quay (e.g., Khersonsky et al. (2007); Thulin (2014)).

Mitigation activities should aim first at cruisers and ferries, as they present the best business cases for shoreside electricity implementation given their high power demand (see also Innes and Monios (2018)). Furthermore, the initial focus should be on those areas in ports where impacts are most intense, such as passenger waiting areas, ports close to residential areas, cruise ships and quays (Winkel et al., 2016).

5.1.2 Frequency levels

Adding to the decision on voltage is the decision of which frequency is to be transferred. The default frequency in the Swedish power grid is 50 Hz. If the vessel's electrical system is using 60 Hz, a frequency converter needs to be used. The majority of international vessels use 60 Hz, but some run at 50 Hz (see examples in Table 9 below). Both HV and LV IEC 8005 standards stipulate that the frequencies should match between shore and ship; otherwise, a frequency converter should be made available from the shoreside, although some vessels choose to have their own converters on board (e.g., Donsötank). Vessels may, on the other hand, need to have their own converters on board not only due to the frequency of use but also because they may need to convert from the ports' AC grid to DC on board to be able to charge onboard batteries. The need for frequency conversion does not affect the cables and connectors (i.e., plugs and inlets). Having to have conversion can cause costs to double (e.g., from 15 million to 30 million SEK for ports) per installation. Some ports would prefer onboard conversion to be possible, but conversion is currently the responsibility of ports, according to the IEC 80005 standards. See Table 10 nedan to see the benefits and drawbacks of picking 50 or 60 Hz-frequencies for onboard OPS installations.

Table 9. Frequency level for different types of vessel (Ericsson & Fazlagic´, 2008).

Type of ship	50 Hz	60 Hz
Container vessels <140 m	63%	37%
Container vessels >140 m	6%	94%
Tanker vessels	20%	80%
Ro-ro vessels	30%	70%
Cruise vessels	17%	83%

Table 10. Pros and cons of 50 vs. 60 Hz-frequency on vessels when connecting to OPS.

Frequency levels on vessels	Pros	Cons
50 Hz	• Cheaper • Compatible with Swedish grid frequency	• Will need conversion for 60 Hz-grid ports
60 Hz	• Does not need conversion in 60 Hz ports (e.g., in USA ports)	• More expensive • Not compatible with Swedish grid frequency; need for conversion

5.1.3 Cable arrangement and connection points

The type of cable arrangement used needs to be taken into consideration by the involved parties. For all vessels except container vessels, the IEC 80005 standards state that the cable arrangement should be on the quayside. For container vessels, the IEC 80005 standards state that the cable arrangement should be on board (this is based on best practice from the US (Los Angeles and Long Beach), due to conflict between the cable arrangement and the movable quay cranes).

As regards other vessels, two current gaps in the standards are to be dealt with. One is that the IEC 80005 standard does not specify, first, where the vessel's inlet should be located and, second, how long the onshore cables should be to reach that inlet. Hence, ports might need to have several connection points along the quayside or a portable cable arrangement or may need to discuss the cable arrangement issue directly with the connecting vessels and arrive at a dedicated solution. See Table 11 for the pros and cons of having the cables onshore or on board.

Table 11. Pros and cons of having the OPS cables ashore or on board.

Cables and plugs	Pros	Cons
Ashore	• Less damage to the cable compared to having the cable on board and pulling it ashore for each connection (except, perhaps, for container vessels) • Vessel does not need to purchase cables and pull them ashore for each connection	• Port needs to invest in and maintain the cables and plugs • Cables might be in the way of quay operations and movable cranes on rails
On board	• Having a cable available in case the port of call does not have a suitable one • Will not conflict with the movable quay cranes in the same way as fixed cables ashore	• Having to invest in and maintain the cables and plugs • Having the cables take up space on board • Having to pull the cable ashore for each connection

5.2 Equipment for ports and vessels

An OPS installation ashore typically requires a shore facility (building, container and/or cable cabinet) with the necessary technical equipment inside, such as switchgear, transformers, frequency converters and control systems, including a safety control system that connects to the ships' switchgear. Filters and cooling systems might also be necessary. In cases where this facility is placed at a considerable distance from the vessel terminal, cables must be laid between the facility and the OPS connection point for ships at the quay. Grid extensions to the port may be needed, and this often requires expensive digging to lay the cables in the ground. Alternative solutions could be laying cables on the seafloor or using power barges. Depending on how the necessary converters and transformers are set up and how many of them there are, one or more ships can connect at the same time to the same installation (different connection points).

For vessels, examples of common changes needed on board to accommodate OPS are:

- Ship couplers and intake cabinet at the power receiving point. This will require a dedicated space on board;
- A new receiving switchboard with a circuit breaker close to the power receiving point;
- Permanent cable run from the receiving switchboard to the main switchboard;
- A transformer to adjust incoming voltage (if needed) to match the ship’s voltage;
- Modification of the main switchboard;
- An upgrade of the ship’s power management system;
- A safety monitoring system that connects to the port’s switchgear safety system.

Planning and installing OPS ashore can take more than one year, depending on the infrastructure and construction needs.

A cable arrangement is typically placed at the quay together with a crane to lift the cables up to the ship’s OPS intake/socket. This arrangement can be fixed or movable along the terminal’s length. In some cases, vessels have cables on board that connect to a socket ashore instead. The choice of solutions/techniques for each OPS installation and connection point will depend on factors such as the suppliers of equipment and target vessel types, whether the port needs or prefers a fixed or movable installation, how much space there is on the quay, and financial resources available. Normally, the choice of technique will be the result of a discussion between the port and a dedicated ship owner if the port installation is to serve the latter’s vessels only. Otherwise, the port will make a decision that seems suitable and flexible for the vessels that normally call. Among possible connection techniques are:

- Fixed crane ashore with a manoeuvrable arm that a crew can control from on board the vessel. The manoeuvrable arm contains a power cable with plug that the vessel brings on board to connect to the inlet socket;
- Mobile crane ashore (same concept as above but movable along the terminal);
- Crane on board the vessel that can pull in the cable (with plug) from shore;
- Container ashore, movable by truck or on a rail track (can include a cable reel or a socket for the vessel’s own cable);
- Container on board the vessel with a cable that can connect to a socket ashore;
- Cables on board that connect to a socket ashore. Trafikverket’s yellow road ferries (LV at 400 V and 50 Hz), for instance, have cables and plugs on board and simply need to

connect the plug to the socket ashore when at berth. These vessels have four installations on board (bow, stern, starboard and portside) to ensure flexibility at every berth they use, except for the cable ferries which require only two installations on board (one at the bow and one at the stern);

- In a few cases, when the vessels to be supplied cannot entirely approach the quay, a cable management system and all necessary electrical equipment can be placed on a barge, as at the Port of Los Angeles in the US, for example (Zanetti, 2013). Power barges, mostly used today to provide electricity to offshore plants (see, e.g., MAN Energy Solutions (2021)), can manoeuvre within a port to supply power at multiple locations (Khersonsky et al., 2007) and can use an ICE, fuel cells (Khersonsky et al., 2007) or methanol to produce the electricity for OPS.

A mobile, more flexible, connection structure and transformer facility might be preferable if it is to be used by different ship terminals and, possibly, ship types. Since flexibility increases the number of potential use scenarios, such a solution could be rented out to other ports and could also have a greater resale market, increasing potential residual value. However, whereas a fixed solution can be designed to serve up to ten vessels simultaneously (depending on power capacity), a mobile solution can typically only serve one or two vessels simultaneously.

Ports can also choose how many stations/connection points they wish to have on each terminal, depending on their needs. For example, ports that intend to prepare their terminals for OPS but do not yet know what vessel sizes they can expect might consider multiple fixed connection points along the same terminal, as was the case of the Port of Skellefteå (also due to the need to offer more cables, different plugs for HV or LV, or different power (current) ratings and to find a unique solution that can serve many ship types). Different connection points along the same terminal or on different terminals can be set up to be used simultaneously or one at a time on a schedule, depending on the infrastructure and energy capacity. At the Port of Helsingborg, at the ForSea ferry quays 200/300, several vessels can be connected at once; at the Port of Visby three vessels could connect at once, one at 60 Hz and two at 50 Hz.

Different OPS solutions may also require more or less manpower to operate them and more or less maintenance, which are also costs to be considered. Shipping companies might also more easily buy into OPS if they do not have to carry their own cables on board, for example, although, from a port’s perspective, ships carrying their own cables might be a welcome compromise to help the ports reduce the high equipment costs that they incur to be able to provide OPS to ships.

