Business case

– potential for onshore power supply at the Port of Helsingør

Conducted as a part of the Interreg Nort Sea Region project: NON-STOP by GEMBA Seafood Consulting on behalf of Port of Helsingør

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Interreg North Sea Region NON-STOP European Regional Development Fund

EUROPEAN UNION

PORT OF HELSINGØR HOME OF HAMLET

Content

Preamble

The European Union Recommendation 2006/339/EC states:

"Member States should consider the installation of shore-side electricity for the use by ships at berth in ports, particularly where air quality limit values are exceeded or where public concern is expressed about high levels of noise nuisance, and more especially in berths situated near residential areas."

The ferry operator FourSeas operates a route to Helsngborg, Sweden from the port of Helsingør and has electrified their operation with the largest battery ferries in the world.

The ferry operation has served as an inspiration for the business case the Port of Helsingør want to implement Onshore Power Supply (OPS) for other operations in the port.

This business case is conducted as a part of the Interreg North Sea Region project NON-STOP (New smart digital Operations Needed for a Sustainable Transition of Ports). The business case is based on various pilots and joint practice between a strong partnership consisting of several ports, business, and scientific organizations.

NON-STOP is led by Ports of Zwolle and the current analysis is done by Port of Helsingør, conducted of GEMBA Seafood Consulting A/S.

1. Executive summary

The executive summary outlines the main findings from the business case of the potential construction of onshore power supply (OPS) in the Port of Helsingør.

The **set up** in Port of Helsingør: Ships are unloading wood crisp in the port and using the ships diesel engine to maintain the electric systems on board the vessels. Diesel powered cranes lifts the wood chips onto trucks.
The **need** for OPS**:** The situation in the Port of Helsingør shows a **need** for an OPS. The statement is based on following: ➢ Ambitions on greening the unloading and crane functions are central action point seen from a port management view. ➢ Electrification of the vessels hoteling and the crane unloading will reduce the locale pollution of SOx and NOx in the city center and reduce the carbon footprint of CO_2.
The **economics** of OPS: The business case shows negative **economic** result based on the current situation and from an economic perspective – despite this there are reasons of establishing of an OPS. The statement is based on following: ➢ The electrification of ports is increasing, and OPS will be a central service of a port and enable a carbon saving to the port and the shipping company. ➢ The investment of an OPS can be seen as a green facility that will lead the Port of Helsingør to a further greening of its profile.
The **environmental** impact from OPS: The **environmenta**l impact of lowering the emission of NOx, SOx and CO_2 is positive for an OPS in – impacts that in the long run may turn the business case in a positive direction. The statement is based on following: ➢ The internalization cost of CO_2, NOx and SOx may increase in the coming years through additional taxation of these emissions and may contribute to the business case. ➢ The reduced environmental impacts from an OPS may secure the "rights to operate" for Port of Helsingør in the future.
The **design** of OPS: The investigations shows that an OPS **design** can be made to fit into the city environment around the port area, the national heritage of Kulturværftet and the Kronborg Castle. The statement is based on following: ➢ The design of a future OPS is seen as a major consideration and the OPS must be able to fit into the city and port area from an aesthetically point of view. ➢ Based on the investigations done about different OPS it is possible to construct component fitting into the environment and/or buried into the quay.

2. Objective

The objective of the business case is to identify the costs and benefits of installing an onshore power supply (OPS) at the Port of Helsingør, and thereby reduce the air pollution of local vessel emissions of SOx and NOx and the greenhouse gas of CO_2. The business case will also make an initial analysis of the opportunities of electrifying the port equipment such as cranes and vehicles.

In 2019 a combined heat and power plant (CHP) was built just outside Helsingør. The CHP uses wood chips that is imported from Germany, Sweden and the Baltic countries and is handled over the Port of Helsingør. This means that during unloading of the wood chips the vessels are using their own diesel-powered ship engines. An OPS system can be a central component to reducing emission from port operations.

The Port of Helsingør is in the city centre of Helsingør which create great requirements to ensure an aesthetic appearance and the design of an OPS is of great importance for the success of the service in the port.

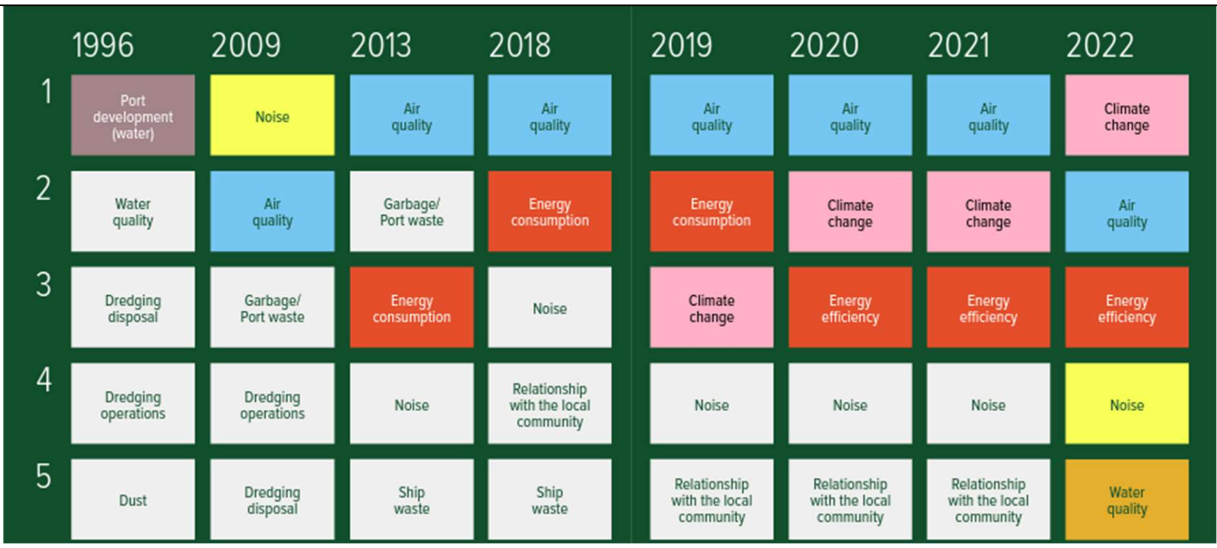
3. Background

Onshore power supply (OPS) is one of dominating strategies to reduce the environmental impact of vessels that are calling a port.

The European Seaport association makes a survey each year about the most important environmental factors for European ports and the survey hence gives an impression of the topics of importance in ports.

Figure 1 illustrates the top five environmental priorities of EU Ports from 1996 to 2022.

Figure 1: Extract of Top 10 Environmental Priorities of EU Ports over time.



