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Sustainable mobile shore power for the Port of Rotterdam

An assessment of a battery-based shore power system, Pilot phase B - Waalhaven

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An assessment of a battery-based shore power system, Pilot phase B - Waalhaven

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Contents

1 Introduction

Port of Rotterdam aims to reduce climate impact and improve air quality. For maritime shipping, shore power can effectively reduce ship pollutant emissions at berth (EPA, 2022). FuelEU Maritime regulation requires that from January 1st, 2030, container and passenger ships greater than or equal to 5,000 gross tonnage (GT) must connect to shore power or use an equivalent zero-emission technology in main EU ports (Zero Carbon Shipping, 2024). This regulation also mandates that all vessel types greater or equal to 5,000 GT have to meet gradually tightening GHG intensity targets (in gCO_2e/MJ), encouraging cleaner port operations. By connecting to zero-emission shore power, vessels can significantly reduce their GHG intensity, supporting ship owners in complying with these requirements. Further details on these regulations and their implications for shore power adoption are provided in the Appendix.

Net congestion in the port area of Rotterdam

At some locations in the Rotterdam port area, conventional fixed onshore electricity grid connections cannot be realised in the short term due to grid congestion. Figure 1 illustrates the expected available grid capacity at the >25 kV AC grid level, the level to which larger industrial energy suppliers and consumers are typically connected (PDOK, 2023). The figure highlights the limited available grid capacity in and around the Port of Rotterdam in the coming years. This availability is estimated based on the Connection and Transmission Agreements (Aansluit- en TransportOvereenkomst, ATO).

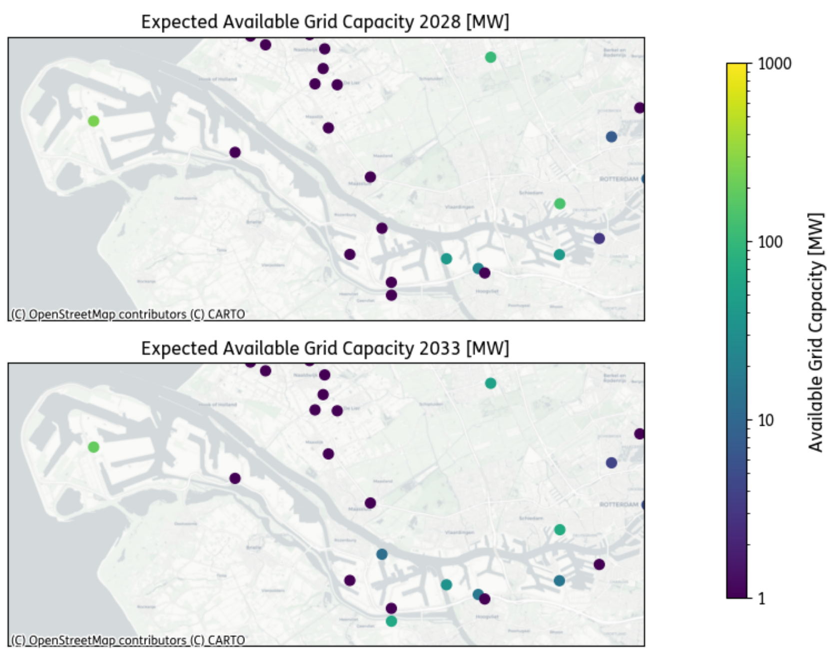

Figure 1: Expected available grid capacity [MW] at the >25 kV (industrial) grid level in 2028 and 2033 around the Port of Rotterdam, on a logarithmic scale (PDOK, 2023).

The total annual energy consumption of berthed vessels in the Port of Rotterdam is estimated to be between 700 GWh and 840 GWh (Strategie Walstroom Rotterdamse Haven, 2020), which results in an average power demand between 80 and 95 MW. Limited grid capacity is expected to be available in the harbour area in 2028 to facilitate this power demand in the form of shore power based on Figure 1, and a limited increase is expected towards 2033.

In this congested electricity network, using fixed grid connections is challenging. Mobile shore power units could provide a solution, since these can be deployed more flexibly, making use of grid connections at a distance, or drawing energy from existing grid connections during off-peak hours. Another reason to consider mobile solutions is the flexible number of ships at berth locations which could lead to very low utilisation of the shore power installation. Mobile power units could be transported to various terminals or used in other (for instance non-maritime) applications to increase the utilisation rate and hence commercial viability.

<u>Flexible cable management system</u>
Greater flexibility in cable management is another innovation desired for many shore power projects. In terminals where numerous different type of vessels dock at different locations along a long quay, the position of the shore power connection point on board of vessels with respect to the quay might also vary. Allowing flexible connection points to be moved and adjusted along a quay to match the position of the shore connection point of the vessels is crucial for the functioning of the shore power system.

<u>Goals of Pilot Phase B</u>
Port of Rotterdam has run an earlier pilot with mobile shore power, "Pilot Phase A at the Parkkade" (Port of Rotterdam, 2020), in which 5 concepts of mobile shore power were tested for the low power segment (<250kW). In the current pilot, Pilot Phase B, a single technology has been tested for the higher power segment (>500kW). As preparation for this pilot, Royal HaskoningDHV (Royal HaskoningDHV, 2020) and TNO (TNO, 2023) carried out assessments of different power conversion technologies that could be considered to be used as mobile shore power units.

Pilot Phase B had two different, but complementary components:

1. Piloting a local zero-emission mobile shore power concept to cover all electrical power needs of the vessel at berth.
2. Piloting an innovative flexible cable management system, which does not have to be mobile.

In this pilot, Pilot Phase B, a mobile shore power installation based on batteries was tested from April 2024 until July 2024. This report covers an evaluation of the pilot and of the mobile shore power system itself. To this end, a mixed methods approach is used, integrating a qualitative and quantitative approach. The qualitative component consists of interviews with all project stakeholders and site visits. The quantitative component consists of data collection- and analysis.

2 Pilot system layout

This section details the layout and operational setup of the pilot system used in the Mobile Shore Power Pilot Phase B.

Terminal operator and participating vessels

The pilot was performed at the terminal of C. Steinweg in the Waalhaven. Several vessels from the fleet of CargoW, a Dutch shipping company, took part in this trial: Sigyn W, Freyja W, Sif W and Frigg W. The participating vessels were Multi-Purpose Vessels (MPV) that sailed between Norway and Iceland via the Port of Rotterdam. The vessels have a gross tonnage of approximately 9,700 GT and a length of 138 m. During the pilot, the participating CargoW vessels followed the following schedule: arriving on Sunday and departing the following Tuesday, resulting in a port stay of maximum three days. The exact arrival times on Sunday and departure times on Tuesday were flexible throughout the pilot.

Components of the shore power system

To provide shore power to these vessels, ZES (Zero Emission Services), a company specialising in modular battery solutions based on containers for inland shipping, has provided a movable power source system based on 8 20ft containers (8x1TEU).

- Six battery containers (*ZES Packs*) based on lithium iron phosphate ($LiFePO_4$ or LFP) with a capacity of 2.9 MWh (2.6 MWh usable energy) per container to provide the vessels with uninterrupted power for their port stay of three days. The dimensioning of required battery capacity will be described further in Section 3.1 and Section 4.
- A container with an inverter unit (discharge station), tasked with transforming the battery power into 3-phase 60Hz 440V AC power, suitable for the Multi-Purpose Vessel's needs.
- A container with a converter unit (charging station), tasked with transforming the AC grid power to DC power for charging the containerised batteries. This charging station is located at 4 km distance from the terminal where the rest of the shore power system was located. This location, further referred to as 'the charging location', is located at the Rotterdam Droogdok Maatschappij (RDM). This solution is selected because of the availability of a sufficiently large electricity grid connection at RDM.

The company Endenburg Electronics was selected to oversee the commissioning, startup and operation of the entire onshore system.

Tested cable management system: IGUS Mobile Shore Power Outlet

The flexible cable management system that was chosen to test during this pilot is the Mobile Shore Power Outlet (iMSPO) from the German manufacturer IGUS. This iMSPO made a flexible connection between the stationary discharge station and the berthing vessels possible. The iMSPO consists of a rail that runs along the quay, with a moving trolley that carries the mobile power outlet. In the pilot the power from the discharge station was supplied to the vessel through the IGUS cable management system. In principle, the power supply system could work with any other cable management system as long as an appropriate interface is present. It is also possible to connect the inverter directly to the vessel.

<u>Layout of the shore power system on the quay</u>

Figure 2, is a photo of the system as installed at the C. Steinweg terminal in the Waalhaven. On the top side, the six white containerised batteries are visible. To make it easy to move the batteries to and from the charging location, the ZES Packs were placed on trailers permanently during the pilot: they were not unloaded from the trailer on the quay or at the charging site. The connection points for power and communication were located at the back side of the containers. Each of the containers was connected to the inverter unit, which was positioned between the batteries and the IGUS system in the middle-right of the picture. The IGUS Mobile Shore Power Outlet is shown on the bottom of the image.