Where to place the connection point(s) ashore depends on the connecting vessels and their lengths, on the length and space on the quay, and on whether there is other equipment on the quay that requires free space around it, such as cranes. These issues often affect choice of technique (fixed or movable), as well as the necessary length of the cables and other issues. Where to place the inlet and hatch on board is also a matter for discussion, in particular, currently, for tankers pioneering tanker OPS connections, since this has not yet been defined in the IEC standards for any vessel type. The location of the side hatch on board depends on the quay arrangement, vessel size and resources, as well as on whether the onboard installation is retrofitted or built in a new vessel. The placement of the equipment on board tankers (i.e., whether the connection point should be in the middle or aft of the vessel) can determine the placement of the equipment ashore and vice versa; hence, this matter has been under discussion between Swedish tanker companies and the ports they call at, primarily the Ports of Gothenburg and Rotterdam. There have, however, been differences between the ports on how they prefer to approach this issue, which has led to a delay in new tanker construction and OPS equipment installation for Swedish tanker companies. As previously mentioned, when there is a lack of standards, trends tend to be set by the first port to make a move within a specific segment.

Examples from the tanker segment

Terntank initially considered having the OPS connection point in the aft of their newbuilds, since they would avoid EX safety requirements that way. However, they concluded that a connection point in the centre would be more operationally practical due to the proximity to the loading arms, despite the added costs associated with the EX safety measures that need to be implemented (over-pressurised facility). This arrangement also has to be class-approved. This solution also requires a certified person on board to perform the connections and disconnections and one ashore on the jetty. The training of Terntank staff is planned to take place in-house.

Donsötank defended that a mid-ship installation on tankers is preferrable since there will always be a part of the quay alongside mid-ship, whereas stern installations on tankers that are lengthier than the quay will be outside the quay. Also, the ship would be able to go alongside the quay both starboard and portside. A different solution (e.g., having the housing on the aft of the ship) would mean the vessel can only go alongside in a certain position, thus reducing flexibility. On the other hand, the interviewee claimed that this solution is cheaper and would allow for a moving crane along the quay, which can be more easily adapted to different tanker sizes.

The Stena Scandinavica example

Stena Line installed and connected their vessels to LV OPS since 1989 and to HV OPS since 2005. Around 2010, Stena Line received an environmental permit, as managers of their own terminals at the Port of Gothenburg, requiring them to further install OPS. Since then, Stena Line has built one more OPS installation (in 2015). The Port of Gothenburg supported Stena Line to apply for funding from “Klimatklivet”, which covered a portion of the total costs of the installation, and to build the station. It is Stena Line that has the direct contract with the electricity provider.

The Port of Gothenburg has a switchgear house equipped with frequency converters, switchboards, and transformers. At the quay, there is a fixed hoist/crane with a single cable via which the ship connects to shore power.

Arriving at the Port of Gothenburg, the ro-ro vessel Stena Scandinavica moors and unloads/discharges. Once the ship has unloaded, a crew member enters the onboard connecting room and prepares for the connection to be made. The ship's side-hatch for OPS is opened, and the shore crane and cable are manoeuvred into the vessel's connecting room via automatic remote controls in the onboard connecting room. Therefore, no additional staff ashore are required. The cable is manually plugged into the socket on board by the crew member. The ship transforms the HV received from shore into its operating voltage on board. The shore grid frequency (50 Hz) is converted ashore to the required frequency on board (60 Hz, like most ro-ro vessels) in the shore switchgear building. The auxiliary engines can be fully shut down once the connection is completed (ProcesskontrollEL, 2012). The power consumption can be visualised on a panel on board. The following YouTube clip shows a typical connection procedure on board the Stena Scandinavica at the Port of Gothenburg: *https://www.youtube.com/watch?v=S99iCNBJYgc&ab_channel=ProcesskontrollEL*

The land-based HV shore connection was built and equipped by the company Processkontroll Elektriska, with ABB and Cavotec as subcontractors, and the equipment on board the Stena Scandinavica was supplied by Marine Global (ProcesskontrollEL, 2012).

Before the first OPS connection occurs, several details need to be discussed and agreed upon, and a representative of the port might be required to go on board to inspect the OPS equipment and confirm that it complies with the standards, a procedure which might take several hours to complete. The standards need to be discussed and a compatibility assessment performed. The location of the OPS system on board and at the quay need to be assessed, and the voltage, frequency and power need to be evaluated and measures taken to match them. The persons in charge (PICs) need to be sufficiently educated in the systems they will operate. The standards also call for synchronised periodic maintenance to be carried out on both the ships' and the ports' equipment. This periodic maintenance must be documented and should be accessible to all parties. If a vessel routinely calls at the port, the connection operation is easier as all the information is known to all parties. Then, the connection becomes more of a routine operation and takes less time to complete.

6 Business models for OPS

6.1 Using the 'business model' to understand OPS

The concept of a business model has been theorised, defined and operationalised in a variety of ways (Teece, 2010). For this report, the business model 'Canvas' (Osterwalder & Pigneur, 2010) was used to analyse and structure the empirical data, since it is the most ubiquitous management tool used to portray and develop business models and has been used extensively in transport research. The canvas consists of four areas (Osterwalder & Pigneur, 2010):

- *Infrastructure* – describes the key activities, resources, and partners necessary for a business model;
- *Offering* – shows what value propositions should be offered to the customers;
- *Customers* – presents customer segments, channels through which to communicate with customers and type of customer relationships; and
- *Finances* – describes the cost structure and revenue streams.

The business model is specific to an organisation, but it can also be used to discuss specific roles within a value chain. Thus, a description of aspects which are central to specific areas of the business model needs to take account of which organisation or role in the value chain the business model is intended for.

Regarding OPS infrastructure, in section 5.2 (p.36), the hardware necessary for OPS ashore and on board the vessel can be found. The interviews carried out for this study indicated that these resources (i.e., upgraded harbour electricity infrastructure, converters, connection points, cables, etc.) may be controlled by different actors or constellations of actors but that the onshore resources tend to be owned by the port and maintained either by the port operators directly or by a third party whose services are procured by the port operator. In the text below, investments in OPS are discussed in detail. The central activities related to OPS are the handling of the connection of the cables and the maintenance of the equipment. There is an interrelatedness between the size of the investments and the labour input required for connection and maintenance. It was indicated that while the capital cost of investing in high-capacity OPS is considerably higher than that of low-capacity OPS, high-capacity cables replace several low-capacity cables, reducing the need for manual handling but raising the requirements for safety equipment and training. Similarly, costly semi- or fully-automated installations reduce the need for manual handling as well as operational risks. These procedures and activities are described in chapter 5 (p.28). Furthermore, there is a need to develop good relationships with primary actors, such as grid and shipping companies, as well as secondary actors, such as manufacturers of hardware and technology consultants, who will be able to give input on different OPS options. Grid and shipping companies may help plan the OPS business model, while the secondary actors are important to ensure cost is kept down where possible. Other important actors are remote ports, with which investments and design choices should be coordinated in order to maximise customer utilisation of OPS, goods owners with an interest in environmentally friendly transport solutions, and industry organisations such as standardisation societies, which may help the growth of OPS by providing recommendations and standardised solutions. These actors are discussed in chapter 4 (p.23). A business model thus needs to take these actors into consideration in order to incentivise the customers to use OPS and reduce costs.

The offering of OPS is dominated by the environmental value associated with the use of electric power and the reduction of fuel costs. That value is, in turn, realised through and associated with other factors, such as the ease of connecting to OPS and the time that the vessel can spend connected. Yet, the environmental benefits of OPS depend on factors such as the energy mix in the grid, the fuel otherwise used, and the capacity to use OPS while at berth. Hence, it is necessary to consider the individual needs and properties of specific customers, or groups of customers, in order to formulate a concrete offering for OPS. The variability in value perceived by the customer also depends on the latter's ability to capture and communicate such benefits to their own stakeholders through, for example, indicators for the reduction of GGE. Otherwise, the value of OPS tends to accrue to actors who do not actively pay for the service, such as property owners and citizens in the vicinity of the port. Furthermore, OPS is associated with some less obvious benefits, such as a less noisy working environment at berth and the opportunity to provide engine maintenance while being connected. Such benefits are discussed in more detail in section 4.2 (p.24). The offering thus highlights that it is not enough for a business model for OPS to merely stipulate that value is being created; it must package and communicate the value in ways that are attractive to the customer.