	1996	2009	2013	2018	2019	2020	2021	2022
1	Port development (water)	Noise	Air quality	Air quality	Air quality	Air quality	Air quality	Climate change
2	Water quality	Air quality	Garbage/ Port waste	Energy consumption	Energy consumption	Climate change	Climate change	Air quality
3	Dredging disposal	Garbage/ Port waste	Energy consumption	Noise	Climate change	Energy efficiency	Energy efficiency	Energy efficiency
4	Dredging operations	Dredging operations	Noise	Relationship with the local community	Noise	Noise	Noise	Noise
5	Dust	Dredging disposal	Ship waste	Ship waste	Relationship with the local community	Relationship with the local community	Relationship with the local community	Water quality

Source: ESPO

As it can be seen from figure 1, the air quality has been on the top of the priority list since 2013 and is an important topic to many ports.

The OPS is one of the techniques that becomes widely used to mitigate this challenge. When at quay, the OPS replaces auxiliary engines that is used for various activities such as loading, unloading, heating, lighting, and other technical onboard systems.

In most vessels, the auxiliary power is generated by the vessels own engines that thereby emits CO2 and air pollutants such as NOx and Sox. With connection to an OPS, the vessels get connected to the local energy grid and thereby follows the emissions profile of the local energy production facilities. Under Danish conditions, approx. 40% of the electricity production comes from renewable resources such as wind, solar and biomass.

There are several design parameters that need to be considered when establishing an OPS at ports. Some of these parameters are geographically conditioned while others are depending on the port structure, i.e., what types of vessels call the port etc.

Table 1 sums up some of these parameters that need to be included in an assessment on the selection of the right system.

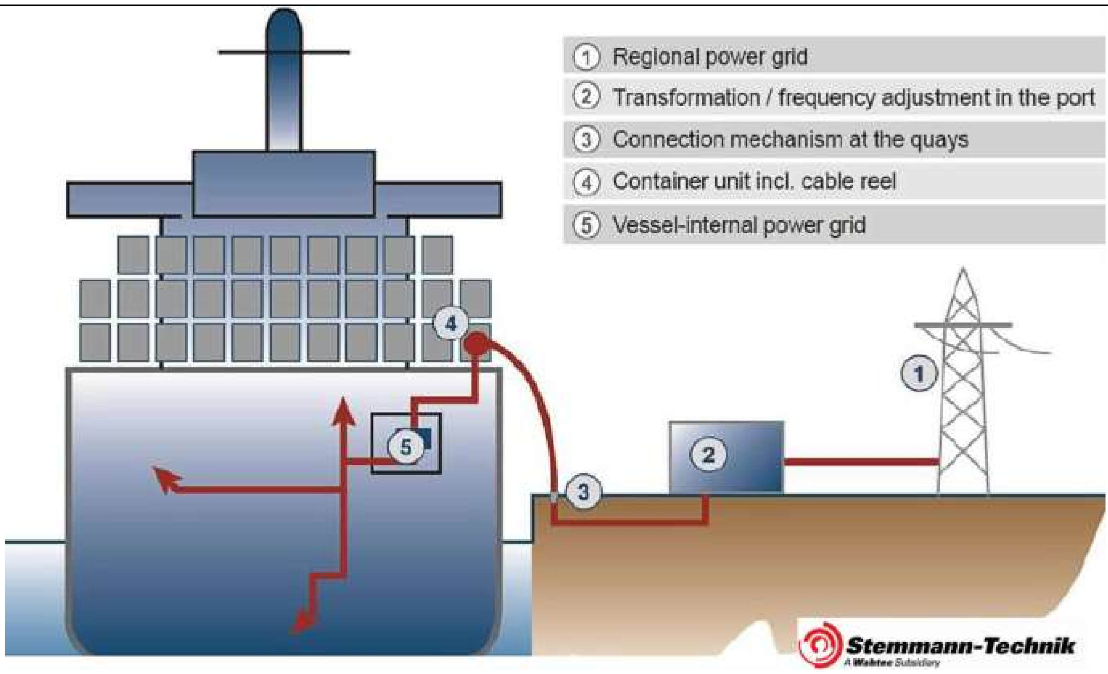
Table 1: Relevant parameters in assessment of OPS systems	
Parameter	Explanation
Power frequency level	Electricity in Denmark (and Europe) is produced with a frequency of 50hz. Most vessels that operate in Europe also uses 50hz, while most vessels in the US requires 60hz.
Voltage	Low voltage (typically 400-480 V) is applied to smaller boats but may require several cables to meet the requirement of larger vessels. High voltage (more than 1,000V) is more common in OPS today.
On board electric system	Not many vessels today can use power from an onshore supply and investments aboard the vessel is required.
Synchronization	When vessels use shore power the power that comes from the grid through the transformer station need to be synchronized with the electric circuit of the vessel. This synchronization can either be made on board the vessels or as a part of the OPS
Type of vessels	The power consumption on board vessels is depending on the utilization of various electric components. While a cruise vessel has a huge power demand for cooling, heating, lighting etc., smaller bulk carriers require much less power.
Bulk carriers	According to xx a typical bulk carrier needs 400/440/690V – 50/60hz and between 100-500kW https://glomeep.imo.org/technology/shore-power/

4. Different onshore power supply systems – setup and design

A shore power system is made up of two main components, the grid connection in the substation and the connection point.

Depending on the type of system that is selected the connection point may be stationary or mobile. Figure 2 shows a sketch of a typical OPS setup.

Figure 2: Typical setup of OPS system



Source: Stemmann-Technik

Depending on the vessel type and vessel tasks there are various requirements to the power demand.

According to a study on Norwegian ports typical system parameters for different system power has been assessed and is presented in table 2.

Table 2: Overview of power systems categories

System category	System power	Typical system parameters
1	< 100kW	230/400/440V – 50/60 hz
2	100-500kW	400/440/6900V – 50/60 hz
3	500-1000kW	690/6.6/11kV – 50/60 hz
4	>1MW	6.6/11kV – 50/60 hz

Source: Landstrøm i norske havner DNV-GL

In the same DNV study, an assessment of requirements from different types of vessels is presented.

As all bulk vessels that calls at the Port of Helsingør are between 1000-5000BT, the needed requirements for an OPS are 400/440/690V at 50/60hz.

4.1. Examples of different OPS in ports

Depending on the profile of the different vessels that call the ports, there are different requirements to the OPS.

Large vessels like cruise vessels requires much more power than a smaller bulk or Ro/Ro vessels. If the shore power is only intended for one type of vessel, e.g., a ferry, the dimensioning of the equipment may be rather simple, but if the port wish to accommodate several different call types, the voltage and frequency need to be variable.

At this point the OSPs become more common around the world there are different standardizations to ensure a uniform layout of the systems. The International Organization for Standardization (ISO) has developed and described a standard that ensure some consistency for the ship owners calling different ports.

The standardization of relevance here is the IEC/PAS 80005-3:2014 Utility connections in port — Part 3: Low Voltage Shore Connection (LVSC) Systems.

