EALING

Deliverable D2.2

Report on the identification of the relevant technical and regulatory elements to facilitate adaptation and connectivity of ships to Shore Side Electricity (SSE)

Co-financed by the Connecting Europe Facility of the European Union

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EXECUTIVE SUMMARY

The EALING project is an EU-funded initiative, aiming at examining and promoting the utilization of Shore Side Electricity (SSE) in the 16 Trans-European Transport Network (TEN-T) network European Union (EU) maritime ports. Within this project framework, Deliverable D2.2 seeks to investigate the technical and regulatory elements necessary to facilitate the adoption of SSE by the maritime fleet and their seamless connection to the shore electrical grid.

Chapter 1, titled "Introduction," provides a concise overview of Activity 2 and outlines the objectives of the report. It serves as an introductory section that sets the context for the subsequent chapters by presenting a brief description of the activities undertaken and the intended outcomes.

Chapter 2, "Vessel types – Case studies selection," serves as a pivotal section in which the Vessel Case Studies to be further investigated are identified. The selection of these case studies is based on a thorough evaluation of various parameters, including technical challenges, regulatory compliance, and market considerations. By considering these multifaceted factors, the project aims to ensure that the chosen case studies represent diverse vessel types and encompass a range of characteristics relevant to SSE implementation.

Chapter 3, "Analysis of EALING Case study Vessels," focuses into the specific considerations necessary for implementing Shore Side Electricity (SSE) onboard vessels. This chapter provides a comprehensive examination of the selected vessel types. It includes detailed descriptions of vessel data, initial assessments, and updated drawings to illustrate proposed modifications. The chapter also offers technical recommendations tailored to each vessel type, covering equipment selection, electrical system modifications, and SSE infrastructure integration.

Chapter 4, "Preliminary Implementation Plan," offers a high-level plan for the implementation of SSE in the selected vessel case studies. This chapter encompasses preliminary estimations of costs, timelines, and work sequences involved in retrofitting the vessels for SSE. Alongside these estimations, the chapter also provides technical recommendations to ensure a smooth and effective implementation process.

Chapter 5, titled "Technical and Regulatory Recommendations," synthesizes the recommendations derived from Activity 2 and this deliverable. This section provides a harmonised overview of the technical and regulatory measures identified throughout the activity that are necessary to facilitate shoreside electrical connectivity for the maritime fleet. By highlighting these recommendations, the chapter aims to support and guide stakeholders involved in the adoption and integration of SSE.

Finally, Chapter 6, "Conclusions," is summarizing the main findings and outcomes of the Deliverable 2.2.

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1. INTRODUCTION

1.1 Objectives of the Activity

Activity 2 plays a crucial role in studying, harmonizing, and proposing a framework that promotes the electrification of the maritime fleet operating across the consortium's ports, with the intention of influencing broader industry practices through engagement with the International Maritime Organization (IMO). Overall, Activity 2 scope is to conduct a comprehensive study of the maritime electrification standards across the ports within the consortium and the vessels operating in these ports.

The first objective of Activity 2, performed in the first deliverable of the activity, was to analyse the current standards and practices of maritime electrification. It involved examining the existing regulations, guidelines, and practices related to maritime electrification. By understanding the existing standards, the activity aimed to identify areas where harmonization is needed to ensure consistent and efficient implementation of maritime electrification.

The second objective of Activity 2 is to focus on the identification of technical elements that should be harmonized. This involves identifying specific aspects related to maritime electrification, such as electrical infrastructure, power requirements, voltage requirements, connector types, and safety protocols. By identifying these technical elements, the activity aims to develop recommendations for harmonization that will facilitate interoperability and compatibility among different ports and vessels with respect to SSE adaptation.

The absence of a harmonized technical and regulatory framework for maritime fleet adaptation to maritime electrification creates challenges in interconnecting the supply and demand side of the Shore Side Electricity (SSE) infrastructure.

The only preliminary consideration of SSE in the previous legislative framework and EU co-funded projects has resulted in a lack of best practices and recommendations for retrofitting vessels with SSE systems. Without clear guidelines on the design and arrangement of electrical infrastructure onboard, decision-making and implementation of SSE onboard are impeded. This lack of specific technical elements and associated costs further obstructs the mainstream development of SSE, as it becomes difficult for stakeholders to assess the feasibility and benefits of adopting SSE solutions.