In both the literature and the interviews, it was clear that there are several ways to define and segment potential OPS customers. Obvious categories are the different vessel types and categories of actors interacting with the port. However, those categories can be further segmented based on the needs and views of the organisations within them. For example, cruise lines may be segmented based on their interest in sustainability and financial capacity to engage in a long-term investment, such as OPS. Most importantly, the frequency with which the customer arrives and how long they stay in port will indicate how much value the customer will be able to extract from OPS at the port and remote collaborating ports. For the port, it is thus important to have the capacity to identify and communicate with customers that will make continuous visits to the port. Customers that have installed OPS are likely to try to maximise the use of OPS-related hardware installed on the ship and thus put pressure on other ports to adopt suitable solutions. Early adopters are thus important both for the initiation of OPS and for its continued growth. OPS was associated with other values that can be used as a basis for segmentation, such as the ability to recharge a support battery, the improved ability to use time at berth for maintenance, and improved working environment for crew. It is thus important to identify customers with an interest in such aspects of OPS and consider if such offerings would impact how OPS is presented and produced. Considering that some vessels arrive infrequently and at irregular intervals, a different approach should be taken when targeting such customers compared to when working with those who have regular interactions with the port. An example of such customers is cruise ships. While they have an interest in OPS, they seldom interact frequently with specific ports, and there is thus a need to enable them to easily access information about the OPS, such as accessibility, pricing, and possible ways to reclaim taxes. Such communications go through the port's usual channels but might imply the need for a change in the customer relationship.

The financial side of the business model is probably the most challenging aspect for OPS. High investment costs and low subsequent cashflows mean that the success of OPS to date has been reliant on stringent regulatory support, subsidies and low-cost/low-capacity installations. The interviews showed that costly investments can be tackled in several ways. First, examples were given of where actors collaborated, shared costs or pooled resources. Procuring partially or wholly standardised components and equipment is also a way to lower costs. Investments were made gradually, starting small and then scaling up, to minimise the risks associated with the choice of technology or partners. In contrast, some investments were made at scale to reduce cost per unit, and other investments were made simultaneously, installing OPS while making other types of investment in vessels or quays. As regards revenues, three principal models for ports that want their customers to pay for OPS were identified:

1) It is possible to make everyone pay a surcharge on the port fee. As a result, those that use OPS benefit slightly since they do not need to bear the entire cost of the OPS. However, this system does not communicate the financial value of OPS to other customers.
2) It is possible to directly charge users only. This system does not subsidise the customer and makes the business case highly dependent on fuel savings and the willingness of the user to pay extra for qualitative values.
3) It is possible to punish polluters by raising the port fee for everyone and giving a rebate to those who use OPS, resulting in non-adopters subsidising adopters. Due to the importance of the financial aspect, investments and revenue design are discussed in detail below.

6.2 Investing in OPS infrastructure

Due to technical and site-specific factors, the total investment costs of an OPS installation are likely to differ considerably from one site to another. The main factors that drive investment costs are ship-related factors (e.g., which vessel types and how many vessels will connect to shore power simultaneously), port-side design and necessary upgrades, and power demand and capacity, with higher power demand resulting in more expensive equipment. If the frequency used on board does not match the frequency at the port's electrical grid, the cost will increase substantially. In this case, a frequency converter must be installed at the port side, according to international standards, which could represent 50% of the total investment cost for the port (Ericsson & Fazlagic´, 2008). In some cases, however, it is the vessel that installs a frequency converter on board.

The different possible configurations make it hard to calculate costs for the investment at the port. The cost for single-ship LV projects can start at approximately 2 million SEK, and can be expanded to systems capable of delivering shore power to 10 vessels simultaneously and with a cost of 10+ million SEK. Mobile OPS solutions tend to serve one or two ships and the cost can be at around 2-3 million SEK, unless the port requires a significant upgrade of the electrical infrastructure. Higher power demands and the need for frequency conversion can drive up the prices significantly. The total budget for a project can reach 50 million SEK for, for example, five connection points for ferries, the necessary upgrades in the electrical system in the port, and the initial preparation for cruise terminal OPS in the station (no cables, etc.). Typically, a container vessel terminal project is around 20 million SEK and cruise terminal project around 30+ million SEK (see Table 12 for an estimation of equipment costs for ports and ship owners, per segment).

Table 12. Approximate OPS equipment and installation costs per segment for ports and for shipping companies.

Approx. equipment & installation costs	Ports	Vessels
Ro-pax/ferry/ro-ro	Each OPS installation can range from 2 million to 30 million SEK, depending on parts of the system, whether it is a fixed or a mobile solution, and segment. 7–15 million SEK (no frequency conversion). This might include strengthening the grid (10 million SEK), transformers (around 1 million SEK each) and plug/socket (half a million to 1 million SEK). 30 million SEK (with frequency conversion). Total budget for a project can reach 50 million SEK for, for example, five connection points for ferries, the necessary upgrades in the electrical system in the port, and the preparation for cruise terminal OPS in the station (no cables, etc.).	5–10 million SEK for OPS on board (retrofitting OPS on board, up to 10 million SEK).
Cruise	30 million-100 million SEK (without or with frequency conversion)	
Container/bulk	8–20 million SEK	
Tanker	25–27 million SEK	6–7 million SEK for one installation

It is possible for the port to utilise stand-alone power sources, such as windmills or power cells charging batteries for energy storage, or an environmentally friendly fuel-driven power plant placed locally at the port. The latter could also be a mobile plant that can be moved between different ports. Such infrastructure investments are, however, likely to be costly and must be evaluated separately to ensure that they make sense both financially and in relation to the value that the port owner wants to offer through its OPS service (Iris & Lam, 2021; Roy, Auger, Olivier, Schaeffer, & Auvity, 2020).

The use of shore-placed batteries is seen in, among other places, Norway, where the electric car ferry Ampere uses this solution since the local grid at the jetties could not supply all the power needed to charge the vessel within the required/available timeframe.

Ports and shipping companies have typically been applying for and receiving funds from “Klimatklivet” from Naturvårdsverket (The Swedish Environmental Protection Agency) and/or from the EU covering 20%–50% of the total cost of installation. Often, when applying for funding, ports collect letters of intent from shipping companies expressing their interest in connecting their vessels to OPS at that port.

The cost of LV installations is lower than that of HV ones, especially if the voltage matches the distribution voltage used by the port, since this means that there is no need for the onboard transformer. Installing OPS on board newbuilds will drastically reduce the cost of OPS for shipping companies compared to retrofitting existing vessels. For container vessels retrofitting OPS, for instance, the cost can approach 1 million SEK. Current policies and directives mandating OPS should result in several ports in Europe adopting the technology, which can lead to a drop in the price of the equipment due to economies of scale (Innes & Monios, 2018).

6.3 Incentives to shipping companies

Incentives such as reduced port fees, reduced tax schemes for vessels with green solutions and so forth can be used to incentivise vessels to install OPS. Yet, this might be challenging to implement for those ports that need to recover their investment in OPS facilities by, for example, increasing port fees. Electricity tax reductions can also become an incentive to adopt the technology. Economic incentives can be implemented by port authorities, as well as by governmental or inter-governmental institutions. A typical economic incentive applied to ships to reduce emissions has been the environmentally differentiated port fee discounts provided by port authorities to vessels with good environmental performance according to, for example, the Environmental Ship Index (ESI). European port authorities have been highly active in administering such incentives as well as in infrastructural investments and administrative policies enforcing shipping emission limits, explained by the strict European regulatory framework and European initiatives to improve air quality (Christodoulou et al., 2019).

Example from port offering incentives

The Ports of Stockholm are offering a financial incentive to vessels that agree to retrofit OPS equipment on board and call at Ports of Stockholm regularly and for at least three years (mostly the ro-pax ferries, rather than the cruise or other vessels that visit the port irregularly). This incentive, which is the port’s own initiative, is worth 1 million SEK per vessel (a one-time payment) (Innes & Monios, 2018), which is borne by the port itself. On top of this incentive, there is a discount on port fees (also covered by the port) connected to the CSI and ESI. The business model surrounding discounts and the increased port fees for OPS has not yet been established.

According to Ericsson and Fazlagic´ (2008) (see also Kotrikla et al. (2017)), the Port of Los Angeles has offered to support shipping companies meet the investment costs of OPS equipment through an $800,000 subsidy for the first vessel of each company that installs OPS. As a result, at the time of their study, more than 50 new vessels had fitted the equipment.