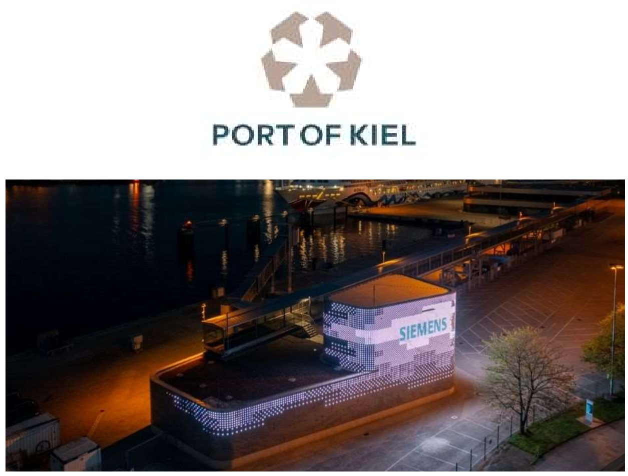
Below are some OPS systems from various ports that may serve as inspiration.

Port of Kiel – Germany

Port of Kiel's first OPS has been in operation at the Norwegenkai since May 2019 and supplies electricity to the ferries of the Norwegian shipping company Color Line.

The system has a maximum power output of 4.5 megawatts at 10 kilovolts and a grid frequency of 50 Hertz. As the OPS is designed only for the ferry transport, there is no need for variable frequency and voltage.

The OPS is much larger than what is required at the port of Helsingør, but there have been large requirements in the aesthetic integration of the shore power at the quay. The system became wrapped in a building with a façade of LED lights and was well received in the community.



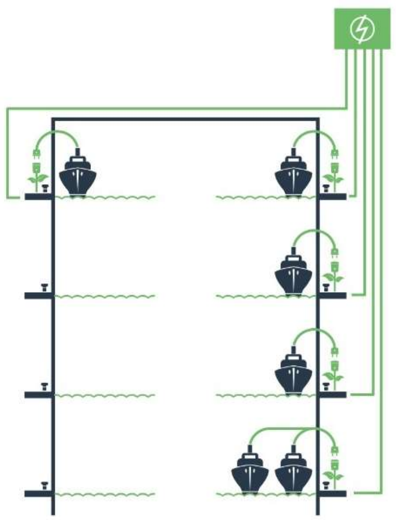
Port of Skagen - Denmark

The Port of Skagen invested in 2021 in an OPS system to accommodate calls from different vessels such as the fishing fleet, bulk, offshore rigs etc. The different vessels have different needs and requires thereby an option for varying the frequency and voltage.

The chosen system was delivered by PowerCon and consists of five shore power outlets with each 350A, variable voltage from 400-690V and variable frequency of 50-60hz.

The entire system has a maximum load of 4MW. The price of shore power from the Port of Skagen is variable and follows the fluctuations in electricity costs to the port.

The entire OPS system is under development in Skagen, and a total cost price is not fixed yet.



SKAGEN HAVN

MARITIMT BUSINESS HUB

The Port of Korsør - Denmark

The Port of Korsør is installing an OPS installation that will be in operation in early 2023.

The installation will deliver 350A, variable voltage from 400-690V and variable frequency of 50-60hz from five different power outlets (connection boxes) along the central quay Amerikakajen. The OPS installation is prepared for plugging in a connection to a port crane to load and unload of goods. The crane power outlet can deliver 700A.

The OPS installation consists of the five connection boxes and two 20" containers that contain the switchgear, transformer, and control units. The two containers are located behind a building and hence not that visible in the port environment.

The OPS has a capacity to serve two vessels at the same time and ensure the operation of two electric cranes. The total cost of the OPS excluding installation, is approx. 1.000.000 EUR.

Design of OPS

According to interview with Soft og Teknik, the solutions they can deliver does not have to be a containerized solution.

For many years transformer stations for our households have come in a great variation of solutions and there are not real constrains as to how an OPS installation could look like. The Danish company Alfred Priess has a tradition for building the houses for transformer stations and could also be a relevant provider of a solution for the Port of Helsingør. It is also possible to get an architect to design a housing for the technology if it complies with certain security measures.

The pictures below are two transformer housings that has been built by Priess and illustrates the possibilities of fitting the design of the structure to the surroundings.

Picture 1: Examples of housings for transformer stations from Priess A/S	
	Transformer station covered with profiled Corten steel delivered to the Port of Odense
	Fully wood-clad transformer station adapted to the urban environment in Skjern

Apart from the housing that are seen examples of above, there is also needed a power outlet at the quay and a cable drum that connects the vessel to the outlet. These also come in many different solutions and sizes. The OPS system at the port of Skagen is delivered by PowerCon and this also includes the power outlet.

Figure 3 below shows a power outlet from the Port of Skagen and a mock-up of a power outlet and a picture of a shore power cable from PowerCon.

Figure 3: Power outlet mock-up from PowerCon and outlets at the Port of Skagen

Source: PowerCon

Source: Port of Skagen

Source: PowerCon

5. Onshore power supply suppliers

There are several potential suppliers of an OPS system for the Port of Helsingør.

Some companies have standardized modules ready for installation while other providers have a more tailored approach. In some cases, the hardware is provided by one company and assembled and tailored for the port by another company, such as it is the case with the Port of Korsør, where the main hardware components were manufactured by Schneider Electric and assembled and tailored to the local needs by Soft og Teknik.

Table 3 below shows some of these companies.

Table 3: Some relevant suppliers of OPS and assembling of systems.

Company	Special attributes and where they are located
PowerCon	PowerCon is a Danish engineering company with a specialized knowledge within electrical power conversion and can connect and assemble shore power systems to fit the requirements from the port. PowerCon connects the parts but is not a direct producer of the different elements in the shore power system. Powercon has delivered shore power systems to both the Port of Skagen and Port of Grenaa. PowerCon delivers complete turnkey solutions delivered in 20 ft containers.
Schneider	Schneider electric delivers shore power systems in all sizes and suited to fit all sorts of demands from low voltage outlet to large cruise ships. Schneider electric has delivered the hardware for the shore power system at the port of Korsør.
Soft og Teknik	Soft and Teknik is a Danish specialist in energy optimization and does not build the actual shore power system but can do the installation, calculations etc. In the Port of Korsør, Soft and Teknik assembled and installed the shorepower system while the hardware in terms of transformer etc. came from Schneider. Soft og Teknik can also deliver turnkey solutions that is ready to be installed directly at the port.

Apart from those OPS suppliers briefly described in table 3 several other companies offer either complete turnkey solutions or different parts of the OPS, these companies include, among others, ABB, Stemmann-Technik, Actemium and Zinus Port Power.

5.1. *Electric port cranes*

Several crane producers have an electric or hybrid option in their catalogue.

Apart from not having any emissions when it is operating on power from a shore power system, it is also much quieter and hence more suitable in an urban port like Helsingør.

Figure 4 shows an example of some cranes that could be of relevance in relation to the Port of Helsingør.