Figure 2: Photo of the shore power system on the shore side, taken from on board of one of the CargoW vessels.

As mentioned, the power supply used in the pilot consisted of 6 ZES Packs. Due to the chosen system topology of the inverter electronics, the ZES Packs were connected to the inverter in pairs, forming 3 groups of 2 batteries (a 3x2 configuration). This design allows the system to function with either 2 or 4 ZES Packs, so it doesn't require all 6 packs to be operational. However, while the system can continue functioning if one group fails, this failure would reduce the total output power. If one battery becomes non-functional, it would disable its corresponding group, but the remaining groups would still function.

Figure 3 provides a schematic overview of the mobile shore power system, showing a footprint of approximately 35x17m. This includes a clear area in front of the ZES Packs for tractor positioning to move the battery containers to the charging site. Grey blocks on the left represent concrete barriers separating the system from the terminal. The discharge unit is centrally placed for easy access, with a 230V AC connection to the right, required to operate onboard systems such as cooling. Although a more compact layout could be considered, extra space was allowed during the pilot to facilitate easy access to all components.

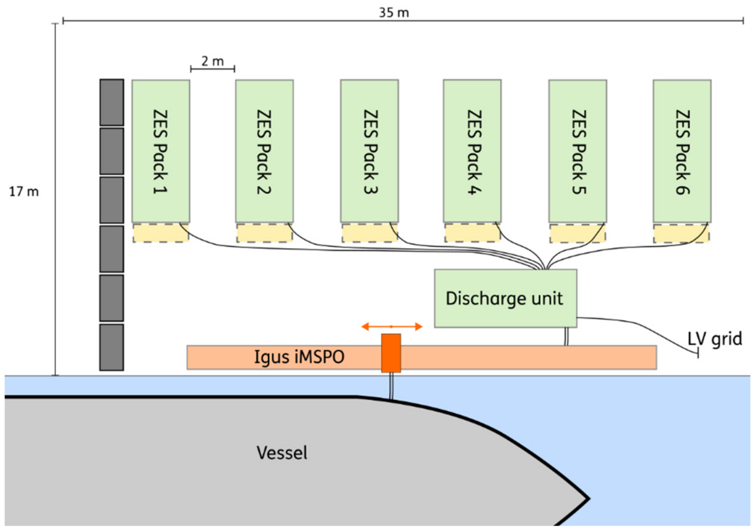

Figure 3: Schematic of the shore power system layout at the Waalhaven.

Between port stays of the vessels, the battery containers were recharged. The battery containers were moved one by one using a truck with the trailers from the terminal to the charging location at a 4 km distance. A grid connection and a converter unit (similar to the discharge unit shown in Figure 2) was present on this location to recharge the batteries. Once they were all charged to the desired state of charge, the trailers were transported back to their slots at the terminal. Figure 4 shows a schematic of the two different locations used in the pilot, and the movement of the ZES Packs between them.

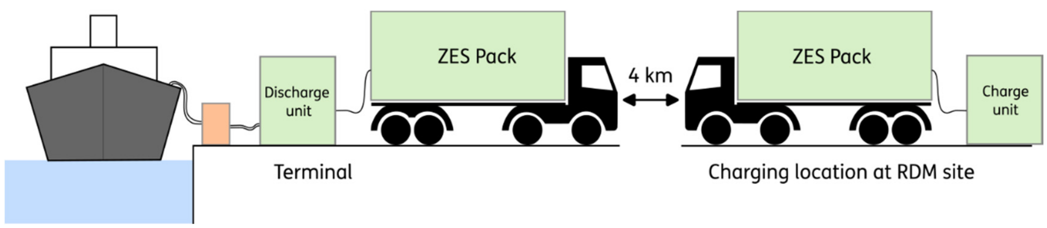

Figure 4: Mobile setup of the shore power system with the two locations: Terminal with the discharge station on the left side, Charging location at the Rotterdam Droogdok Maatschappij site at a 4km distance from the terminal.

<u>Movable system via container-based design</u>

The shore power system is designed to be movable, with a container-based solution allowing all components, including batteries and the inverter, to be relocated to different quays. During the pilot, only one location was used to supply power, and the discharge station was not moved, unlike the ZES Packs. However, as the discharge station is also container-based, it can easily be mounted on a trailer and relocated if needed. Moving the system requires disconnecting and reconnecting all container connections, a process estimated by Endenburg Electronics to take around four hours. Further details on the implications of moving the system are discussed in Section 6.

<u>Operation of the cable management system</u>

The mobile shore power outlet can move along the rail on the quay towards the vessel's power socket, controlled by a handheld remote, at walking speed. This allows the operator to walk alongside it, ensuring the path is clear.

The connection points can be lowered to a comfortable height for easy and safe connection by personnel on the quay and then lifted back upright to clear the terminal space. The same handheld remote is used to move the cart along the rail and to lower or lift the power outlet. As shown in Figure 2 and Figure 3, the discharge unit of the shore power system is connected to the start of the rail of the IGUS Mobile Shore Power Outlet. This setup allows the power generation hardware (the ZES Packs and discharge station) to be positioned along the quay where it causes minimal interference with daily terminal operations. Figure 5 shows the IGUS system in both the upward and downward positions.

Figure 5: Photos of the IGUS Mobile Shore Power Outlet as installed in the pilot: Upward position (left), downward position (right).

3 Pilot preparation and installation

This section focusses on the pilot preparation (technical detailing, planning, discussions, deliveries, delays, permitting, etc.) of Port of Rotterdam and their motivation for certain choices. Most of the content of this section is based on conversations with the project stakeholders.

3.1 Technology selection

Several technology types were considered for the mobile shore power system in the preparation of Pilot Phase B. The main technical requirements for the system in this project were based on measurements on two CargoW Multi-Purpose Vessels (SifW and SigynW) that would participate in Pilot Phase B. For both these vessels the active power (among other signals) was measured for a single port stay. Parts of these measurements are included in Section 4.

Based on this analysis it was decided that the mobile shore power system had to be able to provide:

- 15 MWh of electrical energy (5 MWh per day for a port stay of three days maximum), and
- 800 kVA of peak power.

The highest measured energy consumption of the two involved CargoW vessels for a port stay was 8 MWh. The energy supply requirement of 15 MWh was chosen to ensure sufficient availability in case energy consumption during the trial exceeded the levels measured beforehand.

To determine the most suitable technology to execute Pilot Phase B, an assessment framework was created in a cooperation between Port of Rotterdam and TNO (TNO, 2023). In this framework, multiple technologies and potential suppliers were evaluated based on a set of predefined criteria.

The following technologies were assessed:

- Fuel cells,
- Batteries,
- Hybrid solution of a generator based on biogas or Hydrotreated Vegetable Oil (HVO) combined with batteries, and
- Hybrid solution of a fuel cell combined with batteries.

All of these technologies, along with their respective suppliers, were evaluated based on the following criteria:

- Lead time,
- Maturity of product,
- Innovativeness,
- Modularity,
- Level of Standard Product,
- CO_2 emissions in the chain,
- Local CO_2 emissions,
- Local NO_x emissions,
- Fuel cost,
- Consortium size, and
- Location of supplier.

Later on in the process of selecting the technology type, after creating the assessment framework, a key requirement from the municipality became apparent: the system had to be zero-emission on a local scale. This requirement ruled out the options for the biogas and HVO. The option for the use of a fuel cell based system with green hydrogen has been considered for a large part of the pilot preparation. However, no suitable fuel cell option within the project budget was found within the available time for the technology selection. This left only one feasible option for the pilot: a fully electric system using batteries.

Zero Emission Services (ZES) was selected as a partner to deliver the power source for the shore power system. ZES proposed a system based on its existing technology of the ZES Pack for inland shipping. The battery containers (ZES Packs) that were proposed had a usable battery capacity of 2.6 MWh. To meet the energy capacity requirement of 15 MWh, six of these battery containers would be needed. ZES worked together with a subcontractor (Ebusco Energy) to provide the battery containers and the charge- and discharge station.

3.2 Pilot Phase B preparation

3.2.1 Discharging site

The installation of the battery-based shore power system at the C. Steinweg terminal required a modification to its environmental permit (“Milieuvergunning”) by the Dienst Centraal Milieubeheer Rijnmond (DCMR). The Veiligheidsregio Rotterdam-Rijnmond (VRR) is the legal advisor to the DCMR. For the pilot, the VRR was leading in this process because the focus was on the safety component. This was necessary due to the potential safety hazards and environmental risks associated with the presence of the ZES Packs, particularly in the event of an emergency. To mitigate these risks, the project team ensured compliance with the Publicatiereeks Gevaarlijke Stoffen (PGS) 37-1 guidelines (Rijksdienst voor Ondernemend Nederland, 2023). This standard provides safety protocols for the storage of electrical energy in batteries with a combined capacity exceeding 20 kWh. Although compliance with PGS 37-1 was not yet legally required at the time of the pilot, as it will only become mandatory to comply in 2025 (Heijnen, 2023), the project team chose to implement the standard in advance to ensure long-term safety and regulatory alignment. Figure 3 shows several aspects of the PGS 37-1 in the system layout, such as the safety distance between the ZES Packs and the concrete barriers between the shore power system and the rest of the terminal to prevent impact of vehicles on the terminal with the system.