6.4 How vessels pay for OPS connections

There has been widespread uncertainty about how to charge for the use of OPS, and the complexity surrounding pricing was perceived as a challenge by many of the port representatives in the study. Legislation in Sweden does not allow ports to charge an additional margin on top of the electricity rate decided by the electricity provider. Hence, the ports must provide electricity to vessels at the same price that they themselves pay to their provider. At terminals managed by shipping companies that have a contract with the electricity provider, the payment for the electricity does not typically pass through the port. The tax reduction on electricity that is currently in place is enabled by an exemption from EU legislation which has been extended several times and will be in effect until 2023, which is administered directly by the tax authority to the vessels.

Example of operational costs at Stena Line

At the Masthugget quay (Port of Gothenburg), where connections to OPS are quite frequent, 40-50 öre per kWh has been the average electricity cost historically. On top of electricity costs is the grid fee of 40 öre per kWh. If there is high utilisation, the grid cost will come down. Yet, if power demand increases, so does the grid cost. Not using the auxiliary engines at berth when connected to OPS, and therefore not requiring as much maintenance, represents a saving of roughly 20 öre per kWh. To produce the same amount of electricity on board costs roughly 1 SEK per kWh (when running on oil), which means that connecting to OPS has reduced costs.

On the other hand, other ports can have higher grid costs, and Stena has experienced grid costs as high as 4 SEK per kWh. Such a high cost makes the business case for OPS usage unviable.

Even when a port receives external funding to cover a percentage of the cost of installing OPS, it still has to incur the remaining part of the cost with port funds. In some cases, this cost includes an extension of the local power grid and associated port construction work. Furthermore, maintenance and potential services, such as shoreside staff needed for ship connections, will add to the operating costs. Hence, several strategic questions impact the viability of OPS and must be answered according to each port's unique situation. Examples of such questions are:

- *Which business models are possible, and how will they impact the pricing of OPS?*
- *Should the pricing differentiate between vessel types, and which characteristics should be used as a basis for the creation of customer segments?*
- *How should the use of OPS be encouraged through pricing? For example, should only vessels without OPS pay or vessels with OPS as well?*
- *How should OPS pricing consider environmental aspects such as environmental ratings, and should such aspects be considered when designing the port fee?*
- *How should operating costs, such as OPS service fees, be designed to balance operational costs, encourage proper use, and attract users?*

Examples of how ports have handled such questions are presented hereafter. Some ports, such as Ports of Stockholm, are considering charging a service fee to vessels or augmenting the regular port fees to cover the investment in OPS. Other alternatives mentioned to cover the operational costs of OPS included charging a fee for maintenance and operational costs to those who connect, charging those who do not, and increasing everyone's port fees equally. Ports stated that an ROI would take countless years and was not the main motivation for increasing port fees. OPS was not believed to be profitable in a traditional sense, yet it would improve the port's environmental performance and reputation.

Example of payment model at Ports of Stockholm

Ports of Stockholm stated that the City of Stockholm wants the Ports of Stockholm to continue working on the expansion of OPS and use differential environmental port fees (i.e., incentives and discounts for green shipping); however, it is the port who decides how to implement this. Today, Ports of Stockholm charge connected regular ro-pax ferry traffic for the electricity used and yearly grid costs, and an annual OPS maintenance and service fee. The business model for other vessel segments, such as cruise ships, has not been decided upon, but charging extra port fees to all cruise ships, with emphasis on those which do not connect to OPS, is under consideration.

A payment model describes how the customer pays for a given service; for example, through an added OPS fee on top of the customary port fees. Table 13 shows the payment model items adopted, or under consideration, among the interviewed Swedish and Norwegian ports in the study. The table also shows the number of interviewed ports that have adopted or are considering each particular payment model item. Each port can build up their payment models on several of the items.

Typically, the electricity provided to the vessel by the port will be charged at the exact cost as the electricity provider. In only one case did a port add a surcharge directly on top of the electricity price. Port of Kristiansand, Norway, had thoroughly evaluated their customer base and decided that it was a model that would be not only feasible but profitable. The customer pays a fixed price per kWh for the electricity used. In addition, the customer pays for connection and disconnection to shore power. Costumer price per kWh is evaluated yearly against actual costs. Other ports feared that such a model would deter use. Port of Kristiansand has had a positive experience forwarding shore power and state that their business model has so far proven to be profitable. Success criteria for the port have been volume and keeping costs down.

The port's choice of payment model and pricing strategy are influenced by the type of vessels staying in port and the availability of payment options such as fees or discounts. The most common solution among the interviewed Swedish ports was to charge a separate fee for the OPS designed to wholly or partially cover the cost of connecting to it. In most cases, this fee was not meant to cover the cost of the OPS but, rather, the activity of connecting to it and associated costs such as wear and tear. Another alternative was to take the existing port fees and either raise or lower them in order to cover the port's OPS costs or encourage ships to use it.

Table 13. Payment model items in use or under consideration for OPS connections among interviewed ports in Sweden and Norway.

Payment model items	Number of ports
Electricity rate	5
Electricity rate with surcharge	2
OPS fee	7
Increased port fee	3
Port fee discount	3*
Penalty fee for non-users	2
Connection fee dependent on workload	1
Managed by vessel operator	1
Vessel-differentiated solutions	1

** One of these in combination with other sustainability-related actions.*

Another alternative could be for the port, as part of their 'climate work' and in order to promote shore connections, to incur part of the difference of the ships' costs of connecting to OPS in the eventuality that OPS connections become comparatively more expensive than using the auxiliary engines, as was discussed with the Port of Gothenburg. Yet, from a long-term perspective and given the need for the continued expansion of OPS, most ports require recurring support from external funding sources for each subsequent installation or similar support from other actors, such as their customers, to cover parts of the investment and maintenance costs.

From Stena Line's perspective, a three-to-five-year period is needed for ROI in the adoption of OPS. For tankers, connecting to OPS is unlikely to represent a cost reduction compared to using fossil fuels at this point; hence, much increased port fees for connecting might be an impediment to take-up in this sector. However, if goods owners help cover this cost, connecting to OPS can become more financially viable again.

Due to the difficulty of finding profitable business models, the respondents have, in some cases, eased or completely eliminated the financial requirements in terms of payback or ROI. OPS is thus seen as a strategic investment, and the focus is on the values – such as lowered emissions and noise – that it creates for stakeholders. In these cases, the likelihood of moving forward with OPS will increase if the investment cost can be reduced through subsidies and if key actors, such as important customers, decide that they need OPS to realise sustainability-related goals. It is thus less a question of business model design than one of distribution of costs among the actors that ultimately benefit from the use of OPS. Authorities that regulate pricing of fairway dues, for example, might be of help for ports in the future in setting up how the latter can charge vessels for OPS and, to whatever extent possible, standardise the system across the country, depending on equipment and maintenance.

In the few cases where OPS has turned out to be a profitable investment, specific conditions have been met that can, in isolation, be copied and implemented elsewhere but, as a whole, appear to be difficult to replicate. Business model-related recommendations linked to those examples can be summarised as:

a) Understanding the customer base, which vessels call at the port and, accordingly, what use scenarios are likely to be encountered in terms of energy use, etc.;
b) Identifying the different types of value that OPS will generate for the organisation and key stakeholders as well as the best ways to communicate such values;
c) Exploring where and how investments in OPS can be made as financially attractive as possible with regard to both port and vessel characteristics and future growth scenarios;
d) Identifying potential financial support from public and private actors by searching broadly for sources of funding;
e) Evaluating how hardware solutions hit capital expenditure vs. operational expenditure and identifying a solution that works best with the organisation's financial situation at the point of decision making;
f) Exploring how key customers react to different payment models and potential reimbursement routes while simultaneously evaluating how those arrangements will hit the bottom line.