Figure 4: A display of the Sennenborg 850E crane and Mantsinen 200	
	Sennenborg 850E comes in a Electric Drive version that requires 400 volt at 50 Hz with a consumption of 250 kW
	Mantsinen 200 has a DualPower technology that allows the crane to run on 100% electricity or using its diesel engine. The electrive engine runs with 355 kW, 50hz and either 380V or 690V.

6. Legal and organizational aspects

6.1. Danish aspects

As electricity in many countries gets greener and relies on e.g., wind energy, there is a desire to increase the usage of electricity for process purposes in industries. Today, Danish companies are not paying taxes on energy for production but have hitherto paid a tax on electricity. To change this paradigm, Denmark designed some test schemes in connection to a 'Climate Plan' to initiate a development where companies substitute e.g., natural gas, diesel, or other fossil fuels with electricity.

When purchasing electricity for process energy purposes, such as that of producing power for shore power, there is a relaxation for payment of taxes. Today, the tax relaxation runs as a test scheme for the years 2020 to 2022 but negotiations are ongoing either to prolong the test scheme or to make it permanent. If the tax relaxation will not continue, it will be very difficult to be profitable or at least get some sort of business out of the shore power. This should be in the clear

The electricity tax amounts to 90.3 øre per kWh in 2022 and the tax test scheme means that for 2022, 89.9 øre/kWh of the 90.3 øre will be reimbursed, meaning that only 0.4 øre/kWh will be paid[1]. As of now, since it is a test scheme, the reimbursement needs active reporting from the electricity customer (i.e., the port in this case), but the negotiations for a permanent scheme, may lead to a complete absence of the electricity tax for process purposes and hence no need to ask for reimbursement.

While there are relaxations on the electricity tax there still needs to be paid energy tariffs to the energy net owners.

6.2. European and international aspects

There are no formal requirements that forces ports to invest in shore power systems.

But at EU level the fitfor55 package includes a proposal called 'Fuel EU-Maritime[2]' that suggests that ports in the TEN-T core network should be able to supply shore power by 2025.

Though this is still a suggestion and may not affect the Port of Helsingør directly, it indicates that is a subject that is on the EUs radar and may in the future be a natural service that ports should have to its customers.

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1 https://skat.dk/data.aspx?oid=2234584
2 https://www.europarl.europa.eu/thinktank/da/document/EPRS_BRI(2021)698808

7. Attributes of the Port of Helsingør

The Port of Helsingør is located 45km north of Copenhagen and has an easy connection to the highway E47 and a ferry connection to Helsingborg in Sweden.

Apart from the ferry connection there is some import of wood chips for the local supply heat and power plant. The port can receive vessels of up to 150 meters in length and a maximum draught of 6.5 meters. Currently the largest activity is the ferry connection which brings more that 5 million tonnes of goods and approx. 4 million passengers between Helsingør and Helsingborg each year. The ferry activity is supported by the Port, but the main operation is handled by the shipping company ForSea.

The wood chip operation is carried out to support the fuel supply of the local heat and power plant CHP. The plant will use approx. 110,000 tonnes of wood chip per year and there has been made agreements with three different providers that will deliver sustainably certified wood chips from forests in Denmark, the Nordics, and the Baltics. Wood chips from forest in Denmark will come by road while shipments from the Nordics and the Baltics will be delivered by ship. The most obvious choice would be to have the wood chip delivered at the Port of Helsingør, but other ports in the area are competing for the loads and may be able to deliver other services such as larger quay facility than the port of Helsingør.

In the years from 2019 to 2021 the wood chips were delivered from approx. 1/3-part on trucks from Danish forestry production, 1/3-part from the Port of Hundested and 1/3-part from the Port of Helsingør. In the port of Helsingør, this means 15-20 vessel calls per year with wood chips and each vessel is unloaded and hence at quay operation for approx. 48 hours per call. The wood chip import process in the Port of Helsingør works by unloading the vessels directly onto lorries that brings the loads to the power plant.

Table 4: Wood chip landings in the Port of Helsingør (1,000 tonnes)

	2018	2019	2020	2021
Port of Helsingør (dry bulk)	0	36	16	22
Source: Statistics Denmark				

Table 4 above show number of wood chips landings in Port of Helsingør. The cranes that are used for the operation can handle 1,200 to 1,300 tonnes per day and may be in operation between 7:00 and 18:00 and hence 11 hours per operating day. Each lorry can carry around 35 to 40 tonnes and with 22,000 tonnes of wood chips as it was the case in 2021 approx. 590 truck loads are transported from the port in the city center to CHP power plant. The main activity of unloading the vessels is in the season from late September to late April.

Today the wood chips are unloaded by crane that is either owned or rented by the stevedore and the choice of crane is thereby out of reach for the Port of Helsingør. However, there may be opportunities to either convince or provide incentives to an operator to use an electric powered crane if a supply at the port is available.

7.1. Potential bulk operators and vessels

The vessels that call the port of Helsingør are mainly dry bulk vessels and since the wood chip is imported from mainly Germany, Sweden and the Baltics, the vessels are in near shore operation. The CPH and the Port of Helsingør has found a level between how much wood chip that is needed for heating and power production and the size of the vessels that should bring the wood chip.

A typical vessel that brings wood chip to the port is approx. 80-100 meters long and carry between 1,500 and 3,000 tonnes per load. With a demand of approximately 20-30,000 tonnes of woodchip per year, this leads to approx. 13 calls per year.

There are several shipping companies in this category of bulk vessels, and one of the operators could be Baltic shipping.

Baltic shipping company is transporting cargo and providing a variety of specialized logistic services to companies worldwide.

Baltic Shipping Company A/S has an efficient network and strong presence in the market and offer ships agency in many Danish ports; Copenhagen, Frederiksvaerk, Hundested, Helsingor, Korsoer, Koege, Vordingborg, Orehoved, Nykøbeing Falster, Odense and Lindoe. BSC is specialized in competitive chartering, ships agency, ship management, project cargo and stevedoring for all kinds of cargo. BSC have commercial management of a fleet of +50 dry cargo vessels in range from 1.400 – 5.500 dwt and offer total transport solutions from A-B.

Typical vessel, BREB TRADER/M/S Richeleu

Flag: Portugal [PT]
Gross Tonnage: 2545
Summer DWT: 3850 t
Length x Extreme: 88.6 x 12.5 m
Year Built: 2007

8. Shore power at the Port of Helsingør

8.1. Current need for OPS:

Based on the above profile and attributes of the port of Helsingør and the structure and demand, there is a current need of:

- one power outlet for vessels calling the port and
- one power outlet to support a crane in its operation.

8.2. Potential need for OPS:

However, there are good reasons to future proofing the OPS with two power outlets for vessels and two crane power outlets to ensure that the system will be able to handle two vessels that call the port at the same time.

8.3. Need for electricity to OPS:

At the Port of Helsingør there is an opportunity to use a 63 amps power outlet which is only enough for smaller vessels with very low hotel load.

The vessels that bring wood chip to the port requires more power and a minimum of 180 amp with a variation in voltage from 440-690. If the calling vessel is a self-unloader and it is possible to engage the unloading system by electricity, an amperage of at least 350 would most likely be needed.