As described in section 3.1, energy consumption measurements were done on board of CargoW's vessels that would participate in this pilot. During these measurements, it was concluded that the vessels consumed about 8MWh of energy each during a port stay.
To determine the necessary amount of usable energy in the batteries, this energy consumption of the vessel has to be divided by the energy efficiency of the discharge unit. For this pilot, a total of six ZES-packs (each 2.6MWh of usable capacity) were used to provide energy, adding up to a total of 15.6 MWh. TNO was not directly involved in the system dimensioning, so the specific efficiency assumptions used to determine the required battery capacity for this project remain unspecified.

3.2.2 Charging site

Finding a suitable place to charge the batteries with a sufficient grid connection close to the Waalhaven was challenging. Given the schedule of the participating CargoW vessels that berthed from Sunday to Tuesday, a grid connection of at least 500kVA was desired to charge the batteries fast enough. With a power of 500 kVA, all six ZES Packs could be fully recharged within approximately 2 days, which was required to have the ZES Packs back at the quay in time for the arrival of the next vessel, including the transport time of the ZES Packs.
A shortlist of locations with sufficient capacity (or possibility to upgrade) in the vicinity of the Waalhaven was created. From this shortlist, the location Rotterdam Droogdok Maatschappij (RDM) was the most suitable considering the distance to the terminal and the impact on other electricity users in the area at the RDM site.

The grid connection at this location had an older voltage level standard of 500 V, which was modified to a more modern 400 V connection since the charging station operated at 400 V. As mentioned above, a power of 500 kVA is sufficient to recharge all ZES Packs.
The maximum of power at a connection point is defined by the Connection and Transmission Agreement (Aansluit- en TransportOvereenkomst, ATO) and by the maximum available grid power at this connection point. At this grid connection of the RDM site, the available power is 1,000 kVA, but the ATO was limited to 500 kVA. An increase of the ATO to 1000 kVA was requested and approved to enable faster charging of the ZES Packs, if necessary, due to unexpected changes in planning.

Since the chosen grid connection for the charger was in a public location, a permit ("omgevingsvergunning") was not required, at the moment of the pilot. The area used for charging at the RDM location was located on a public parking area. The area blocked parking spots and parts of the road that was intended for navigating around the parking area.
For this, a Temporary Traffic Management ("Tijdelijke Verkeersmaatregelen", TVM) was in place at the RDM site during the pilot. Road markings and signs were put in place to clarify the modified traffic situation. Also concrete blocks were placed around the infrastructure at the charging location, following the same principles from PGS 37-1 around impact protection. Fences were placed to surround the charging area, and security cameras were installed to prevent theft or vandalism, also according to PGS 37-1.

3.2.3 Preparation challenges and delays

Given the innovative nature of the pilot system, several tasks during the preparation phase required more time than initially planned.

Some of the key delays encountered include:

- The tendering process took longer than originally anticipated: First, two tenders were carried out by the Port of Rotterdam that were focused on a hydrogen powered system, but neither of these was successful because of long delivery times, the CAPEX exceeding budget, and no availability of green hydrogen. After these two attempts, TNO carried out an assessment (TNO, 2023) to redefine the project scoping. After that, the Port of Rotterdam performed a third tender that focussed on battery powered systems.
- The shore power system that has been used in this pilot was not marked ready, which lead to a higher demand of the staff of the involved project partners. This holds specifically for ZES, Ebusco Energy and the installation company Endenburg Electronics for debugging and testing the equipment.
- The delivery of the ZES packs, charging station, and transformer for the discharge station was significantly delayed. The system as utilized during this pilot was not yet in operation anywhere else, and all the parts were still being tested and developed.

3.3 Shore power system installation

3.3.1 Original installation plan and contingency measures in place

In the original planning, the operational phase of the pilot would start on the 1st of May 2024. A Site Acceptance Test (SAT) would have been successfully completed before that moment and the system could be operated from the 1st of May. However, due to the challenges and delays mentioned in Section 3.2.3, the installation phase started later than originally planned.

3.3.2 Implications of altered planning on installation

The starting date of the pilot was fixed: the pilot had to start before May 2024. Therefore, the challenges and delays mentioned in Section 3.2.3 made the project schedule challenging.

This had certain implications on the installation phase:

- To realise the start of the pilot in time, the hardware components (ZES Packs and discharge station) were shipped to the terminal before all integrated system tests were completed and passed.
- Since the integrated tests were not performed yet, these had to be performed at the terminal. During the system tests at the terminal, several issues were identified. Among these were system communication issues between the ZES Packs and the discharge station.
- Due to the terminal's policy restricting the presence of external visits after 15:00, and all external visits requiring prior registration as part of International Ship & Port Facility Security (ISPS) certification, testing and resolving issues on the quay is more cumbersome that performing those actions at the factory.
- Some tests required the presence of a dynamic load which would simulate a vessel to fully test the shore power system.

The discharge station is designed to supply AC power to the ship, with the capability to quickly adjust the available power (current) based on the vessel's requested load. Since there is no direct communication between the ship and the discharge station, control is based on available signals, such as voltage and frequency. Given the novelty of this system, testing under actual dynamic load conditions was required, rather than relying solely on static loads. As there is no such system at the facility of ZES (or that of their subcontractor Ebusco Energy) capable of dynamically testing the system at this scale, it became necessary to perform the test when connected to the vessel.

- Due to the vessel's presence at the quay only between Sunday and Tuesday and due to the terminal's policy restricting the presence of external visits after 15:00, the available time for testing the mobile shore power installation with the vessel on-site was very constrained. This tight schedule allowed for minimal total testing time with a vessel on-site. Tests for which a dynamic load was not needed could be performed during the rest of the week.
- Operational business requirements sometimes caused last-minute shifts in the vessels planning, causing reduced availability of the vessel for testing the mobile shore power installation with a dynamic load.
- Engineers responsible for the shore power system, who were critical for addressing installation issues, had to be present during these limited testing windows. These engineers were travelling from various locations, including the Netherlands, Germany, and China, further complicating the scheduling. If any issue remained unresolved during the time the vessel was present, the next opportunity to test with a dynamic load would be delayed by a week, until the next vessel's arrival on Sunday, leading to an extended testing process overall.
- The pilot kicked off on April 25th, 2024, when a voltage was measured at the power outlet of the IGUS system, but further testing was required before the vessel was first running fully on the energy supply from the shore power system on May 28th, 2024. Until the end of the pilot on July 31st, several more tests were required, and a fully operational phase was not reached during the pilot. This is discussed further in Section 4.

4 Power supply analysis

In this section, the data gathered during the pilot is used to analyse the performance of the shore power system during Pilot Phase B.

4.1 Available data

To analyse the system, a high quality data set of all major components of the system was required. However, due to unforeseen issues and miscommunication within the project, the data set is not available. Only limited data was shared.

The following issues were encountered with the data:

- Data from the battery containers was deemed unreliable due to unrealistically high-frequent oscillating behaviour in the power signals, indicating corruption of data. No data on State Of Energy (S.O.E.) or State Of Charge (S.O.C.) was available from the batteries to trace back energy levels in the battery containers.
- Data from the charging unit shows conflicting numbers on power: the Apparent Power signal included in the data did not correspond with calculating the Apparent Power by using the logged currents and voltages of each of the phases.
- Data from the discharging station has a sampling frequency of 0.001Hz, one data point every 15 minutes. In earlier measurements on the CargoW vessels, it was observed that the power demand of the vessels can be highly dynamic, , depending on which systems are active on board. Heavy equipment such as cranes, hatches and ballast pumps can induce sudden peaks in power and sampling with this low frequency could hide these peaks in the power signals. This type of equipment is typically operated on the timescale of minutes, so this should be reflected in the sampling time of the data: a sampling frequency of around 0.01Hz (roughly one data point every minute) would be required to see the dynamic power demand in the data.
- No logbooks were available with specifications of arrival/departure times of vessels, executed tests or issues with the shore power system. The lack of logbooks makes the interpretation of the available power data more difficult, since it is unknown when a vessel was connected, when tests began and when the system was in operational mode.

4.2 Energy consumption overview

As described in Section 3.3, several technical challenges were still encountered after the kick-off of the pilot on April 25th, 2024. This is visible in the power data from the discharge station in Figure 6. The figure shows an overview of the active power measured at the output of the discharge station throughout the pilot. Vessels berthed during all weeks in the pilot period. In Figure 6, the 3 day time windows between Sundays and Tuesdays are marked in light blue to roughly indicate the presence of a vessel.