Additionally, the immature level of consideration of SSE has also led to a lack of uniform electrical standards and regulatory frameworks across different EU ports and member states. Although IEC 8005 standards aim to resolve these issues, several inconsistencies have been identified. These non-harmonized items in the existing standards and regulations disrupt the SSE application, making it difficult for vessels to seamlessly connect to shore power supply across different ports and member states. The varying procedures for connecting and disconnecting to shore power supply further create inefficiencies and safety concerns.

The reliance on private industry initiatives for SSE development has resulted in a focus on ship-specific or company-specific arrangements rather than broader and uniform implementation of SSE. This fragmented approach hampers the interconnection on a larger scale while the lack of a harmonized framework limits collaboration and coordination among industry stakeholders.

In summary, the absence of a harmonized technical and regulatory framework for maritime fleet electrification poses challenges to interconnecting the supply and demand of SSE related stakeholders (vessels / ports). Addressing these challenges and establishing a harmonized framework would facilitate the promotion of the widespread use of SSE in the maritime sector.

The goal of Activity 2 is to provide valuable insights that facilitate the development of a proposal towards the International Maritime Organization (IMO). This proposal's purpose is to outline the recommended harmonized technical and regulatory framework for maritime fleet electrification. By presenting a unified approach to electrification, the proposal seeks to facilitate the adoption of SSE in the maritime industry while ensuring safety, efficiency, and environmental sustainability.

1.2 Objectives of the Deliverable

The main objective of Deliverable D2.2 is to provide a comprehensive analysis and set of recommendations for the harmonization of technical elements in maritime electrification. Building upon the second objective of Activity 2, this deliverable aims to identify and address specific aspects related to the electrical infrastructure, power requirements, voltage requirements, connector types, and safety protocols in the context of maritime electrification. By examining existing regulations and industry practices, Deliverable D2.2 seeks to develop a harmonized technical and regulatory framework that promotes interoperability and compatibility among different ports and vessels, focusing on the vessel side.

The recommendations outlined in this deliverable will play a crucial role in facilitating the adoption of shore-side electricity (SSE) systems by providing clear guidelines on the design and arrangement of electrical infrastructure onboard, addressing associated costs, and establishing uniform electrical standards and regulatory frameworks across EU ports and member states. Ultimately, Deliverable D2.2 contributes to the development of a proposal towards the International Maritime Organization (IMO), promoting a unified approach to maritime fleet electrification that ensures safety, efficiency, and environmental sustainability.

To fulfil its objectives, Deliverable D2.2 will involve the identification and detailed analysis of five different vessel types within the context of maritime electrification. This analysis will be based on a combination of sources, including the information provided by questionnaires answered by shipping companies, the results obtained from TEN-T EU ports, and a comprehensive review of relevant regulations. By leveraging these sources of information, the deliverable aims to gather a comprehensive understanding of the technical elements and requirements associated with maritime electrification for a diverse range of vessel types.

The questionnaire responses provide valuable insights from industry stakeholders, allowing for a better understanding of the specific challenges and considerations related to electrical infrastructure, power requirements, voltage requirements, connector types, and safety protocols in the context of maritime fleet adaptation to electrification. The results obtained from ten EU ports will offer real-world data and experiences, highlighting the practical implementation of SSE systems and providing insights into existing best practices and potential areas for improvement.

Additionally, the review of relevant regulations will contribute to the identification of existing standards, guidelines, and frameworks that govern maritime fleet electrification. By examining these regulations, both at the national and international levels, the deliverable will ensure that the proposed harmonized technical and regulatory framework for maritime electrification aligns with and builds upon existing legal frameworks.

The detailed analysis of the five identified vessel types, based on the aforementioned sources, will enable Deliverable D2.2 to provide specific and actionable recommendations tailored to each vessel type. This comprehensive approach ensures that the proposed harmonized framework addresses the unique needs and characteristics of various vessels, promoting interoperability and compatibility across the maritime industry.