For an electric crane to operate at the port, a higher power supply will be needed. The Sennenborg 850E requires 250 kw at 400 volts and hence 625 amps (A=W/V), and a power outlet for the crane to be included in the shore power system will need to be around 700 amps.

Electricity in Europe has a frequency of 50hz and so do most vessels that operate in this region. However, there may be some vessels that uses a frequency of 60hz and in order for these vessels to connect to the shore power, the frequency need to be converted to the vessel. Apart from the frequency conversion, there is also a need for the shore power system to be able to synchronize with the vessels electricity circuit.

Through discussions with the port, desk research and talks with ports from the NON-Stop network it has been assessed that the Port of Helsingør will need one power outlet of 350A to supply the vessels and one outlet of 700A to supply a crane. The power outlet for the vessels should be able to change the frequency between 50hz and 60hz to comply with the calling vessels requirement. The same goes for the voltage that should be adjustable from 400V to 960V. The outlet for the crane does not need the same flexibility in frequency.

8.4. *Need for design of OPS:*

The actual transformer and converter are often built into one or more 20 feet container depending on the size of the system. With the requirements stated above it should be possible to fit the solution into either one 20 feet container that may be covered to fit the surroundings or be built into a different solution like the transformer shed.

Figure 5 illustrates a potential location of the transformer/converter and power outlet.

Figure 5: Suggested location of the transformer/converter and the power outlet at Kongekajen

It is also an option to locate the transformer/converter farther away from the quay, e.g., behind the 'Kulturværftet' and drag the cable under the roads etc. to the quay area. There are some power losses in the cables and additional installation costs for this operation. The cable path from Kulturværftet to Kongekajen is approx. 550 meters. A picture of location and cable trajectory is found in the appendix.

It has been discussed with OPS suppliers whether it is possible to put the OPS under the ground, either completely or partly. The OPS suppliers agrees that it is a possible solution and do not see why it should not be possible. There is, however, a need for ventilation and hence some structure above the ground to ensure the cooling.

Another solution is to have a mobile OPS. This means that the system should be moved to the location where it is needed when the ship arrives. This solution ensures that the system does not take up much space at the Kongekajen, but the container need to be stored somewhere else and moved by truck to the quay when needed. This transportation of the system also requires an additional cost.

9. Cost perspectives – case of OPS in Helsingør

In an analysis of the costs and benefits of a shore power system it is required to have information about the actual investment cost of an OPS, but also the potential revenue streams from the selling of the shore power. In order to get an understanding of the how much the ship owners are willing to pay it is necessary to understand the production cost of electricity on the on-board auxiliary engines or generator.

9.1. Electricity costs

Most vessels at the quay uses their auxiliary engines or generator to produce the electricity they need for hoteling and potential other equipment. Some port operations such as unloading with self-unloader or pumping pelagic fish to the factory may require more power and there is a need for using the main engine.

There are some variations in the on-board power production mainly based on the fuel costs, the load of the engine when producing and age of genset. Based on talks with ship owners and industry knowledge the production cost of on-board power was in 2021 approx. 0.13 to 0.15 €/kWh. However, with the current fuel price that sees great fluctuations and currently at a very high level, these numbers will not correspond to energy production cost today. Figure 6 shows the Global 20 Ports Average and illustrates that prices has gone up from around 600 USD in 2021 to around 800 USD in 2022, an increase of 33%.

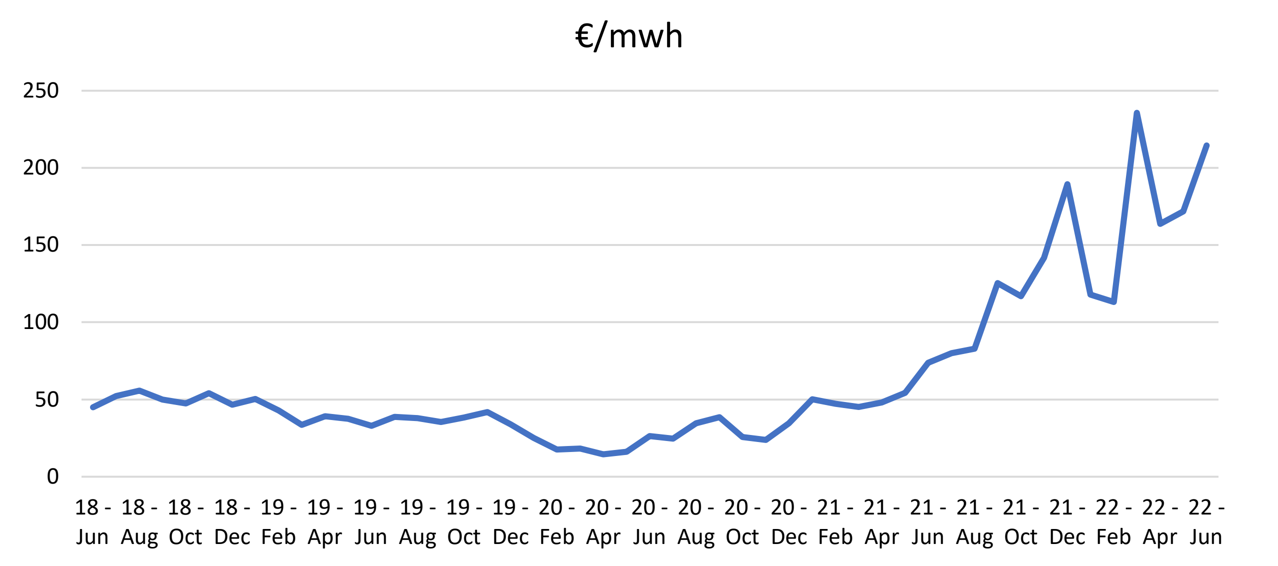
Figure 6: MGO fuel cost from October 8 to September 12 in USD per tonnes

Source: Global 20 Ports Average, https://shipandbunker.com/

The fuel price needs to compete against the electricity price produced at the power plant.

Figure 7 shows the development in raw electricity price from Nord Pool measured in €/MWh. The raw price is the pure price of electricity and does not include any transmission costs, taxes etc.

Figure 7: Danish raw electricity price in €/MWh (day-ahead prices)



Source: NordPool -

As seen from figure 7, the electricity price was stable from 2018 to early 2021 where the prices saw rapid increases to reach more than 200 €/MWh in 2022. With a price of less than 50€/MWh in 2020 to the average 170€/MWh in 2022 is an increase of 240%.

With an increase in the electricity cost that is much higher than that of the fuel cost the opportunity to sell shore power at a lower price than vessel-produced electricity on the auxiliary engines gets worsened.

9.2. Grid connection cost

Apart from the actual electricity cost, there is a connection cost to the grid owner. The grid connection fee is a one-time cost and is paid according to the amount of amps that the OPS should be able to deliver. The grid connection fee is standardized in Denmark and for business customers in 2023, the first 25 amps has a cost of 16,400 DKK and any additional power on top of this has a cost of 1,170 DKK per amp when connected directly to the 10kV grid[3].