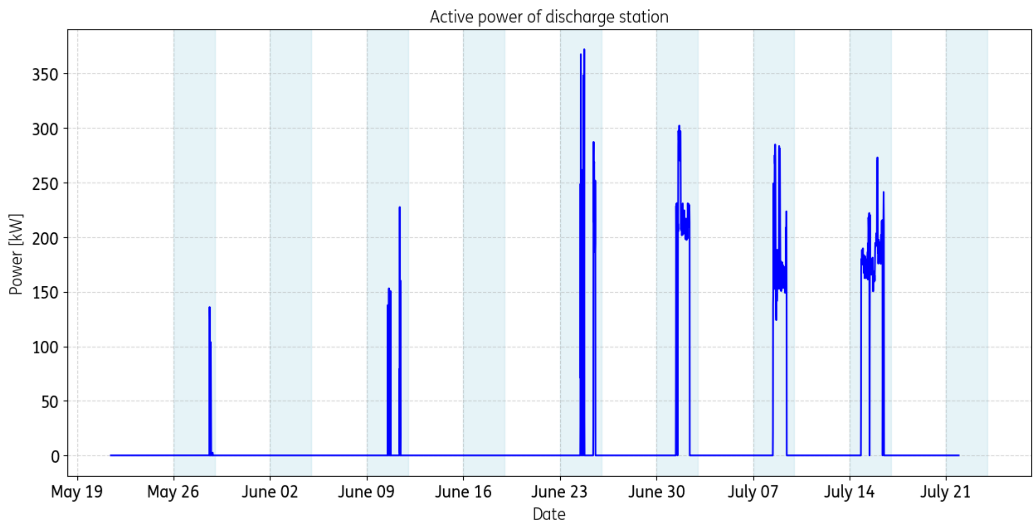

Figure 6: Overview plot of the active power (AC) measured at the discharge station output throughout the pilot.

Figure 6 shows the first moment the vessel ran on the shore power energy supply momentarily on May 28th. No power output was measured for the three port visits of June 2nd to June 4th, June 16th to June 18th and July 21st to July 23rd. Table 1 shows a summary of the port visits during which power was supplied, including the corresponding energy amounts, average active power levels, and power factor. In calculating the average active power, the power disruptions have been excluded. The power levels and power factor are not presented for the first three entries, as the power supplied was too unstable to allow for accurate calculations.

Table 1: Discharged (active) energy over the course of the pilot.

Expected start of port visit	Expected end of port visit	Total Active Energy discharged [MWh]	Average Active Power (excluding disruptions) [kW]	Power Factor [-]
26-05-2024	28-05-2024	0.13	-	-
09-06-2024	11-06-2024	0.3	-	-
23-06-2024	25-06-2024	1.7	-	-
30-06-2024	02-07-2024	5.3	227	0.87
07-07-2024	09-07-2024	4.3	183	0.91
14-07-2014	16-07-2014	7.2	184	0.86

Figure 7 shows zoom in on the period from June 30th, 2024, until July 16th, 2024, the period in which the biggest power supply to the vessel was realised.

1. The first port stay in this period shows a power supply of approximately 24 hours, with one power supply interruption visible in the data.
2. The second port stay in this period shows a power supply of approximately 24 hours as well, without power supply interruptions visible in the data.
3. The third port stay in this period shows a power supply of approximately 40 hours, with two power supply interruptions visible in the data.

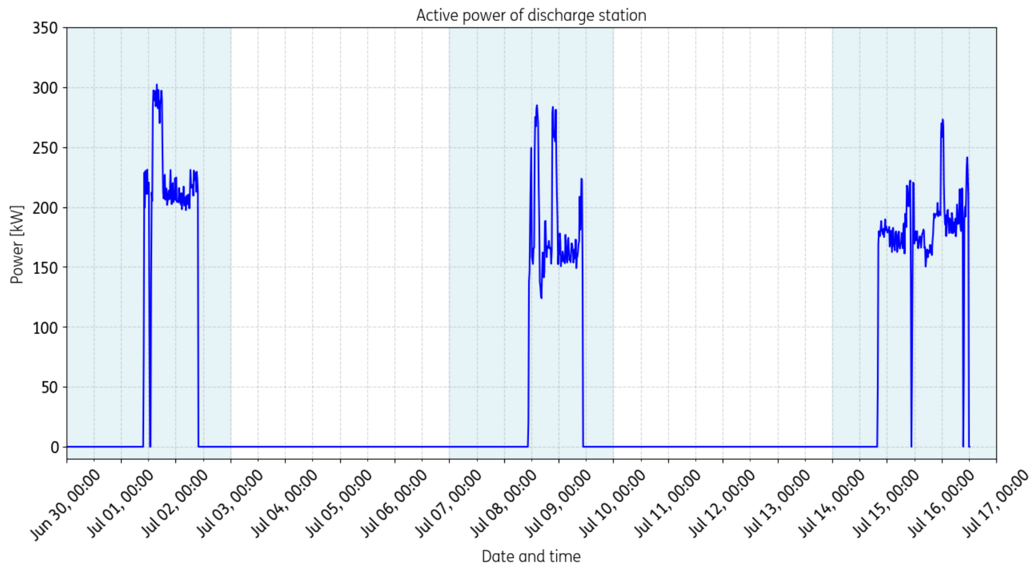

Figure 7: Active power (AC) measured at the discharge station output from June 30th, 2024 until July 16th, 2024.

These maximum duration of connection during this time was 40 hours. In the periods during this pilot in which the shore power system was connected to the vessel and in operational mode, the average active power output of the discharge station was around 200kW (excluding power interruptions). This would mean a total energy demand from the vessel of around 8 MWh, which is in accordance with what was observed in measurements on CargoW vessels prior to the pilot, mentioned in Section 3.1.

4.3 Power comparison between Pilot Phase B and prior measurements

To further analyse the data from the discharge station, it can be compared to measurements performed on board of two CargoW vessels during port stays in the Port of Rotterdam. This comparison is shown in Figure 8. The first plot in this figure shows the average active power supplied to the vessel during Pilot Phase B, sampled at 0.001Hz. This is compared with active average power measurements recorded in 2021 on the CargoW vessels SifW (second plot) and SigynW (third plot), sampled at 0.017Hz. All three plots display a 12-hour window of the vessels' port stays, starting at midnight.

In the figure, the difference in sampling frequency is immediately visible: The measurements from SifW and SigynW, with their higher sampling rates, capture more of the dynamic fluctuations in power compared to the pilot data, where the lower sampling frequency obscures finer variations. Despite this, the overall power levels observed during the pilot are consistent with those measured before the pilot, in 2021. However, due to the 15-minute sampling interval in the first plot, any shorter-duration power spikes or dips may have gone undetected and are therefore not visible in the data.

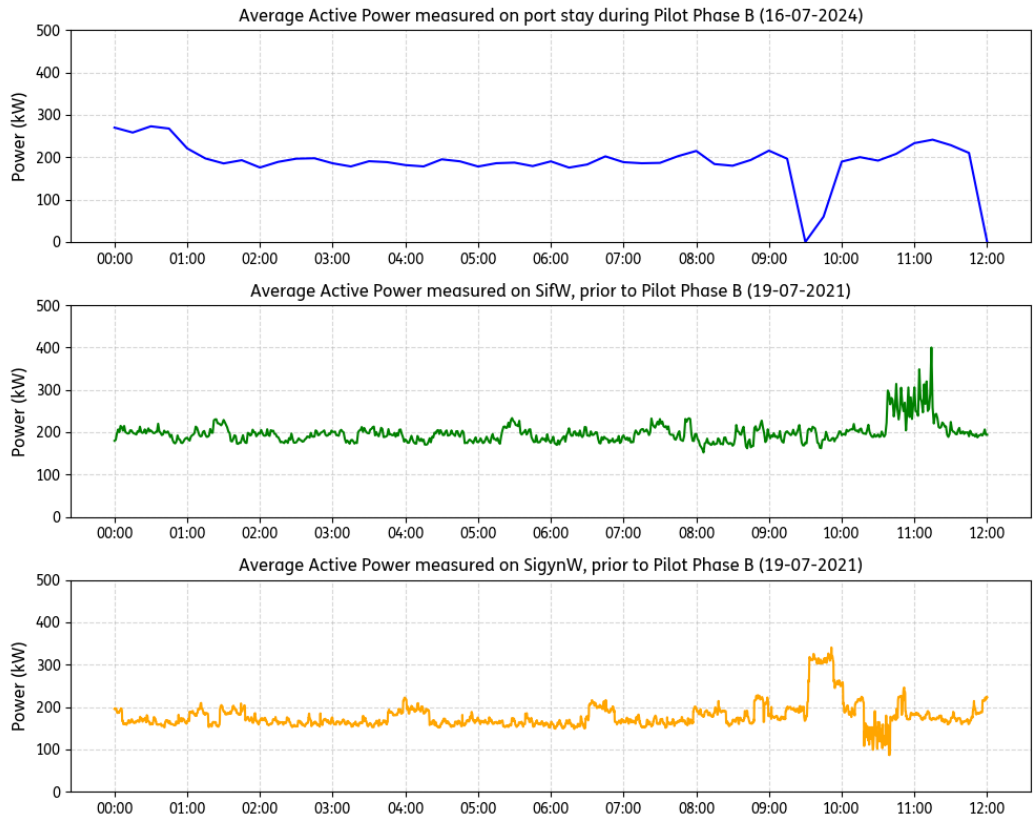

Figure 8: Comparison of power supplied to the vessel for 12 hour windows starting at midnight during Pilot Phase B (first plot, blue), and measurements on board of SifW (second plot, green) and SigynW (third plot, orange) in 2021.