6.5 Linking business model innovation to organisational development

As evident from previous research on OPS and the empirical data, decision making on the business model does not take place in a vacuum. It is thus important to contextualise the work of developing a business model for OPS within the specific organisation in which the OPS is to be implemented. Theoretically, it is necessary to consider how the business model that is explored in cooperation with key stakeholders fits within the overarching strategy of the organisation (Magretta, 2002) that aims to provide OPS. For example, port operators often have clear guidelines with regard to their environmental work which can be used as support when making decisions on the aggressiveness with which to scale up OPS. Referring to such guidelines can make it easier to argue for some of the more ambitious investment strategies or take the risk of low utilisation over a certain period after the OPS has been installed. Besides the need to consider the business strategy while developing a business model, it is important to map which types of business processes will be incorporated in the business model and which processes and resources will be performed by key partners. The business processes within the business model will need to be managed for efficiency both individually and as a collection of interrelated activities. Otherwise, the potential synergies that the business processes should generate when managed within one business model will not be realised. In relation to OPS, it can be seen that there are certain key business processes that actors such as port operators prefer to keep control over, such as those related to direct interaction with their main customers (e.g., ferry operators) and the central resources that the port operator manages (e.g., quays).

7 Current and future challenges when installing OPS

The previous sections have mentioned a number of choices and challenges faced by shipping companies and ports during the process of installing OPS. In this chapter, first, the current challenges are summarised; and second, one of the major challenges in upscaling OPS in the future is discussed, namely access to electricity.

7.1 Current challenges

The identified challenges faced by shipping companies and ports when installing OPS are related to four areas: financial, business, technical and operational, as shown in Table 14.

Financial challenges are obvious for both actor groups, since the investment costs when installing OPS are high, although they vary depending on technical choices (e.g., voltage, frequency, cable arrangement and equipment), as discussed in more detail in chapter 5 (p.28) and section 6.2 (p.43). Retrofitting an existing vessel might also be costlier than the additional cost for a newbuild, which has been mentioned in a previous study as an impediment for ship owners (Khersonsky et al., 2007). For ports, there are uncertainties about how to ensure ROI, based on the lack of a business model or uncertainties about how many vessels are likely to connect to the OPS system. For shipping companies, there are uncertainties about the potential savings on operational costs when at berth, as this depends greatly on electricity pricing, which might vary.

For business-related challenges, there is a reluctance on the part of ports to install OPS if calling vessels are not prepared to connect to it. The unpredictability in the number of vessels expected to call at the port, in combination with the lack of a defined business model for a port's OPS infrastructure and operations, makes the entire business case uncertain. In similar reasoning, there is a reluctance on the part of shipping companies to prepare vessels to use OPS if OPS is not offered in the ports at which the vessels are planned to call. This challenge is particularly obvious if the vessels are planned for tramp trade (i.e., sailing without a fixed route). A non-match between the shipping company's routes and the ports' development towards offering OPS makes the business case for shipping companies uncertain (see chapter 6, p.41, for a deeper discussion on business models for OPS.) The lack of appropriate business models for OPS has been linked, in previous research, to ports not benefiting from OPS or to its not being more widely applied (Kumar et al., 2019). Winkel et al. (2016) mentioned problems of low profitability for those investing in shore power, whether shipping companies or ports, as it is not always evident how the investment costs can be distributed between different parties and how profitability can be achieved. This is especially true for ports which anticipate a low utilisation rate or for ships which do not expect to be able to connect in all ports at which they call (Winkel et al., 2016). Collaboration between important stakeholders (e.g., ship owners, terminal operators, port administrators, policy makers) has been referred to as a way to address the gap and promote OPS (Kumar et al., 2019). In this context, policy and regulation are seen as important from the standpoint of portside investments, vessel retrofit and design, and running costs, such as the comparative cost of electricity (Kumar et al., 2019; Winkel et al., 2016).

Technical challenges relate to the many options available for both ports and shipping companies when choosing which OPS technology to install, as explained in more detail in chapter 5 (p.28). In sum, there is limited guidance from standards, for example regarding connection set-up design and dimensioning, location of connection set-up on shore and location of onboard equipment. Deciding which technique to use may be very challenging. An important aspect is the alignment of technical choices between ports and vessels. If two ports choose different technologies, it might not be possible for a vessel calling at both ports to connect at both. From the port's perspective, moreover, it is challenging to find one universal solution that may fit all vessels calling in at the port.

Finally, operational challenges relate to access to power and risk of electricity scarcity, as discussed in the next section. Furthermore, if ships stay too short a time at berth, achieving financial benefits from connecting may be challenging from the shipping company's perspective, as less than two hours is typically considered too short a period to justify the connection and disconnection process.

Table 14. Challenges to the installation and use of OPS for ports and shipping companies.

Challenges	Ports	Shipping companies
Financial	High costs of installation	High costs of installation, especially retrofitting in existing vessels
	Planning ROI	OPS operational costs – uncertainty regarding electricity prices vs fuel prices
Business	Reluctance if calling vessels are not prepared to connect	Reluctance if not offered in ports
	Irregular/unpredictable port calls/relationship between port and shipping companies	Irregular/unpredictable port calls/relationship between shipping companies and ports
	No defined business model for OPS	
Technical	Limited guidance from standards	Limited guidance from standards
	Deciding which technique (incl. space ashore, amount of power required, voltage, frequency, cables, plugs, fixed or mobile, location ashore, number of vessels to connect at once); Incompatibility with other ports	Deciding which technique (incl. amount of power required, voltage, frequency, cables, plugs, location on board); Incompatible equipment in ports
	Inflexibility of infrastructure for other vessels	
Operational	Electricity scarcity	Short time at berth

7.2 Access to electricity

Access to power is crucial for OPS services in ports. In the future, moreover, it is likely that it will be even more difficult to secure a sufficient power supply for such services, making it all the more important to investigate e.g., energy management and related technologies (see e.g., Letafat et al. (2020); Tang et al. (2018)).

A recent report by the Intergovernmental Panel on Climate Change (IPCC) pointed at the urgent need to act for the environment and proposed electrification as a way forward. Sweden's electricity is currently mainly produced from wind, hydropower, biofueled combined heat and power plants, and nuclear power, with a very small portion coming from solar power. Currently, local electricity providers in a number of regions in Sweden (especially in the south) are struggling to produce the amount of electricity necessary for private households and industries to sustain their everyday activities. Electricity providers in the north (e.g., around Piteå), on the other hand, are typically producing enough power from renewable sources for the time being, at least prior to the establishment of any larger energy-consuming industries, and unless there are any momentary natural or technical obstacles to the production of power.

There are examples from industry of planned production units being stopped because of difficulties in supplying enough power (Dagens industri, 2019; SVT Nyheter, 2021a). At the same time, the transport sector is being pushed to transition to the use of electrified solutions, including OPS in Swedish ports, while there is an ongoing debate about the downsizing of nuclear power in Sweden. The Swedish energy sector is working on ways to manage the issue of potential power deficits, even though this might come with changes and consequences for users. Intermittent and renewable energies such as wind and solar make up a growing share of the production capacity, as well as more flexible distribution, incentive programmes, subscriptions for activity prioritisation (e.g., timing high-capacity demand), and digital technologies to manage the peaks and lows of electricity use. One electricity provider in the north mentioned the national plan to extend the grid to facilitate the sharing of surplus power between regions, but it is thought this extension will take at least a decade to complete. The long timespan indicates a need for communication between ports, electricity providers and Svenska Kraftnät early in the process when pursuing OPS.

The interviews with grid operators and electricity providers pointed to expectations of more volatile future electricity prices. In the case of OPS, electricity is not always more cost-efficient than fossil fuels, for example for some ships in the tanker segment. For such vessel segments, the motivation to connect to electricity might be the desire to benefit the environment, the competitive advantage, and/or the environmental index-related discounts on port and fairway fees. Yet, unless fossil fuels also become more expensive or OPS becomes mandatory, a large increase in electricity prices could render OPS less attractive for ships. OPS seems to be one of the best existing alternatives to fossil fuels for ships at berth today, as it helps to reduce local air pollution and noise for the operators and for residents around port areas, especially since innovative green fuels are not yet accessible. However, OPS might not be the most practicable option for all ports (e.g., small ports with low and irregular traffic), a problem aggravated by the electricity scarcity issue, which must be investigated further to ascertain that all of Sweden's OPS installations can be utilised and to justify the investment and allocation of national and EU public funds. Furthermore, accessibility to green fuels in the future could pose an alternative to OPS unless such fuels are very costly to purchase.

Examples of activities to secure power

The Port of Gothenburg and Stena have the problem of electricity in mind, especially as regards their electric vessel Stena Electra, and are currently investigating the possibility of energy storage on quayside to facilitate the charging of batteries on board. The possibility of the port having its own power production is also under investigation, but this would still require infrastructure for power storage since the port's power needs are intermittent.