In the Port of Helsingør, the OPS outlet for vessels should be 350 amps and the outlet for the electric crane should be 700 amps. This means that the connection cost to the grid operator for the OPS will be approx. 1.2 million DKK. However, the Port of Helsingør

[3] https://elektrus.dk/priser

already has access to more amps than the 25 that are included, and there will be a reduction in the costs for these. In total the costs will be around 1 million.

There are also opportunities to have a service that allows the grid operator to shut down the power supply if there is a need for the power elsewhere in the grid. This will not require the port to purchase amps, but requires an installation of a unit in the OPS that allows the grid operator to shut off the power. This unit and the installation will according to the grid operator be as expensive as the purchase of the amps and

9.3. OPS costs

Shore power system comes in different shapes and sizes, and this is reflected in the price of the systems. There are many different designs and providers of OPS systems and depending on the exact design and properties of a solution there are great variations in the costs.

For the Port of Helsingør there is a requirement of one power outlet of 350A to supply the vessels and one outlet of 700A to supply a crane. The power outlet for the vessels should be able to change the frequency between 50hz and 60hz to comply with the calling vessels requirement. The same goes for the voltage that should be adjustable from 400V to 960V. The outlet for the crane does not need the same flexibility in frequency.

In dialogue with two OPS suppliers the estimated cost of a system that would fit the requirements at Port of Helsingør is between 2.5 to 4 million DKK including costs for the connection point.

9.4. OPS construction costs

The construction and installation costs are highly dependent on the selection of design and location of the different parts of the system. There have been discussions with two different OPS suppliers, and they have been able to give some very general overview of the construction costs, that to a great extend will be depending on the local circumstances, such as distance between the power grid and the location of the actual shore power system, distance from shore power system to connection point etc.

A rough estimate given by one of the OPS suppliers was a cost of approx. 2 million to bury the cable 550 meters from Kulturværftes to Kongekajen. It has also been discussed to sink the construction into the port area to make its appearance less obvious in the surroundings, but it has not been possible to get exact cost estimates for this operation.

With a location of the OPS and connection point at Kongekajen, the construction costs are kept as low as possible and most likely around 250.000 DKK.

9.5. Total costs – sum-up

As described in the section above, there are several levels that has costs connected to is and these levels are visualized in figure 8.

Figure 8: Visualization and consideration of cost types.

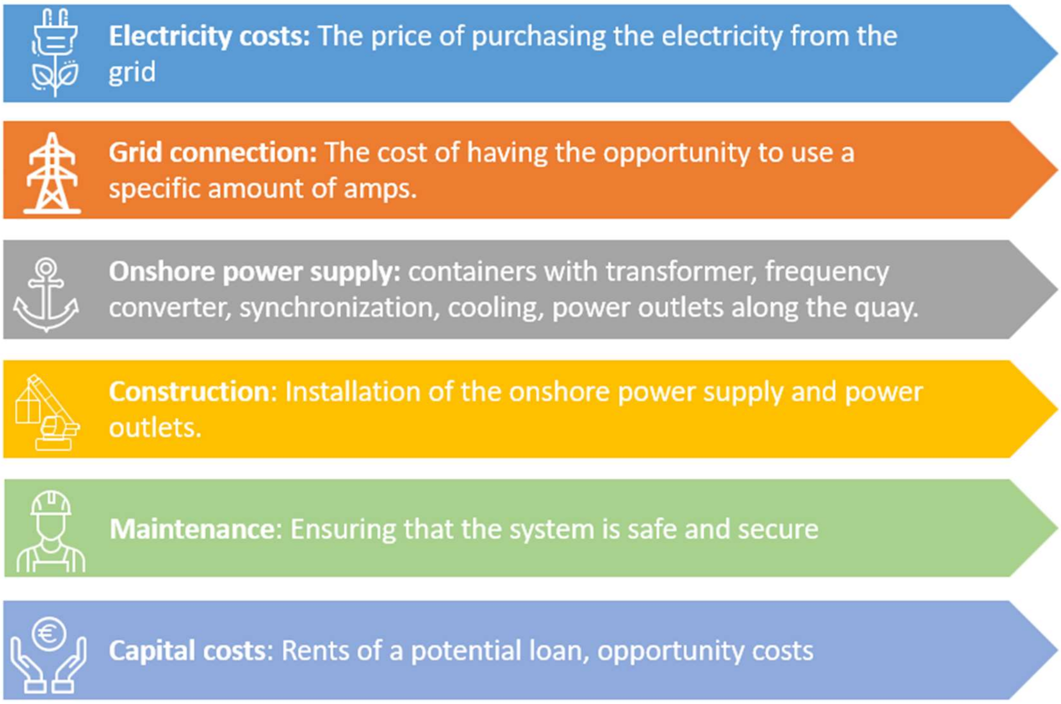


Table 5: Breakdown of costs and total costs of OPS.

Purchase of amps	approx. 1 million DKK
Transformer and connection point	approx. 2.25 million DKK
Construction and beautification	Location by Kulturværftet: approx. 2 million DKK Location at Kongekajen: approx. 250.000 DKK
Total costs	Location by Kulturværftet: approx. **5.25 million DKK** Location at Kongekajen: approx. **3.25 million DKK**

All costs are very approximate and not in any way binding. If more exact costs should be assessed there will need to be formulated a tender and potential OPS providers should give an offer on the assignment.

10. Financial analysis - considerations

A financial analysis of a shore power system at the port will include an analysis of the costs, both the capital expenditures (CAPEX) that relate to the actual investment in the shore power system as well as the operational expenditures (OPEX) that are connected to the daily operation, repair, and maintenance.

The OPEX and CAPEX should then be compared to revenue that may be obtained from selling of the power to the ship owners.

The CAPEX for the shore power system comes from mainly three different sources:

- The actual system, i.e., the containers with the transformer, frequency converter, synchronization drive, and cooling system together with the power outlets that are installed along the quay.
- The installation of the shore power system.
- Investment costs, i.e., potential interest rate costs and opportunity costs.

The OPEX cost for the daily operation of the system mainly comes from the purchase of energy that is sold to the vessels, and some operation and maintenance cost of the system.

The revenue for the utilization of shore power comes from two sources:

- The actual sales of energy in DKK/kWh.
- A one-off connection fee that should be paid to connect the vessel to the shore power system.

With knowledge about these cost types and revenue streams it is possible to make an evaluation of whether a shore power system is a profitable investment for the port of Helsingør.

At this point there are many uncertainties connected to the actual evaluation though, now few vessels can connect to the shore power system and there will be a period where the shore power system is not fully utilized. Apart from the connections of vessels to the shore power the system also allows the port to connect an electric port crane. When operating on electricity, the crane may have a positive contribution to the business case.