Based on the available data, the shore power system was able to meet the vessel's power demand on multiple occasions for extended periods. However, power interruptions still occurred during the final phase of the pilot. Due to the low sampling rate of the discharge station's power measurements during the pilot, it remains unclear whether the system can meet dynamic power demand fluctuations that are expected to occur based on the measurements on the vessels in 2021 (second and third plot in Figure 8). It cannot be concluded which conditions led to the power interruptions. It could be the case that a high power demand or large dynamic power fluctuations caused the power interruptions, but these effects do not appear in the data due to the low sampling rate. Currently only a limited amount of data on the power consumption during shore power connections of the participating CargoW vessels participating in this trial is available. It would be valuable to monitor power consumption at other ports where these vessels connect to shore power, to gain more insight into how dynamic their power usage is and to understand better how power consumption varies dependent on the equipment in operation on the vessel.

Due to limited available high quality data (as described in Section 4.1), it is not possible to accurately evaluate the charging times and the efficiencies of the charge- and discharge unit. In order to calculate the average efficiency of the charge unit, the energy output of the charge unit should be divided by the energy drawn from the grid during charging.

This could still be performed after the pilot period if a sufficiently large grid connection is available to test at representative power levels. No vessel (or other load) is necessary to test this efficiency. Testing the average efficiency of the discharge unit requires a load that is representative of a vessel in terms of power levels. If a representative load is available, the average efficiency of the discharge unit can be calculated by dividing the total energy drawn from the batteries by the energy output of the discharge unit.

Only on three occasions power was supplied to the vessel for a period of 24 hours or more. Two of these occasions still showed power supply interruptions. As mentioned, the maximum duration of a connection between the shore power system and a vessel during the pilot was 40 hours. Based on the average active power levels in Table 1 this would lead to a total energy demand from the vessel of about 8 MWh. However, since the efficiency of the discharge unit is not known, it is not possible to assess the required battery capacity on the quay to meet the total energy demand of the vessels.

5 System functionality, reliability and safety

In this section the functionality, reliability and safety of the system is described. It first provides an assessment of the shore power system as a whole, followed by an assessment of the piloted flexible cable management system. Section 5.3 covers the safety aspects of the entire project.

5.1 Shore power system

5.1.1 Functionality

Main functionality

The main functionality of a shore power system is providing uninterrupted shore power to a vessel in port. During the pilot, the shore power system has provided the participating CargoW vessels with power on several occasions, for varying amounts of consecutive hours. However, the goal of the pilot was to supply the participating CargoW vessels with uninterrupted shore power for the entirety of their port stays throughout the pilot, which was not achieved.

As was discussed in Section 3 and 4, extended testing at the terminal was needed throughout the pilot period. During these tests many blackouts occurred when the power supply was automatically shut down by its safety system. These blackouts were particularly concerning for CargoW, because they can damage equipment on board. Agreements on testing time were made prior to the tests to limit the risk for equipment on board. However, CargoW expressed dissatisfaction as both the testing time and the number of blackouts exceeded initial expectations.

The shore power system did not reach fully operational mode for extended periods of time by the end of the pilot. This means that the pilot system, at least at the end of the project, is not yet ready to be deployed and that further development and testing is required. This applies especially to the installation at the terminal: the ZES Packs and the discharge station. The charging station did not experience major issues after installation. Its main functionality for this pilot was to recharge all six batteries in time before the next vessel arrived, and that was achieved.

Shore power system connections

Another functionality of the system is connecting and disconnecting the battery containers to the charging and discharging systems. The type of connectors that were being used to connect the ZES Packs to the charging station and discharging station were Stäubli connectors. Each battery container is connected to the inverter station with three connectors (Positive, Negative, Protective Earth) and a separate communication line. Several options for connecting were possible, as shown in Figure 9. Since the batteries need to be recharged, they are connected and disconnected weekly.

This makes the system more vulnerable to problems due to potential incorrect connections or issues with system communication as compared to a system of which all components are stationary. For the piloted system, these connections and disconnections required a system expert to be on site to make sure all connections were correct. So the functionality is there, but it could be improved by making the connection easier and more ‘fool-proof’.

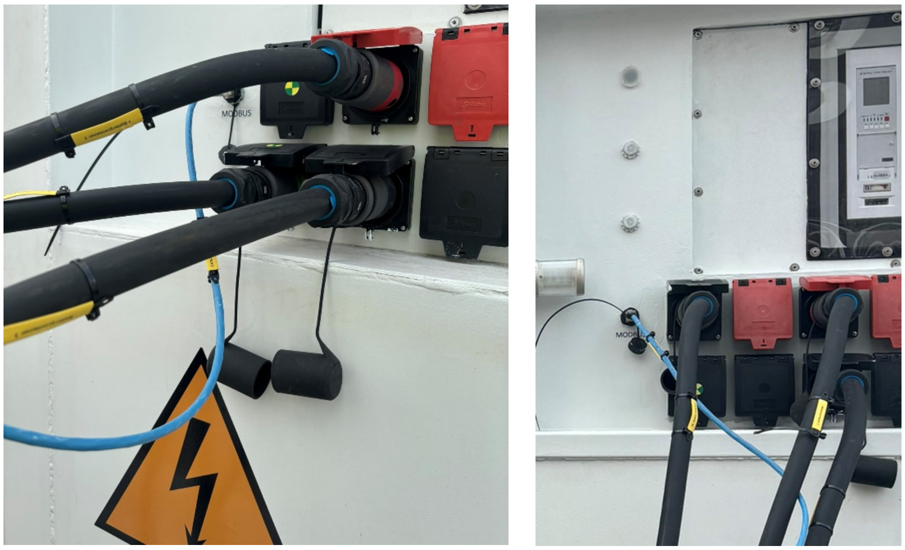

Figure 9: Connectors at the back side of two of the battery containers (ZES Packs). In black, the Stäubli Connectors for: Positive, Negative, Protective Earth. In blue: communication line. The cables are connected to different plugs at both containers.

5.1.2 Reliability

From conversations with CargoW, one of their most important criteria for a shore power system is reliability: the ability to consistently deliver power to vessels without interruption or failure during operations. Due to the extended testing phase and persistent technical issues encountered, the mobile shore power system that was used in the pilot did not demonstrate consistent reliability during operational periods. A significant portion of the time when the system was connected to a vessel was spent resolving these issues, making it difficult to assess its performance under normal operational conditions. Further improvements towards a reliable system are required before CargoW will consider using this technology as a viable solution for their operations.

There are some findings, however, with respect to the redundancy of the system. As was mentioned in Section 2, the ZES Packs were connected to the inverter in pairs, forming 3 groups of 2 batteries (a 3x2 configuration), allowing the power supply to still function with either 2 or 4 ZES Packs. Although this setup provides some flexibility, it does not offer true redundancy. The system’s output power is limited when fewer packs are available, meaning it cannot maintain full operational capacity if any of the groups drop out. In the event of an issue with one battery or group, the remaining groups can continue to supply power, but only to the extent that they can meet the vessel's demand, potentially at a lower output.

5.2 Cable management system

5.2.1 Functionality

One of the goals of this pilot was to test an innovative flexible cable management system. Depending on the vessel type, where exactly a vessel is berthed, and the position of the shore power sockets on the vessel, the shore power has to be connected on a varying location on the quay. To deal with the varying position of the vessels' shore power connection point on the quay, a flexible cable management system might be desired. When a flexible cable management system is used, it is not necessary to transport all of the equipment that is needed for the power generation (in the case of the pilot: the ZES Packs and the discharge unit). Figure 10 illustrates the varying location of the vessels power socket.