The Ports of Stockholm produce own energy from solar panels for the buildings on site. In 2019, the amount of electricity purchased for Ports of Stockholm was around 39 million kWh, 11 million of which were used for OPS. About 60% of their ferry traffic calls in Stockholm in 2019 connected to OPS.

There is currently no up-to-date inventory of all planned and expected OPS facilities and associated power needs in Sweden, and existing reports on electrification do not normally discuss OPS. Some individual ports and organisations, on the other hand, have undertaken their own investigations on this matter. When planning for OPS or any other activities in port that require the use of electricity, close contact and discussion with the local electricity provider is key for the port to confirm that its plans are feasible. It is estimated that Sweden's total consumption of electricity of 140 TWh today will increase with 55 TWh more in 20 years (SVT Nyheter, 2021b), and, in the highest case scenario, it is expected by Svenska Kraftnät that it will more or less have doubled by 2045 (Svenska Kraftnät, 2021). Svenska Kraftnät has received an increasing number of applications for wind power and from offshore in the southern part of Sweden as well as, over the past year, more applications from large consumers (mostly located in the north and around the main cities). It was estimated by an electricity provider, as previously mentioned, that a cruise ship may need as much power as a small city (equalling around 10,000–15,000 households) when connected to OPS (e.g., 10–16 or more MW (Sweco Energy AB, 2020)), which, alone, represents up to 5% of the maximum capacity for this electricity provider. Their total capacity is of about 405 MW and, e.g., the city Helsingborg alone typically accounts for half of the need (Helsingborg.com, 2021). In light of the overall projected future demand for electricity, the portion and impact of OPS might be relatively small. Yet, meeting the local power demand could become a significant challenge. Furthermore, as power shortages impact price volatility, the expansion of OPS might require grid improvements in order to avoid situations where OPS competes for power, increases price volatility and loses attractiveness to users due to pricing.

One way to help manage limited power capacity at ports is to consider having a generator ashore to provide electricity to vessels (Innes & Monios, 2018; Sciberras et al., 2015) as a complementary solution. The use of fuel cell units at berths where natural gas is available as a fuel source, and where smaller vessels (e.g., tugboats, commercial fishing boats and crew/supply boats) are hoteling, might also be an alternative to OPS (Khersonsky et al., 2007).

Table 15 below lists the challenges and possible co-solutions to support the ports in relation to power access.

Table 15. Electricity scarcity-related challenges and co-solution possibilities or needs.

Challenges	Co-solution possibilities
• Great energy need • Production of necessary electricity • Need for grid extension • Large increase in electricity prices could make OPS less attractive • No inventory of foreseeable power needs from Swedish OPS facilities • Combined solutions and infrastructure for power storage might be needed to cope with electricity scarcity	• Possibilities for energy storage on quayside • Possibilities for power production in ports • Vessels as power source to local grid • Potential use of allocated power capacity for other activities, such as charging electric vehicles

8 Recommendations for ports and shipping companies

Aspects that practitioners should take into consideration when installing OPS have been identified in this study, and these are described in detail in chapters 4-7. The main aspects are compiled and highlighted in the sections below as recommendations to ports and shipping companies. Each section contains recommendations linked to four key areas for OPS: financial, business, technical and operational. Thereafter, a section of this chapter is dedicated to addressing the importance of collaboration between actors when installing OPS; another section to OPS guidance provided by external sources dealing with key issues; and, finally, a section discussing the implications of policy and regulation on OPS adoption.

8.1 Four important aspects for ports

Key aspects which ports should consider when dealing with the challenges mentioned in section 7.1 (p.51) are compiled in Figure 4. Note that these aspects are not presented in any particular priority order, and the situation in each port will determine the level of application.

Important aspects for **PORTS** implementing OPS

FINANCIAL

- ☐ Secure external funding to support installation
- ☐ Consider cost-sharing with shipping companies (e.g. cables, maintenance)
- ☐ Plan for how to recover investment
- ☐ Plan how to cover operational costs (maintenance, staff)

BUSINESS

- ☐ Secure agreements regarding vessels to connect
- ☐ Coordinate technical solutions with vessels and other ports
- ☐ Define business model including payment model to cover investment and operational costs Guidance is available from regulatory bodies

TECHNICAL

- ☐ Map power demand and secure availability
- ☐ Coordinate technical solutions with vessels and other ports (for increased compatibility and utilization)
- ☐ Get guidelines from standards, experts and authorities
- ☐ Determine voltage and transformer needs
- ☐ Map frequency requirements and need for converter
- ☐ Consider plugs and cables
- ☐ Map infrastructure and connection points incl. which quays, locations of cranes, transformer station
- ☐ Consider energy storage

OPERATIONAL

- ☐ Ensure sufficient power capacity
- ☐ Get necessary certifications
- ☐ Set up training for HV connections
- ☐ Inspect compatibility and maintenance onboard
- ☐ Perform safety check of equipment
- ☐ Plan and perform continuous maintenance
- ☐ Check conditions (wind, draft) and perform connections

Figure 4. Important aspects for ports implementing OPS.

Financially, external funding to support installation is one important factor to help overcome the high investment costs. An example among the interviewed ports is Gothenburg, where funding from "Klimatklivet" made it possible to plan for OPS service for tanker vessels, which will be offered from 2023. Another point to consider is how cost-sharing between ports and shipping companies can be achieved, for example regarding the purchase of cables and the maintenance of the equipment. In general, a plan for how to recover from the investment, as well as the operational costs, such as maintenance and staff, will be helpful and represent the first step towards a business model.

With regards to business-related matters, ports can try to secure agreements regarding which vessels are planning to connect. From the interviewed ports, it was seen that shipping companies have an important role in stating what demand will be made on ports. In this dialogue, the technical solutions need to be coordinated not only with the shipping company but also with other ports. It is crucial to define the business model, including a payment model to cover investment and operational costs. Possible ways of dealing with this matter can be found in chapter 6 (p.41).

Attention should be paid to technical issues from the start of the process of preparing for an OPS installation. As mentioned in chapter 5 (p.28), the port can face several possible choices, and there is no single straightforward option. First, the power demand needs to be mapped in order to secure the availability of power. Due to the considerable variability in demand for power, it is necessary to confirm whether the estimated demand profile can be supplied in the port. The scale and cost of different scenarios should be evaluated jointly with the local grid operator, both with regards to the current situation and potential future developments. Mapping power demand also requires an understanding of OPS customers, and a dialogue with shipping companies will make it possible to better understand their ambitions. Still, regulations such as ‘Fit for 55’ (see section 2.4, p.17, for more detail) will probably influence the market to prepare more quickly to use OPS.

Further, the choice of technical solutions for OPS should be coordinated with the shipping companies as well as other ports to increase compatibility and utilisation. It is recommended that ports use guidance from standards and also consult available technical expertise or hire a recommended external consultant who can investigate power needs and limits, vessel and terminal characteristics, technical solutions and prices, the operational pros and cons of each solution, as well as business model options. Finding the right help can, in itself, be a challenge, even for ports that have previously installed OPS, possibly because unique OPS cases require bespoke solutions. It is advisable, nonetheless, to follow the existing OPS standards, as this ensures a higher level of compatibility between ships and ports. In some cases, it might be helpful in procurement processes if ports and shipping companies can specify the functionalities that they wish to achieve in the requirements list rather than specify which equipment they expect to use, so as to give the manufacturers a chance to propose specific solutions based on the functionalities. In addition to other technical choices, the port might want to assess energy storage options (i.e., batteries) for peak shaving or intraday trading, to secure the power supply in the future.

While operating OPS, it is necessary to be aware of the risks associated with electricity price fluctuations and potential future lack of power. Before each OPS connection, the power availability must be checked, since the increased and fluctuating energy demand in society and respective prices may change the playing field for OPS quickly. Furthermore, before the OPS is in operation, a number of operational issues must be taken care of: the necessary certifications and training required by the standards and classification societies, inspections of compatibility and maintenance on board, safety checks of the equipment, and planning and performing continuous maintenance of the equipment. When the OPS is in operation, the conditions of each connection must be checked (e.g., wind and vessel draft) so that it can be performed in a safe manner.

8.2 Four important aspects for shipping companies

The key aspects for shipping companies to consider when dealing with the challenges mentioned in 7.1 (p.51) are summarised in Figure 5. Note that these aspects are not presented in any particular priority order, and the situation in each shipping company will determine the level of application.