At a wider societal perspective, a shore power system will lead to a lower emission of local pollutants such as NOx, SOx, and particulate matter that in the end will lead to better air quality that has a positive impact on savings of health care costs as a contribution to fewer hospitalizations with lung diseases etc.

Emission of these local pollutants therefore have a socioeconomic cost that is external to the port and ship owners and is therefore said to be externalities. Including the savings of externalities that the port has on the local environment should not be included in the actual financial analysis of the investment but should be considered in relation to the societal benefits that shore power systems have.

A final type of pollution that is difficult to assess exactly is the noise reduction that the shore power system gives. When the vessels can shut off their generators and the cranes for the loading and unloading process can be electrified by the shore power system, there is a great reduction in the noise pollution. To urban ports, such as that of Helsingør, the noise reduction may lead to great benefits for the local inhabitants as well as the port and ship operators that can work in a more pleasant environment.

The investment should therefore also be seen in relation to the greening of the port and doing what they are able to do to support this development.

11. Business case calculation

A calculation tool that enables a variation of several input factors, such as number and duration of calls, vessel power consumption in port, electricity cost and sale price, together with costs of investments has been developed.

The calculation tool enables an analysis of whether the investment through a variation in number of port calls and power consumption, power price and cost will be profitable. In the following, the different steps in the calculation tool are presented. When there are cells that are green it means they may change, while the yellow cells are calculations that should not be changed.

To exemplify a calculation with the tool, the assumptions sketch out in table 6 are made:

Table 6: Calculation tool for port calls

Port call assumptions, i.e., of number and duration of calls, summations, assessment of hotel load, and total power demand from vessels and power demand from the grid

Port call assumptions					
Calls pr. year	15	of hours	48	Total	720
Calls pr. year	0	of hours	0	Total	0
Calls pr. year	0	of hours	0	Total	0
Calls pr. year	0	of hours	0	Total	0

Total calls	15	Pr. year
Hours at quay	720	Pr. year
Vessel hotel load	80	kW
Demanded electricity	57.600	kWh pr. year
Efficiency of shore power	80%	%
Electricity bought	69.120	kWh pr. year

The example sketched out in table 6 shows that the port has had 15 calls with a duration of 48 hours and hence a total of 720 hours. The hotel load is in this case set to 80 kW, meaning that the power needed to supply the power load for the vessel while at the quay which includes lighting, galley, air-conditioning, and instruments etc.

Shore power systems have a degree of efficiency around 80% which means that the shore power system owner need to buy approx. 20% more energy than what is sold because of energy losses in the system including cooling of the transformer.

With the example sketched out above, the port has a demand of 57,600 kWh per year from the calling vessels and need to purchase 69,120 kWh per year.

Next to the port call assumptions seen in table 6, there need to be some assumptions based on the economy, i.e., cost of the shore power system, cost of electricity, sales price of the electricity, depreciation, connection fee, maintenance costs, and interest rate. These assumptions are shown in table 7, below.

Table 7: Economic assumptions for OPS systems

Economic assumptions		
Electricity price purchase	1,00	DKK/kWh
Electricity mark-up	1,00	DKK/kWh
Elctricity price sold	2,00	DKK/kWh
Connection fee	500,00	DKK/anløb
Maintenance costs	0,15	DKK/kWh
Construction costs	3.000.000	DKK
Interest rate	3,00	%
Depreciation	30	year
Linear depriciation	100.000,00	DKK/year

As seen in table 7 the cost price of electricity is in this example set to 1.00 DKK/kWh and a mark-up of 1.00 DKK/kWh makes a power price of 2 DKK/kWh. The connection fee is set to 500 DKK/call and covers the connection to the system. The maintenance costs are based on a cost pr used kWh and is in this case set to 0.15 DKK/kWh. The construction costs are set to 3 million DKK with an interest rate of 3% depreciated over 30 years and i.e., with 100,000 DKK/year.

With a coupling of the port call assumptions and the economic assumptions it is possible to calculate the costs and revenue of the system and get a financial result of the investment and operation of the system. The financial result is presented in table 8, below.

Table 8: Financial account of CAPEX and OPEX of the shore power system and hence the assessment of the profitability of the investment.

Financial result			
Costs:	Purchase of electricity	kr.	-69.120
	Maintanence	kr.	-10.368
	Total	**kr.**	**-79.488**
Revenue:	Connection fee	kr.	7.500
	Electricity sales	kr.	115.200
	Total	**kr.**	**122.700**
Gross income		**kr.**	**43.212**
Depreciation		kr.	-100.000
Operating income (EBIT)		**kr.**	**-56.788**
Interest rates year 1		kr.	-90.000
Annual result		**kr.**	**-146.788**

Table 8 shows there are expenses to purchase of electricity of 69,120 DKK, maintenance costs of 10,368 DKK and hence a total cost of 79,488 DKK per year. The revenue comes from a connection fee of 7,500 DKK and sales of electricity of 115,200 DKK giving a revenue of 122,700 DKK per year. The gross income sums to 43,212 DKK and a depreciation of 100,000 DKK pr year the result before taxes is 56,788 DKK. The interest rates sum to 90,000 DKK and hence a negative result of 146,788 DKK.

11.1. Environmental savings and benefits

Based on the total energy saving in terms of fuel saved by a connection to the shore power system it can be calculated how much CO_2, SOx and NOx that is saved by having the vessel connected.

Based on the above examples and assumptions the 57,600 kWh per year that is used in hotel load can be calculated to a volume of fuel that is saved by the vessels in the port. The assumptions and calculations are presented in table 9.

Table 9: Environmental savings due to OPS

Environmental assumptions		
Generator consumption, fuel	200	g/kWh
Fuel consumption in port	11.520	kg fuel
CO2 in fuel	3,2	kg CO2/kg fuel
CO2 emission	36.864	kg CO2/year
NOx in fuel	68	g/kg fuel
NOx emission	783	kg NOx/year
SOx in fuel	5	g/kg fuel
SOx emission	58	kg SOx/year

As it can be seen from table 9, the generator consumption at the vessels is set to 200g/kWh which is an average value of many generators. The fuel consumption can be calculated by adding the 200g/kWh by the total power demand and results in a consumption of 11,520 kg fuel that is not used by the vessels because of the sore power connection.

In the combustion process the long chains of carbon in the diesel are broken down into mainly water and CO_2 that has higher weight than the individual carbon atoms and hence leading to 3.2 kg CO_2 in each kg of fuel. This in turn lead to an emission saving from the diesel engines of 36,864 kg CO_2 per year in the port. Using the same analogy, the shore connection may lead to a reduction of 783 kg NOx per year and 58 kg of SOx per year.

11.2. Reference points

The emissions presented in table 8 only give meaning when compared to other reference points. The model provides a reference point to how many kilometers of transport with lorries the saved CO2 emissions corresponds to. Table 10 provides this overview.