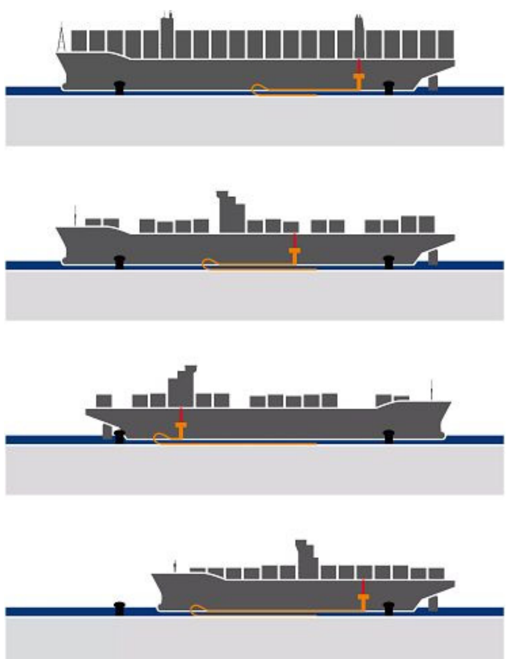

Figure 10: Varying positions of power sockets on vessels can be facilitated by using a flexible cable management system. (IGUS)

<u>Main functionality</u>

For this pilot, the IGUS Mobile Shore Power Outlet (iMSPO) was tested. The primary function of the system is to ensure that a quick connection can be made, regardless of the exact position of the vessel's power socket. It is important to note that the IGUS system was specifically designed for container vessels operating in container terminals. The participating CargoW vessels in this pilot were not container vessels, and the terminal of C. Steinweg is not primarily a container terminal. However, the project team chose to include the IGUS system in this pilot, as it provided an opportunity to test the system on a small scale and in a controlled environment before testing the system in the dynamic and fast-paced setting of a container terminal.

The shore power connection points on board of the different CargoW vessels that participated in this pilot were always in the same location on the vessel. The berthing position of the vessel on the quay was also always the same. Therefore, the position of the vessels' shore power connection point relative to the shore power installation on shore did not change much and a short rail of the IGUS system of about 20m sufficed for the pilot. The maximum length of the IGUS system is 400m, making it a flexible solution to supply power to vessels along a large quay without the need to move the power source of the shore power system. The IGUS system as used during the pilot was installed on the quay and required a significant amount of terminal space as can be observed in the photos and the schematic of Figure 3. This was done because of the temporary nature of this setup.
The IGUS rail in a permanent setup can be mounted on the quay wall as shown in Figure 11. That way, the rail uses the space between the vessel and the quay that is typically not utilised. This reduces the footprint of the shore power system on the quay itself.

Due to the short rail used in this pilot, the interference of the IGUS system with loading and unloading of the vessel and bunkering could not be assessed during this pilot.

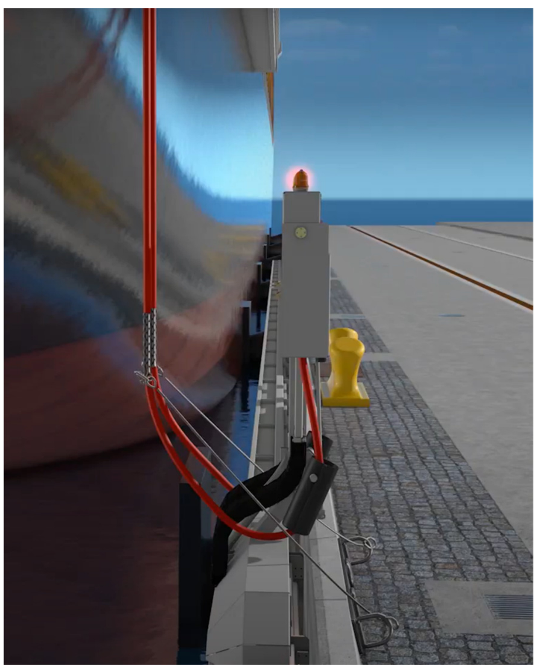

Figure 11: IGUS Mobile Shore Power Outlet mounted on the quay wall to save space on the quay. (IGUS)

Connecting cables

The vessels participating in this pilot required a low voltage shore power connection (440V, 60 Hz). Two cables were needed to supply the necessary amount of power to the vessel. As the use of shore power in ports around the world is increasing, the need for standardisation also increases. The standard IEC 80005-3 exists, but it currently has the status of "Publicly Available Specification", meaning it is currently not acknowledged and can be called a pre-standard (Movares, 2022). Further standardisation is currently being developed. One of the items this standardisation will provide requirements for is the cable management: the standard will prescribe whether the cables needed for making the connection to shore power are carried on the vessels, or should be supplied from the quay.

In this pilot project, the vessel did not have the shore power cables on board; instead, separate cables were supplied from the quay to connect to the IGUS system to the vessels power sockets. This means that the cables connecting the mobile power outlet to the vessel had to be transported to the position along the quay where the power sockets of the vessel are. Since the cables are relatively heavy, this is not ideal. During the pilot the vessels always berthed in the same location, so cables could remain at the same location on the quay. However, when the position of a vessel relative to the shore power system changes it is most convenient to have the shore power cables on board. That way, the cables can be lowered towards the mobile power outlet without any extra movements. Using cables that are supplied from on board of the vessel, cable handling will be less time consuming, less labour intensive and easier.

Besides the fact that separate cables were needed, it also turned out that the cables used in this pilot were not the optimal cables for this application. Ideally, multi-core cables would be used, but due to the time constraints of this pilot these couldn't be on site in time. Instead, three single-core cables (one per phase) were combined and placed in a protective cable shielding tube to hold them together. This resulted in two heavy and bulky (combined) cables.

Due to the size and weight of the cables, handling these cables by hand was not easy. A small crane on board of the vessel was used to hoist both cables aboard, one by one. Figure 12 shows the process of the connecting of the cables to the vessel. The use of these combined single-core cables in the shielding tube was a one-time solution in order to make sure the pilot could start in time.

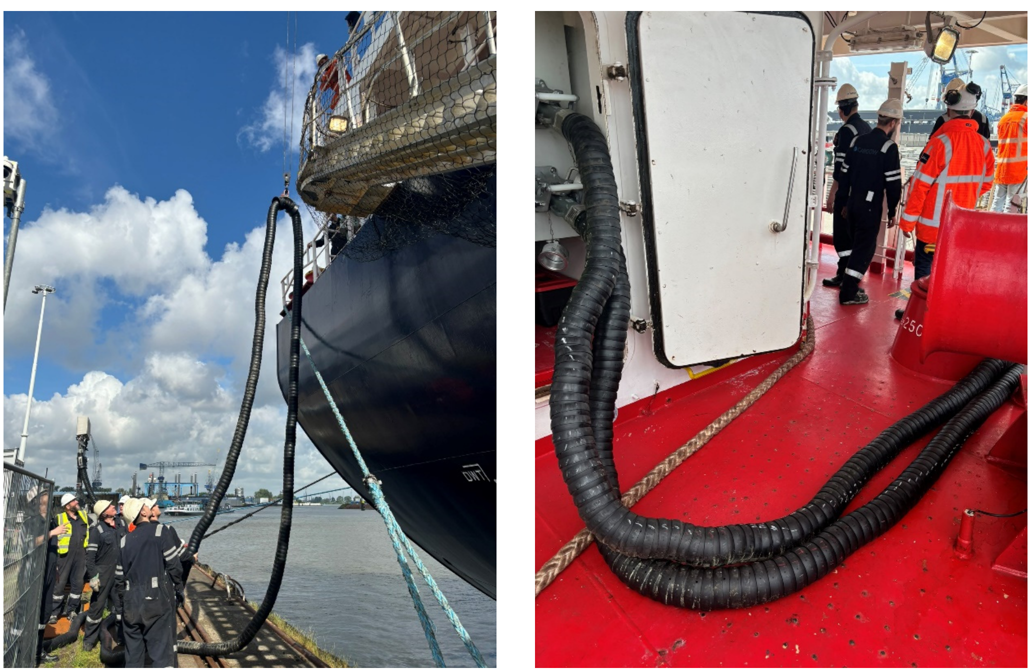

Figure 12: Hoisting shore power cable aboard and connection to shore power plugs of vessel.

In the form that was tested during the pilot, hoisting the cables on board and connecting them to the socket takes roughly 45 minutes and at least four persons: one person attaching the lift equipment to the cable, one person operating the crane, one person on the gangway securing that everything is clear and safe and finally one person on deck to receive the cable on board. When a multi-core cable is used, such as the type that is used by the same CargoW vessels for their shore power connections in other ports, the handling of the cable is expected to be significantly easier. In conversations with CargoW it became clear that a multi-core cable can be handled by a single person using the gangway without the need of using a crane. The expectation is that connecting the vessel to the connection point on shore would in that case be about 10 minutes with 1 or 2 crew members.

Figure 13: Difference in cable size. Combined single core cables in energy chain used in pilot phase B (Left), and multi-core cables used by CargoW in port in Norway (Right).

5.2.2 Reliability

After a faulty wiring internally to the IGUS system was detected and resolved, the system worked throughout the pilot without issues. This pilot was not considered to be a challenging case for the flexible cable management system, since the shore power socket of the participating vessels were always in the same location on the quay and it was not required to move the power outlet along the rail.

5.3 Safety

As described in Section 3.2, the project complied with the Publicatiereeks Gevaarlijke Stoffen (PGS) 37-1 guidelines for large-scale storage of electrical energy in batteries. These guidelines cover safety measures for preventing risks associated with lithium-ion batteries in energy storage systems.