Important aspects for **Shipping companies** implementing OPS

FINANCIAL

☐ Secure external funding to support installation
☐ Plan for how to recover investment
☐ Plan how to cover operational costs (connection fee, maintenance etc.)

BUSINESS

☐ Get ports' confirmation that they offer OPS
☐ Coordinate technical solutions with ports
☐ Define business model to cover investment and operational costs.
☐ Receive support from policy makers on e.g., stable electricity prices, tax exemption

TECHNICAL

☐ Get guidelines from standards, experts and authorities
☐ Coordinate technical solutions with ports (for increased compatibility and utilization)
☐ Determine voltage and transformer needs
☐ Map frequency requirements and need for converter
☐ Consider plugs and cables
☐ Determine connection point

OPERATIONAL

☐ Enough time at berth (above 2-4 hours)
☐ Get necessary certifications
☐ Get necessary training for HV connections
☐ Perform safety check of equipment
☐ Check conditions (wind, draft) and perform connections
☐ Plan and perform continuous maintenance

Figure 5. Important aspects for shipping companies implementing OPS.

First, the aspects compiled in this section are directed at shipping companies, which includes ship owners as well as ship operators. As mentioned in section 4.1 (p.23), these two roles could be played by the same company or different companies. In this section, no distinction will be made between the two roles. However, the financial and technical aspects might be most relevant for ship owners, whereas the business and operational issues more relevant for ship operators.

Financially, external funding to support installation is one important factor to help overcome the high investment costs. For example, tanker company Donsötank received funding from "Klimatklivet" which contributed to the installation of OPS equipment as well as energy storage systems on newbuild vessels, to make it both possible to connect to OPS and charge batteries in port (Sjöfartstidningen, 2021). Further, when it comes to financial issues, a general plan for how to recover from the investment and any additional operational costs will better prepare the business for operation.

With regards to business-related matters, shipping companies need to obtain the ports' confirmation that they offer OPS compatible with the vessel in operation. Examples from the interviews show that dialogue with the ports is important and must include how technical solutions will be coordinated.

Technical issues need attention from the very start of the process of preparing for an OPS installation. As mentioned in chapter 5 (p.28), shipping companies can face several possible choices, and there is no single straightforward option. First, the vessel's power needs must be communicated to the port in order to confirm the supply. Regulations such as 'Fit for 55' (see section 2.4, p.17, for more detail) will probably influence shipping companies to prepare to use OPS more quickly. Further, technical solutions should be coordinated with the ports to increase compatibility and utilisation. It is recommended that shipping companies use guidance from standards and also consult available technical expertise or hire a recommended external consultant who can investigate power needs and limits, vessel and terminal characteristics, technical solutions and prices, the operational pros and cons of each solution, as well as business model options to cover investment and operational costs. Finding the right help can, in itself, be a challenge; it is advisable, nonetheless, to follow the existing OPS standards, as this ensures a higher level of compatibility between ships and ports. In some cases, it might be helpful in procurement processes if ports and shipping companies can specify the functionalities that they wish to achieve in the requirements list rather than specify which equipment they expect to use, so as to give the manufacturers a chance to propose specific solutions based on the functionalities. When entering the operational phase, one important factor is to have enough time at berth, found by previous studies to be a minimum of two hours, as less than two hours is typically considered too short a period to justify the connection and disconnection process.

Also, before the OPS is in operation, a number of operational issues must be taken care of: the necessary certification and training for HV equipment handling, inspections of compatibility and maintenance on board, safety checks of the equipment, and planning and performing continuous maintenance of the equipment. When the OPS is in operation, the conditions of each connection must be checked (e.g., wind and vessel draft) so that it can be performed in a safe manner.

8.3 Collaboration between actors when installing OPS

Initiating an OPS implementation project can be challenging as shipping companies are reluctant to install OPS if the ports they call at or intend to call at do not yet offer OPS, and vice versa. They are also reluctant to purchase additional OPS equipment to accommodate a vessel or a port that has incompatible equipment, considering the high costs of each installation (see Table 14, p.52). The standards offer limited guidance about choosing the equipment/distribution systems for shore-to-ship connections for each segment, and there is no unique solution that fits all vessel segments at once. The most clear-cut cases of HV OPS in Sweden have, until recently, been ferries/ro-pax vessels that travel to the same ports routinely and frequently. Ferries receive shore power only for lighting and ventilation purposes. In addition, ferries have no cargo-handling machinery and undertake little dockside activity. Therefore, the electrification process for ferries is much simpler than it is for segments such as oceangoing cargo ships (Khersonsky et al., 2007). Moreover, whether a project to ensure OPS capability is started on the initiative of the port, the shipping company or even the goods owner, the main success factor for implementation has been that ports and shipping companies can collaborate on decision making in terms of choosing compatible OPS equipment for a specific terminal, applying for external funds (although the applications are normally written separately for each party), reaching an agreement about the use of the facilities, etc. It is thus understandable that negotiating/discussing such terms will tend to be easier between ports and their regular customers (e.g., ferries) than with more sporadic customers with less predictable routes (e.g., cargo vessels). This sort of collaboration often involves the shipping company and the port, but at times ports need to communicate with other ports to make sure they install the same type of technique for the vessels travelling between them. Previous projects have, indeed, shown that collaboration between actors, particularly between specific ports and shipping companies, is essential in enabling electrical connection at the quay, which, among other things, is highlighted in initiatives that have taken place in the Port of Gothenburg (Jivén, 2004). Further, communicating power needs with the grid and electricity companies and securing the power supply is a key initial question for the port when considering installing OPS, which requires an early dialogue with the shipping companies whose vessels are planned to connect to shore and with the grid operator and electricity provider.

8.4 Existing guidance for ports and shipping companies

Existing support for ports and shipping companies includes the international shore power standards, the work done at Transportstyrelsen (Mohebbi, 2015), and OPS webinars held by DNV, Lighthouse and EMSA and corresponding materials. Ports and shipping companies can also contact other ports and companies that have implemented OPS or participate in consortia regarding the topic. Many ports stated that they contacted other ports with OPS to learn more about what infrastructure can be used and what the common practices are. A minority of the interviewees, however, were part of groups/consortia that have discussed this topic. External technical expertise to investigate specific OPS needs and solutions, as well as help to involve the right stakeholders can also be hired before a procurement process is initiated. Some ports have technical staff in-house that can support with OPS investigations and decision making.

Organisations such as Sveriges Hamnar and Svensk Sjöfart can also be contacted to provide advice or referrals. Published research might also be a means of finding decision support. For example, Yu et al. (2019) have developed a strategy to provide environmental and economic decision support to shipping companies with regards to investing or not, and when, in installing a shore-power connection on board, based on a multi-objective approach. The 'KAJ-EL' project, reported here, will hopefully also offer guidance towards what steps to take when installing OPS as well as a path to reach people who can help find the necessary information to initiate an OPS planning process.

A publicly available report by Transportstyrelsen (Mohebbi, 2015), providing guidance regarding shoreside electricity for vessels, can be downloaded from their webpage, transportstyrelsen.se. This report is currently being updated with new OPS developments. The guidance aims to be a support tool for shipping companies and other stakeholders involved in OPS and to increase the safety level of HV connections and general knowledge about electrical shore connections and their risks. The guidance contains information about rules and standards, safety, technical descriptions, responsibility between ship and shore, and training in relation to using OPS.

EMSA has been developing technical guidelines for shoreside electricity and is currently documenting the results of the project. These should be made available on their webpage in 2022. The objective of this guidance is to support port authorities and administrations with reference elements to assist with the planning and with the technical and operational decision making on shoreside electricity for a greener environment and emissions reduction for EU port cities. The guidance aims to supplement existing information and fill gaps. It is divided into two parts: one offers information about the technology and equipment used for shoreside electricity, while the other addresses governance, planning, technical feasibility, power calculations, operations, safety, competence, and certification. However, the financial evaluation, environmental and sustainability aspects and utility grid outside the port are not covered in the guidance, although it does cover shoreside battery charging, shoreside power banks and port generators.

8.5 Policy implications

Interviewees suggested that legislation mandating OPS would push the adoption of standardised technologies and make it easier to choose which solution to purchase (see also Arduino et al. (2011)), and ports and shipping companies might then not need to be concerned about the risk of installing an OPS facility that will not be used (unless there is not enough power supply). Other interviewees, on the other hand, suggested that emission-reduction policies should be technology-neutral, not promoting any one technology over others but letting each organisation choose which technology, or combination of technologies, best fits each situation.