Table 10: reference points to CO_2 emissions from other sources

Reference points		
CO2 emission from lorry 34 - 40t	675	g/km
Corresponding emission lorry 34 - 40t	54.613	km
Avg. DK power production CO2 emission	142	g CO2/kWh
If power produced by avg. power grid	9.815	kg CO2 pr. year

12. Scenario analysis

By using the calculation tool described above, it is possible to create some scenarios to illustrate the profitability of the system under various conditions.

The cost of the shore power system is varied from 3 million to 5 million to visualize the different scenarios this will lead to. The number of calls and hence hours at quay are also varied to visualize the revenue structure under different circumstance.

All scenarios are calculated based on that the port need to take a loan with an interest rate of 3% and a linear depreciation to zero of 30 years.

In the following there has been made three scenarios that are described in table 11, below.

Table 11: Scenarios of profitability of an OPS system						
	Total cost of the system (M DKK)	Number of calls	Number of hours at quay	Annual Result (1.000 DKK)	CO2 – emission reduction (kg)	NOx – emission reduction (kg)
Scenario 1	3.25	15	720	-191	36.864	783
Scenario 2	3.25	30	1444	-177	73.728	1.567
Scenario 3	5.25	15	720	-318	36.864	783
Scenario 4	5.25	30	1444	-303	73.728	1.567

As table 11 illustrates, the annual result is in all scenarios negative based on the settled assumptions. A relevant parameter that could change the calculations considerable is if the port is able to finance the investment from its own equity and hence avoid the financial costs of repaying a loan. With an interest rate of 3% the financial costs make up 97,500 DKK per year of a loan at 3.25 million and 157,500 DKK per year with a loan of 5.25 million DKK.

Table 11 also include the depreciation costs of the asset (i.e., the OPS) and hence delivers a negative result with the given assumptions. However, by excluding the depreciation costs and evaluating the EBITDA (Earnings Before Interest Taxes Depreciation and Amortization) the OPS gives a positive result of 28,824 DKK per year with 30 calls (1440 hours) and a positive result of 14,412 DKK per year with 15 calls (720 hours).

13. Discussion

As it can be seen from the scenario analysis and the example that is used to illustrate the calculation tool, an investment in a shore power system may not be profitable at first sight at the Port of Helsingør.

The investment in a shore power should be seen in connection with the ongoing electrification and sustainability agenda of the Port of Helsingør and the ongoing pressure that is put on the port to reduce local pollution and the noise that is emitted by the vessel in port.

There are currently no binding requirements, or regulations that forces a port to provide shore power to vessels that call the port, however, there are getting more and more pressure on all companies and entities to be able to document their carbon footprint and provide solutions as to how this footprint may be reduced. Investments in an OPS is such an option and contribution to the decarbonizations goals that are governing the port. An investment in a shore power system can therefore be considered as one of the most relevant tools a port has to lower its impact on the local environment and the global greenhouse gas emissions. Investments in technologies that in the Port of Helsingør may become a prerequisite for the port to operate and expand.

There are no formal requirements that forces ports to invest in shore power systems but at EU level the fitfor55 package includes a proposal called 'Fuel EU-Maritime[4]' that suggests that ports in the TEN-T core network should be able to supply shore power by 2025. Though this is still a suggestion and may not affect the Port of Helsingør directly, it indicates that is a subject that is on the EUs radar and may in the future be a natural service that ports should have to its customers.

[4] https://www.europarl.europa.eu/thinktank/da/document/EPRS_BRI(2021)698808

14. Conclusion

The business case on a potential onshore power supply at the Port of Helsingør is negative seen in a purely economic perspective.

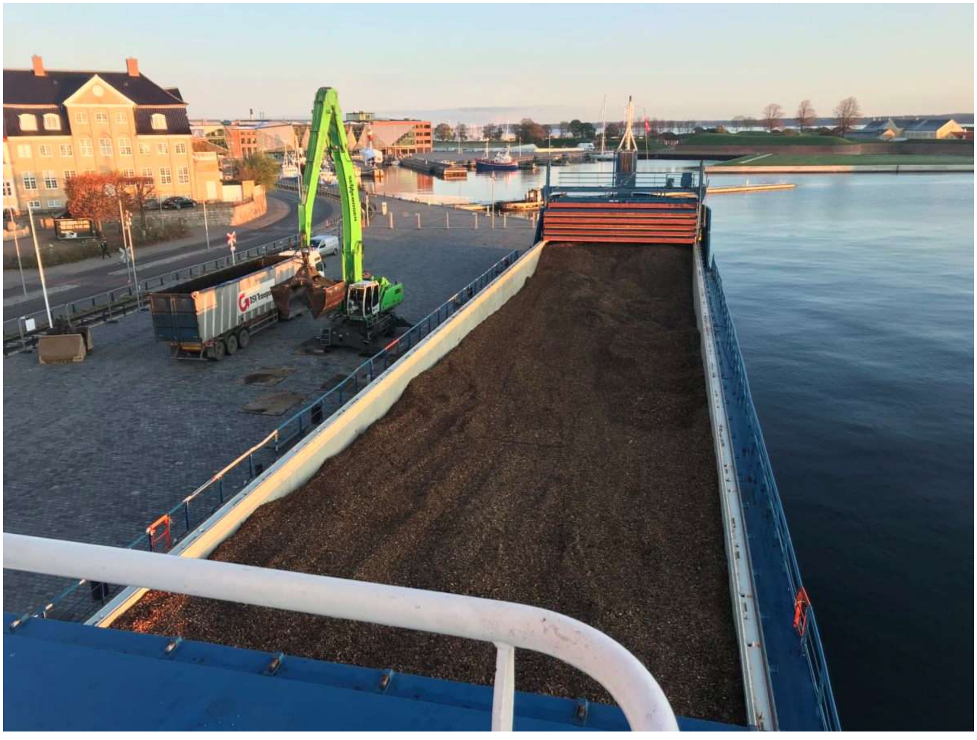
This result is not surprising due to the nature of the investment. Based on the interconnected aspects as environmental development and port technologies the investment can be judge and seen in a more sustainable way. Another important fact is also to secure the Port of Helsingør "right to operate" in the future as business port in the center of Helsingør.

An OPS in Port of Helsingør will reduce the CO2 impact from the port operation and in a future environmental tax-regime and OPS will reduce costs for the port and ships using the port consolidating the business case in a positive direction.

In this way alone - the ambition and strategy for greening - the unloading of wood crisp and the crane operation at quay area may be seen as core argument for the investment - despite the negative business case on an OPS at the Port of Helsingør.

The impact from the greening of the FourSea ferry company may not be underestimated as agenda setting activity running other port operations in the Port of Helsingør - in this way a neglection of the general ongoing green development in port operations must be considered.

Based on a more holistic approach the arguments for an OPS - with a design to fit into the port area respecting the national heritage - is a sustainable option for the management in the Port of Helsingør to establish.



Appendix


Kulturværftet – opportunity to locate the container section. Cable trajectory approx. 550 meters
Potential location of transformer/converter
Kongekajen
Potential location of power outlet