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2. VESSEL TYPES – CASE STUDIES SELECTION

2.1 General

The purpose of this chapter is to identify the Vessel Case Studies that will be studied in further detail in this deliverable. The Vessel Case Studies are identified based on several technical, regulatory, and market-based parameters.

2.2 Review of results from Questionnaires

As part of the work performed in Activity 2, a questionnaire was devised and sent to shipping lines in Europe. The main objective of this questionnaire was to gather information on the status of the shipping sector regarding the adaptation to SSE infrastructures in EU ports and on the technical, regulatory, administrative, and other related aspects that affect its implementation. Two questionnaires were formulated and shared with participating entities:

- Questionnaire 1 was addressed to Shipping Lines.
- Questionnaire 2 was addressed to Classification Societies / Flag Administrations.

Following, this section reviews the answers received and highlights results that are considered relevant for the analysis of the use cases and the recommendations for the deployment of SSE connection on the ship side. The questionnaires were answered between June and December 2021. In total, 18 Shipping Companies, 4 Classification Societies and 2 Flagships participated in the questionnaires.

The EU MRV Regulation defines a **shipping company** as the shipowner or any other organization or person, which has assumed the responsibility for the operation of the ship from the shipowner[1]. Regarding the **number** of shipping companies, according to the Fourth Annual Report from the European Commission on CO2 Emissions from Maritime Transport (period 2018-2021)[2], in 2021, 1.688 shipping companies submitted emission reports to the Thetis MRV repository[3], 53.1% of these companies registered in the EU and 2.3% in an EEA (European Economic Area), non-EU country (i.e., Norway, Iceland and Liechtenstein). The following Figure, obtained from this report, illustrates the evolution in the number of shipping companies reporting emissions in the years 2018 to 2021.

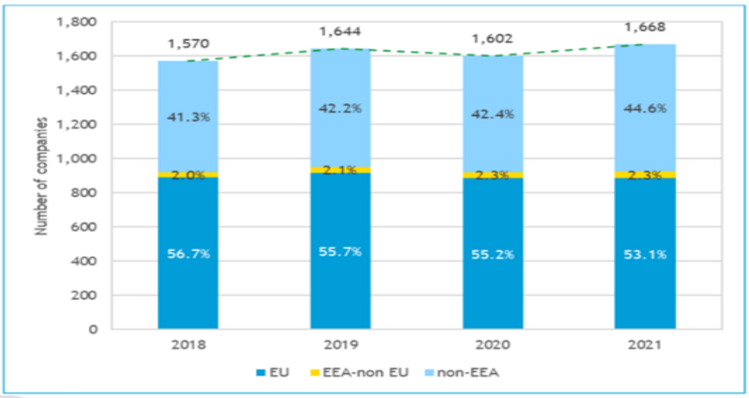

Figure 1: Number of companies and distribution over the region, 2018 to 2021. Source: Fourth Annual Report from the European Commission on CO2 Emissions from Maritime Transport (period 2018-2021). March 2023.

[1] https://climate.ec.europa.eu/system/files/2020-05/swd_2020_82_en.pdf

[2] https://climate.ec.europa.eu/system/files/2023-03/swd_2023_54_en.pdf

[3] https://mrv.emsa.europa.eu/#public/eumrv

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Considering the EU and EEA registered companies, **the total number of shipping companies that reported emissions is 935**. The questionnaire was answered by 18 shipping companies, being 7 of them mostly freight or cargo lines, 9 passenger ship companies, and two providers of tug, pilot and/or barge services.

The analysis presented is based solely and exclusively on the responses of the participating entities. The only intervention made by the EALING team was to correct or disregard some content errors detected during the processing of the data. Given the number of responses received, to derive some conclusions about the representativeness of this group of companies to the whole "population" of shipping companies in Europe, the formula for the statistical sample size of a finite population is used:

$$n = \frac{Z_\alpha^2 \, N \, pq}{e^2 \, (N-1) + Z_\alpha^2 \, pq}$$

Where:

- *N* is the finite population size.
- *Z* is a constant whose value varies with the confidence level defined. The confidence expresses how trustworthy the results might be. Values are obtained from a typical normal or Gaussian distribution. The following table gives some of the values most frequently used.