In time, newer ships may come ready with OPS capability, and port authorities may start investing further in OPS installations due to new upcoming environmental regulations. Here, the role of regulatory bodies and regulation is shown to be impactful in technology adoption (Zis, 2019). A different approach to speeding up adoption of shore power may come through the reduction of electricity prices in relation to existing bunker prices (Zis, 2019).

9 Conclusions

The intent of the KAJ-EL project was to offer decision support to ports and shipping companies about the implementation and use of shoreside electricity in Swedish ports. This is done by identifying the driving forces and barriers, actions and conditions to realise viable business arrangements in shoreside power. The project team investigated mainly national provision of shore electricity to ships at berth via a number of interviews and workshops with relevant actors, focusing primarily on the following aspects of OPS:

- The motivations among ports and shipping companies to offer or use OPS;
- The decision making steps and actors involved in the process of adopting shore power;
- The costs and business arrangements for installing and operating shore power connections;
- The challenges in the installation and operation of shore power;
- The different OPS equipment used in Swedish ports and on board vessels;

Accordingly, this project has gathered an overview of the OPS situation in Sweden and put together recommendations for future OPS implementation and research, as summarised below.

9.1 Sweden at the European forefront

Sweden is currently the country in Europe with most ports (9) providing OPS, mainly within the ro-pax and ferry segment. Swedish shipping companies, in particular within the ro-pax and tanker segment, has pushed the development towards the installation and use of OPS in several examples. In addition to the existing provision, several other Swedish ports are currently considering the preparation for and installation of OPS. Still, Swedish ports and shipping companies are highly dependent on the development outside of Sweden, since in order to have a viable business case, vessels want more than one port to connect to. To reach such development, a dialogue and coordination of technologies between ports are necessary.

9.2 Regulatory pressure increases

Currently, there is a broad political push for the electrification of the Swedish transport sector, and OPS at maritime ports fits well within that paradigm. The pressure on the Swedish actors is also likely to increase as new regulations on the EU-level are expected to steer towards using OPS to a larger extent in the future (e.g., through the possible implementation of ‘Fit for 55’). As seen in this study, strict emissions regulations are one of the strongest driving forces behind the implementation and use of OPS. Furthermore, at a local level, OPS has been highlighted by authorities as an important alternative for ports to evaluate when they apply for new environmental permits. Still, the knowledge among non-experienced ports is low and further guidance on OPS installations is needed to meet upcoming regulations. Also, the investment costs are high and external funding is often required. Authorities thus need to be aware that investments in OPS might represent a large financial burden on ports and shipping companies and thus they might require financial support to speed up adoption as has been done in the ports of Gothenburg and Stockholm.

9.3 Securing electricity supply in ports

The electricity demand is expected to increase dramatically in the coming years, along with the electricity prices, due to the general electrification trend. Thus, OPS will compete with other sectors when it comes to securing access to power. When considering installing OPS in a port, an early dialogue with the grid operators and electricity providers is therefore necessary.

The electricity scarcity issue must be investigated further to ascertain that Sweden’s OPS installations can be utilised and to justify the investment and allocation of national and EU public funds. There is currently no inventory of all planned and expected OPS facilities and associated power needs in Sweden, and existing reports about electrification do not normally discuss OPS. To get a better overview of the OPS power needs in the future, further work should investigate possible power demand scenarios from the development of OPS services and its usage in Sweden, in line with upcoming regulations, and also taking into account possible implementation of future zero-emission vessel alternatives. Furthermore, OPS should not be analysed in isolation; rather be set as part of the full port system which might include other services demanding power, such as charging electric vessels, handling equipment and trucks.

Also, other ways of securing electricity supply for OPS could become crucial in ports, e.g., using batteries for evening out the difference between demand and supply, which is one approach considered among Swedish ports. Still, such options, as well as other possibilities of supplying electricity, should be further investigated as part of all the port’s services requiring electricity.

9.4 Collaboration between actors is key to successful OPS implementation

OPS is most successful when it results from a concerted effort between ports and shipping companies, consultants (who can help to investigate ports’ needs and OPS techniques), and grid operators and electricity providers (in what concerns energy capacity).

Uncertainty remains over the long-term usefulness of OPS installations, especially for those ports that do not have predictable traffic with regular incoming vessels and long-term contracts with shipping companies, or for shipping companies calling at various different ports. To counteract these uncertainties, ports and shipping companies should reach agreements regarding solutions for OPS. The situation might, however, improve due to the increasing interest in and adoption of OPS. Coordination of OPS techniques/equipment between ports and shipping companies is central, and the difficulties to decide on technical options could be guided by standards (partly), experts and authorities.

Business models among ports are often financially weak but various approaches are possible, such as different payment models. To succeed with an OPS installation, ports and shipping companies need to take financial, business, technical, and operational issues all into account. The viability and longevity of OPS are not always thoroughly investigated in advance, and such investigations should be carried out on a case-by-case basis.

9.5 Higher level of standardisation can play an important role

Standards are important and can help speed up the further introduction of OPS. International OPS standards IEC 80005 (LV and HV) are being updated to include more vessel segments. Nonetheless, there is still variation in the possible technical combinations, stations, and connection points. These are typically chosen based on the vessel segment and size that will connect (including their power, voltage, and frequency needs), the available space on the quay, the needs and resources of the port, etc. The further development of the technical standards could be helpful in guiding and speeding up OPS implementation among ports and shipping companies, especially for those with no earlier OPS experience. There are, though, different viewpoints regarding the degree to which the standards should be developed and if is it possible to establish a universal solution for OPS. Even if development is taking place, further research would be valuable on this topic, e.g., to assess the recommendations in the standards and find development paths that are most feasible for OPS installations among involved actors.

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Appendix

Appendix A. Data collection events

Table 16. Data collection events (this does not include any email correspondence for follow-up questions).

Type and number of data collection events	Interviewee(s)/Participant(s)
Interviews	
5	Ports of Stockholm
2	Port of Gothenburg
1	Stena Teknik (Shipping company – ferries; terminal owner)
1	Terntank (Shipping company – chemical/oil tankers)
1	Port of Norrköping
1	Port of Gävle
1	Port of Trelleborg
1	Port of Skellefteå
1	Port of Piteå
1	Stemman-Wabtec (Equipment manufacturer/supplier)
1	Port of Helsingborg
1	California State University Long Beach, about Port of Long Beach
1	Port of Umeå
1	Visby/Gotland Ports
2	Port of Seattle, North West Sea Port Alliance (also about Port of Tacoma), University of Washington
1	Trafikverket Färjerederiet (The Swedish Transport Administration’s yellow road ferries) (Shipping company – public ferries)
1	Donsötank (Shipping company – chemicals/oil tankers)
1	Göteborg Energi (Grid operator)
1	Unifeeder (Container vessel charterer)
1	Ahlmark Lines (Bulk vessel charterer)
2	Powercon Denmark (Equipment manufacturer/supplier)
2	ABB (Equipment manufacturer/supplier and systems integrator)
1	Cavotec (Equipment manufacturer/supplier and systems integrator)
1	Öresundskraft (Grid operator and electricity provider)
1	GEAB (Grid operator and electricity provider)
1	Port of Kristiansand Norway
1	PiteEnergi (Grid operator and electricity provider)
1	Svenska Kraftnät (Transmission systems operator – governmental authority)
Webinar attendances	
1	ABB (Equipment manufacturer/supplier and systems integrator)
1	Sjöfartsstyrelsen Denmark

1	Baltic Ports OPS Webinar
1	EMSA OPS Guidance Workshop
1	Lighthouse, RISE, Port of Gothenburg, Stena
Workshops	
1 – Business models for OPS	Ports of Stockholm Port of Gothenburg Port of Gävle Port of Norrköping Port of Umeå Port of Helsingborg Ports of Visby/Gotland Port of Kristiansand, Norway Unifeeder Donsötank Trafikverket Färjerederiet (The Swedish Transport Administration's yellow road ferries) Stena Teknik Sveriges Hamnar Svensk Sjöfart Transportstyrelsen Rejlers
1 – Port perspective with Port of Norrköping	Port of Norrköping
Final seminar	
1 - Presentation of results - Panel discussion (Sveriges Hamnar, Stena Teknik, Transportstyrelsen, ABB and Göteborg Energi)	32 external participants including ports, shipping companies, electricity providers, equipment suppliers, researchers, and authorities