Examples of safety measures implemented based on PGS 37-1 include:

- Novec 1230 fire suppression systems were installed inside the battery containers.
- A mobile water storage tank was available at the terminal to ensure access to fresh water, and the battery containers were equipped with a water inlet compatible with firefighting systems ("bluswateraansluiting"). This was done in order to supply water for cooling the containers in case of an incident to be able to supply water to the containers, cooling down the battery containers in case of an incident.
- Safety instructions were shared with all stakeholders visiting the charging or discharging site to ensure awareness of the potential risks and procedures that were in place.
- Warning stickers indicating safety hazards were placed on the exterior of the containers housing electronic equipment, ensuring visibility of potential dangers.
- Adequate safety distances were maintained to reduce the risk of fire propagation in case of a fire.

Although the guidelines of PGS 37-1 were followed, some safety concerns were observed in the project.

- Concrete barriers were placed on the side of the installation on the quay to prevent impact from the traffic present at the terminal, as was described in Section 3.2. However, no safety barriers were present on the top side of the project area in Figure 3. Barriers were not placed on this side, as this would restrict trucks access to the trailers with the battery containers. The absence of barriers on this side leaves some of the hardware on the quay vulnerable to impact from terminal traffic.
- Only certified personnel was allowed to be present inside of the battery containers, the discharge station and the charging station. This was not always strictly enforced, causing safety risks.
- The inverter was capable of supplying voltage even without the cable being connected to the vessel. This poses a significant safety risk, as the crew could connect the cables between the IGUS system and the vessel while the voltage was already active, potentially exposing them to live electrical components. This underscores the need for enhanced safety protocols to ensure the system cannot be energised until a secure connection to the vessel is established, preventing accidental contact with live parts.
- Hoisting the cable to the vessel during the pilot raised several safety concerns. There was a risk of the cable swinging or the connection point of the cable shield failing during the hoisting process. Since personnel on the quay were required to guide the cable up and down, they were exposed to this risk for an extended period—approximately 45 minutes, as each cable had to be connected individually. Additionally, swinging cables could cause damage to the vessel. Beyond hoisting, the heavy cables could potentially be dropped while being moved on the quay or onboard, posing risks of injury to personnel or damage to equipment.

Some of these risks could be mitigated by using lighter multi-core cables, which are easier to handle and would reduce the time and personnel required for hoisting. If the vessel were to carry the cable on board, the connection process would be further simplified. However, even in such cases, the risk of a swinging cable would remain, so using a guiding rope as a precautionary measure would still be advisable.

6 Mobile concept, logistical and operational implications

This section evaluates the system on its mobility, and assesses the logistical and operational implications of using the piloted shore power system. This section mainly focusses on the power supply part of the system (ZES Packs, charging- and discharging station) and not on the IGUS system, since the cable management system tested in this pilot was not intended to be mobile. The word “mobile” in this context denotes the ability and effort needed to move the entire power supply system in order to supply power at a different location.

6.1 Evaluation of the mobile concept

Mobility and Transport
The system’s design allows for relocation between quays using trailers. However, the relocation process involves several considerations:

Transport Requirements: A trailer is essential for moving the ZES Packs, while a crane or forklift may be needed for handling containers. Trucks are required for transporting trailers to new locations.
Handling Complexity: The system's reliance on multiple containers that do not fit onto a single trailer complicates logistics. Disconnecting and reconnecting these containers adds significant time and effort, estimated at approximately four hours per move.

Connection and Setup
Reconnection Process: Each relocation requires disconnecting and reconnecting all system components, including the discharge station and supporting infrastructure. This process is time-consuming and adds to the complexity of the system.
Supporting Hardware: Concrete barriers, cameras, and cables need to be transported separately or designated at each site, increasing the logistical burden.
Location Requirement: As was mentioned in the introduction, the discharge station needs its own permanent power supply (230 Volts, 32 amperes) to function. This means that the system can only operate in a location where a low-voltage AC connection can be facilitated.

Protective Measures
Safety Barriers: Concrete blocks are necessary to protect the system, but they require separate transport or dedicated space at each location. This adds to the overall effort and cost of relocation.

6.2 Logistical and operational implications of the shore power system

Impact of shore power systems footprint on terminal operation

There were several implications of having the shore power system placed on the quay in the terminal. Firstly, the current configuration of the proposed system has a relatively large footprint on the quay. Space is not readily available in terminals, especially close to the vessel as it is primarily used for equipment movement or cargo handling and storing. As became clear in conversations with terminal operator C. Steinweg, this quay space is highly valuable as it directly affects operational efficiency and the ability to store and handle cargo volumes efficiently. Therefore, a system with a smaller footprint would be required to minimise the impact of the shore power system on the terminal's daily activities. It is worth mentioning that for this project the area of 35x17m as shown in Figure 3 was reserved, and could be fully utilised during the pilot. The required space for the current system can be optimised by more efficient placement of the containers and other equipment, but the ZES system inherently has a large footprint due to the need of seven 20ft-long containers. This space might not be available on all quays in a terminal.

Impact of shore power on terminal movements

Besides the occupied space, the presence of the mobile shore power system on the quay involved additional movements on the terminal. Any type of mobile shore power would involve a certain number of extra movements on the terminal. For a battery-based system however, the number of transport movements was quite significant since it required moving all six batteries from and to the quay every week. Since the energy density of batteries is low compared to some alternative mobile power sources such as biofuels, a large volume is required when a battery system is used. In the pilot, six 20ft containers were used that all needed transport to and from the charging station between port visits. Even though these extra movements impacted operations, C. Steinweg did not consider this problematic. A key factor that facilitated this process was the involvement of a transportation company already familiar with the terminal, ensuring that drivers were well-acquainted with the terminal's protocols and operations.

Impact of shore power on logistics and planning

The use of a battery-based shore power system requires a certain level of planning. Depending on the total battery capacity and the available grid connection, recharging the batteries takes a certain amount of time. A grid connection of 1MVA was used in the pilot, and therefore all six ZES Packs could be recharged within 24 hours. Ideally the grid connection would be located elsewhere on the same terminal. This would limit the number of external visits to the terminal. For the pilot there was no sufficiently large grid connection available on the same terminal, and an external charging location was used. To limit the time required for recharging, it is crucial that the charging location is close to the quay where the shore power is supplied.

As mentioned, the participating vessels followed a schedule: arriving on Sunday and departing the following Tuesday. This meant that after the vessel had disconnected from shore power, there was enough time to schedule the transport of the batteries to the charging location and back, without exceeding the operational hours of the terminal.

This relied on the following two conditions:

- There was always a relatively big window of approximately four days (including three business days) between the departure of one vessel and the arrival of the next.
- All six ZES Packs could be fully recharged within 24 hours.
- Transporting all six ZES Packs to the charging station and back to the quay could be done in a matter of hours due to the short distance between the two locations.

With a three-business-day window between the connecting vessels, there was sufficient time to prepare the connection before the arrival of the next vessel. However, if a tighter schedule is needed, there may not be enough time to complete all necessary transportation, installation and system checks within the terminal's operational hours, which could increase the overall impact on terminal operations.

External personnel on terminal
Connecting and disconnecting the ZES Packs to the discharge station at the terminal, before and after charging, required a person knowledgeable about the system. This task was managed by a representative from Endenburg Electronics during the pilot. Due to the terminal's ISPS certification all visits to the terminal must be registered and checked. Therefore, these visits impact the daily operation of the terminal. Ideally, these installation activities should occur during the terminal's operational hours and on weekdays to avoid violating terminal policies and incurring high labour costs.

A system specialist also needed to be present when the vessel arrived to start the power supply from the shore power system to the vessel. This is needed because starting the power supply requires several actions and checks before the shore power system is ready. The required presence of a system specialist in combination with the flexible arrival time on Sunday involved inconvenience in terms of planning, as well as for the terminal operator that had to register and check the visit. As part of the maturing of the shore power system, a good step would be to reduce the complexity and effort of starting the power supply to the vessel once the vessel arrives. The shore power should be easy enough to operate such that the vessels' crew can perform all the required actions. That way, no external personnel is required to be on call.

Towards reliable applications of battery-based shore power
Terminal operator C. Steinweg recognizes the potential of battery-based mobile shore power to be part of the solution for quays on which a permanent grid connection is not possible on the short term. However, technical improvements are essential to enhance system reliability, minimize reliance on external system specialists, and improve the ease and efficiency of system connection.

7 Conclusions and recommendations

7.1 Conclusions

During Pilot Phase B, a battery-based mobile shore power system was piloted at the Waalhaven in the Port of Rotterdam. Due to the innovative nature of the project, several challenges and delays were encountered as described throughout this report, causing the preparation and installation phase of the project to be longer than anticipated. Given the fixed start and end date of the pilot, limited time was left to test the shore power system in operation.