Table 1: Typical confidence values and the constant to be used when calculating sample size. Source: Wikipedia.

Confidence level (%)	Constant
80	1.28
90	1.65
91	1.69
92	1.75
93	1.81
94	1.88
95	1.96

- *e* is the expected error in the sample, i.e., the maximum error to be expected when surveying just the sample, compared to surveying the total population.
- *p* and *q* represent the percentage of individuals that possess a specific feature sought in the sample (p) compared to those that do not possess it (q = 1-p). In case no specific feature is sought, p=q=0.5.
- *n* is the sample size.

Assuming, for the case of Europe, a total number of shipping companies, both cargo and passenger, of 935, the adequate sample size, for a confidence value of 95% and an expected error of 5%, would be the following:

$$n = \frac{1.96^2 x 935 x 0.5 x 0.5}{0.05^2 (935-1) + 1.96^2 x 0.5 x 0.5} = 272$$

This value is far from the number of shipping companies that answered the questionnaire. With 18 companies as a sample size, values obtained for the error and the confidence interval might be the following:

$$n = \frac{1.28^2 x 935 x 0.5 x 0.5}{0.16^2 (935-1) + 1.28^2 x 0.5 x 0.5} = 16$$

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Being the **confidence interval 80% and the error of around 16%**. This result indicates that the sample is not representative enough, with a low confidence interval and a sampling error of up to 16% in the results, compared to surveying the 935 companies. Even though this is not an optimal sample, however, the results are still considered valuable for informative purposes, especially regarding the barriers highlighted by the companies and their contribution to the analysis of the use cases in this deliverable and the final recommendations produced. These main results from the questionnaire are summarized next.

2.2.1 Main Findings of Questionnaire 1 - Addressed to Shipping Lines

Among the different questions asked to the companies, one that allows to capture at first sight the nature of the shipping lines is the services that they offer. The answer to this question is grouped into the main ship types following the taxonomy defined by the Thetis MRV repository. The result can be observed in the following Table.

Table 2: Services offered by the 18 shipping companies that answered the questionnaire

Classification according to Thetis MRV taxonomy	Service offered as answered in the questionnaire	No. of companies
Bulk carrier		
Chemical tanker	Chemical/products tanker	1
Combination carrier		
Container ship	Containerships	4
Container/ro-ro cargo ship	Con-ro	1
Gas carrier	LPG Tanker	1
General cargo ship		
LNG carrier		
Oil tanker		
Other ship types	Piloting Tugs Supply ship Barge Yachts/Boats Fishing	1 2 2 1 2 1
Passenger ship	Passenger ship Cruise ships	4 2
Refrigerated cargo carrier		
Ro-pax ship	HSC (High-Speed Craft) Ro-pax	4 8
Ro-ro ship	Ro-ro	5
Vehicle carrier	Car carrier	2

The most common services offered by the companies that answered the questionnaire are Ro-pax vessels (8 companies), followed by Ro-Ros (5 companies) and containerships, HSC and passenger ships (4 companies each).

2.2.1.1 Foreseen load profile from Shore Side Electricity supply

One of the questions addressed to the shipping companies was related to the knowledge of the energy demand profile that their vessels would have in terms of shoreside electricity demand.

The answers depict a variety of power demand profiles, closely related to the characteristics of the group of vessels operated by each company (the type of vessel, its size, etc). The following Table summarizes the results.

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Table 3: Questionnaire for shipping companies. Overall load requirements at berth. (Note: 4 companies out of 18 (22.22%) did not answer this question)

Type of vessel	Max. Power demand (kW)	% of vessels at 50 Hz
Car carrier	NA 800	0 0
Chemical/Product tanker	2000	0
Containership	7700 800 300	5 66 100
HSC	NA 5000 480	100 0 NA
Passenger	3000 2000	50 100
Ro-Pax	NA NA 2500 2000 350	50 50 20 100 100
Ro-Ro	NA 3200 800 280	0 100 0 100
Tugs	50	100

The main conclusions are that **the voltage levels of SSE infrastructure will cover the two options, high voltage for the demand of more than 1,000 kVA and low voltage** for equal or low than that and that ships' frequency varies, making necessary the **deployment of frequency converters**, to supply electricity from the European power grid operating at 50 Hz. It can also be observed that in some cases the power demand is unknown, a fact that can be given by the lack of technical knowledge of the person answering the questionnaire, or also because no assessment of the power demand for SSE supply has been done yet by the company, by the time the questionnaire was answered. In the cases that this information is given.