<u>Maximum power output</u>
The shore power system has proved to be capable of supplying the participating Multi-Purpose vessels with shore power on several occasions. However, several power supply interruptions still occurred. Due to the low sampling rate it cannot be concluded with certainty that the shore power system was able to meet the peaks in power and the dynamic power fluctuations that the vessels demand. Long-term reliability still needs to be tested and improvements on system-level are required to make this type of system marked-ready.

<u>Energy storage capacity</u>
During the pilot phase, the shore power system operated in full operational mode for only a limited period, with a few port stays where shore power was actively provided to the vessel, rather than being used in testing. The maximum connection duration recorded was 40 hours. With an average active power of 200 kW, this translates to an approximate total energy demand of 8 MWh from the vessel, aligning with observations from previous measurements on CargoW vessels before the pilot.

Due to limited high-quality data from the ZES Packs, it was not possible to assess the efficiency of the discharger accurately. Consequently, the battery capacity required (i.e., the number of ZES Packs needed) to fully meet the vessels' total energy demands during port stays could not be determined.

<u>System mobility</u>
The modular, container-based design of the piloted shore power system offers flexibility in relocating the system. It can be moved between locations as needed, and having the battery containers permanently on trailers supports this mobility. However, the need for multiple containers, extensive disconnection/reconnection procedures, and separate handling of protective measures results in a complex and time-consuming relocation process. The system's large footprint on the quay and associated logistics further complicate the process. Besides this, the site preparation and permitting make up a significant portion of the cost per unit of energy provided. These large costs underscores the challenge of moving the system to new locations. The costs associated with preparing each site would make it financially impractical to relocate frequently.

Flexible cable management system

The IGUS Mobile Shore Power Outlet (iMSPO) was piloted, and proved to be a reliable and easy to operate cable management system in this pilot. Since the vessels that participated in this trial always berthed at the same location, little movement of the mobile power outlet was required. To make the connection between the IGUS system and the vessel easy and fast, the IGUS system is best used in combination with vessels that carry the cables on board.

7.2 Recommendations

Given the challenges that are faced in the industry with respect to mandatory use of shore power, Green House Gas (GHG) intensity reductions and a congested electricity network, the use of battery based mobile shore power systems is an option worth investigating further. Below, recommendations for several aspects of the project and the piloted system are described.

Preparation and installation

- Make sure enough time is available for component testing, and integral system testing and commissioning before starting the pilot with operational procedures.
- Testing at the terminal should be minimised, as terminal policies may restrict the available testing time and access to the shore power installation.
- If testing with a vessel is needed during the installation or testing of the shore power system, in order to introduce a representative load to the system, it is essential to establish clear agreements with the ship owner and crew early on in the project. Testing the shore power system with a vessel can cause power interruptions on the vessel, risking damage to the vessel’s equipment. By securing clear agreements on testing and schedules with the vessel, the operation of sensitive equipment can be limited or entirely halted during the designated testing periods, minimising the risk of damage.
- Given the complexity of this pilot with many stakeholders and a range of components that have not been tested in a similar way before, communication and alignment between stakeholders is of utmost importance. In the executed pilot, there were differing expectations amongst the project stakeholders: ZES expected to have the ability to further test their system, while the terminal operator (C. Steinweg) and shipper (CargoW) expected a fully operational system at the start of the pilot. Good communication and clear alignment of capabilities and expectations between the stakeholders, both before and during the pilot can contribute to an improved collaboration.

IGUS system

- During the pilot, the appropriate cables to make the connection between the IGUS system and the vessel were not available. Using the more lightweight multi-core cables will ensure an easier and safer connection between the quay side system and the vessel.
- The most potential of the IGUS system is obtained when it is used in combination with vessels that can supply the shore power connection cables from on board of the vessel. Otherwise external cables have to be moved to the correct location on the quay and need to be hoisted up to the vessel’s connection point. This makes the total connection less flexible and more labour intensive and more time consuming.

Connections between hardware components
To help making the connections quicker and more “fool proof”, a possible improvement for the system is to use the Megawatt Charging System (MCS) connection. Using MCS connectors, the Positive, Negative, Protective Earth and communication lines can be combined into a single connection, reducing the number of actions required to make a connection, and reducing the risk of faulty connection. Since MCS is being adopted in many high power applications, using MCS would also increase the flexibility of the system. For example, the ZES Packs could be charged using existing infrastructure based on MCS, instead of requiring a dedicated charging site such as was in used in the pilot.

Limiting the impact of shore power system on the terminal
- Reduce the footprint of the system of the terminal as much as possible without sacrificing safety.
- Make the connection between the ZES Packs and the discharge station and charging station as fool proof and quick as possible to limit the amount of time needed for personnel to make the connection.
- The charger should not be too far away from the quay where the shore power is supplied, as the same people who disconnect it will need to be there to connect the ZES Packs to the charger.
- Prepare the shore power system as much as possible before a vessel arrives: make sure all connections have been made and the system is completely ready when the vessel arrives.
- The start of the power supply (once all components have already been connected) should be as easy and quick as possible.
- Limit the need of external or specialised personnel on the terminal, as safety protocols on the terminal might impose restrictions on accessibility on the terminal and specialised personnel increases the cost.

Increasing movability
To improve relocation efficiency, consider investigating the option to integrate all equipment onto a single small vessel. This approach could streamline the relocation process, reduce the need for frequent reconnections, and minimize the required footprint on the quay.

Data collection
Requirements on data logging during operation should be clear to all involved parties prior to the hardware design, and clear agreements on data sharing should be in place to allow for analysis and draw conclusions for improvements or for future projects.

Reducing preparation and permitting cost
Site preparation and permitting is a significant cost attribute of the system. Design the mobile shore power system in a way that reduces on-site preparation and developing a standardised or modular approach to setting up the system at multiple sites may help in reducing these preparation expenses.

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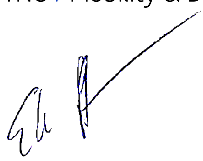
Signature

TNO Mobility & Built Environment Den Haag, 16 December 2024



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Appendix A
FuelEU Maritime regulatory context

As mentioned in the introduction, the FuelEU Maritime regulations will require container and passenger vessels with a gross tonnage of 5,000 or more to connect to shore power at major EU ports by 2030. Expansion to other vessel types and sizes is likely in the future when the technical standards will become available. These standards are under development or planned.

Moreover, the FuelEU Maritime framework does set targets for the greenhouse gas (GHG) intensity of energy consumed by all vessel types of 5,000 GT and above when operating in EU or European Economic Area (EEA) waters. This intensity is measured in grams of CO_2 equivalent per megajoule (gCO_2e/MJ), accounting for emissions from a “well-to-wake” perspective. In other words, it considers everything from fuel extraction and production to its final use on board, providing a comprehensive view of a vessel’s environmental impact.

Zero emission shore power offers a straightforward way for vessels to reduce their GHG intensity, as it increases the denominator (energy) in the GHG intensity calculation without adding emissions to the numerator. These targets will become more stringent over time, leading up to 2050 and beyond, as shown in Figure 14. Ships that don’t meet these progressively ambitious targets will face penalties, calculated based on the gap between the regulatory target and the ship’s actual GHG intensity, multiplied by the vessel’s total energy consumption (ClassNK, 2023).

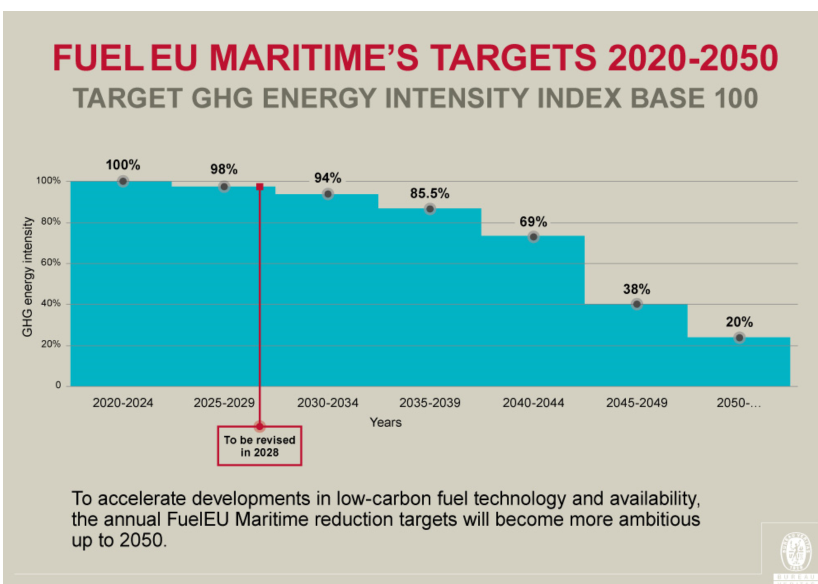

Figure 14: Green House Gas (GHG) emission intensity (gCO_2e/MJ) targets decrease over time (Bureau Veritas).

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