- *Main barriers that can affect the adoption of SSE*

A question regarding the main barriers that can affect the adoption of SSE in the maritime industry was included in the questionnaire to the shipping companies, with blank space left for them to express their opinions. Of the answers received, there are mainly two that it is worth highlighting in this document**: the costs and the lack of SSE infrastructure available** at ports. Regarding this latter barrier, the slow deployment rate of SSE systems in Europe, this topic has been addressed and studied in Activity 1 of this project. The barriers to the mass deployment and the recommendations for a better harmonization framework in Europe can be consulted in the Milestone 6 document, published under the title "Final recommendations for a harmonised framework on SSE in EU ports".

Regarding the costs, the shipping companies mention costs of two types: the **retrofitting costs** and the **refuelling costs** (i.e., the price of the electricity being supplied to the vessel). The price of electricity is a topic of discussion, also addressed in the Milestone 6 document, where an in-depth analysis is included and some recommendations at the economic policy level are produced. Retrofitting costs are addressed in this deliverable, in Chapter 4.

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- *Supporting mechanisms to promote the adoption of SSE*

Enquired about possible ways or mechanisms to help overcome barriers and accelerate the deployment of SSE, most of the answers received agree on two main mechanisms: **taxes or fee discounts, exemptions, or rebates**, and receiving **incentives or funds**. The first mechanism relates to obtaining a reduction in the taxes and the port fees for connecting to SSE supply while at berth. This is a mechanism that port authorities may put in place to make SSE more economically attractive for shipping companies. Regarding the incentives and funds, financial support mechanisms at European and National levels are mentioned, such as the Next Generation Funds.

2.2.2 Main Findings of Questionnaire 2 - Addressed to Classification Societies and Flagship entities

A questionnaire was also prepared for classification societies and flagship entities. Six answers were received to this questionnaire. Even though the participation was low, it is considered relevant for this document to highlight some of the answers to the free text questions that were included.

- *Is your entity involved in promoting the use of SSE among your customers/ registered ships?*

The answer to this question was “Yes” by four entities, “No” by one entity, and another one did not answer. It is interesting to note that classification societies are developing their own **Class Notations** for SSE infrastructure on board. The lack of harmonization of these class notations may become a source of doubts regarding the readiness of the infrastructure on board in the future.

- *What type of technological issues must be considered to harmonise or homologate SSE in fleets?*

From the answers received, the most relevant found for the present study can be divided into two groups. One group refers to technical issues regarding voltage levels, synchronisation of the supply between shore and ship, protection and security issues and **technical details needed for shore connection**, all of them currently addressed by the international standard IEC/IEEE 80005. Of all these issues, probably the **short circuit contribution** could be an object of further study, given the broad range of vessels and their unique characteristics. This aspect, however, is also addressed by the standard, with generic values defined per ship type.

The second group of suggestions focus on the varying through time **power demand from the vessel** and the power quality of the supply from the shore. More information is needed regarding this issue, not only a value of maximum demand expected but also regarding the complete hoteling demand power profile during the time that vessels stay at berth. This topic has been approached previously in this project, and recommendations have been produced in the Milestone 6 document, “Final recommendations for a harmonised framework on SSE in EU ports”. In the present work, this topic is also addressed from a different approach, that is from the perspective of the loads and generators that can be usually found at the vessels.

- *Main barriers at the regulatory level that can affect the adoption of SSE*

The results obtained when enquiring about barriers differ. Some of the entities indicate that the current standard IEC/IEEE 80005 provides all the requirements. Other entities, however, mention as a regulatory barrier the **national legislation related to the ports and the utilities**. This is a topic also addressed in Milestone 6, and it affects directly, in the case of utilities and the electricity sector, the regulated tariffs and the final price of the electricity being charged for the service.

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➢ *Training needs*

Almost all the respondents of the questionnaire agree in highlighting that proper material to train personnel on board needs to be produced regarding SSE, which implies that there is an important gap here related to staff safety and security. The request is made regarding the operation of SSE on board. A **manual for the crew** must be produced, along with adequate training on it. Another request is to update the Standards of Training, Certification and Watchkeeping (SCTW) with all the issues dealing with SSE.

2.3 Review of results from the TEN-T EU ports

The marine traffic in the TEN-T Core and Comprehensive ports of the EALING Action will be analyzed for the identification of the indicative case studies that are the most usual vessel types calling at the maritime ports of the project.

As part of the EALING project activities, Front-End Engineering Design (FEED) studies were performed on the participating ports. Based on the acquired data from six (6) of the EALING participating ports, the following Table provides a general overview.

Table 4 shows the types of vessels and number of berths at the EALING participating ports. For each berthing position the power capacity and the nominal voltage are given.

The most common vessel type berthing on the six (6) of the EALING participating ports are Ro-pax vessels (17 berthing positions), followed by Containerships (12 berthing positions), Bulk Carriers (11 berthing positions), and cruise ships (4 berthing positions).

The main conclusions are that:

- The vessel types berthing at a specific position is one of the main parameters of the SSE design. Based on the vessel type, among others, the maximum power provided, the nominal Voltage and the number of power cables are decided.
- Whether the provided power is more or less than 1 MVA is another main parameter of the SSE design. IEC/IEEE 80005 -1 is applicable for HVSC systems for ships requiring 1 MVA or more or ships with HV main supply, while the provisional IEC/IEEE 80005 -3 is applicable for LVSC systems for ships requiring up to 1 MVA. For most of the studied positions above more than 1 MVA is planned to be provided, making IEC/IEEE 80005-1 applicable.
- Based on the actual electrical power demands of the vessels calling to a berthing position, the provided power of each berthing position is chosen. The proposed provided power (MVA), as shown in the table above, may be less than the maximum power determined by the applicable Standard. In this way over dimensioning of the cabling and the equipment are avoided, making the installation of the SSE equipment more cost effective for the port.
- The provided nominal voltage is determined by the applicable standard. When IEC/IEEE 80005 -1 is applicable, nominal voltage of 6,6 kV AC or 11 kV AC are provided, whereas when IEC/IEEE 80005 -3 is applicable, nominal voltage of 400 V AC or/and 440 V AC or/and 690 V AC are provided. More specific requirements apply according to the ship type and port's infrastructure.

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Table 4: EALING participating ports FEED study summary results

Ship Type	no. of Berths	MVA Provided per berth	Voltage
Port: Constantza			
Bulk carrier	4	1	440V
Container ship	2	5	6,6kV
LNG carrier	1	5	6,6kV
Ro-pax ship	1	5	11kV
Ro-ro ship	1	1	440V
Vehicle carrier	1	1	440V
Port: Piraeus			
Ro-pax ship	1	0,5	440V
	1	1	11kV
	3	4	11kV
Port: Rafina			
Ro-pax ship	2	1,5	11kV
	2	1,5	11kV
Port: Valencia			
Container ship	1	7,5 MVA - in case of only one vessel connected	6,6kV
		5 MVA for each vessel - for the case when there are two vessels connected simultaneously (a total of 10 MVA maximum capacity at the SSE substation)	6,6kV
Ro-pax ship	2	4	11kV
Passenger ship (cruise ships)	2	16 MVA in one berth and 20 MVA in the other berth, as recommended in the IEC 80005 standard for large cruise ships	11kV / 6,6 kV
Port: Burgas			
Bulk carrier, Containerships, General Cargo Ships	6	2,5	6,6kV
Container ship	2	7,5	6,6kV
Ro-pax ship	1	2	6,6kV
	1	4	11kV
Passenger ship (cruise ships & Ropax)	2	16	11kV
Port: Varna			
Bulk carrier & General cargo ship	1	2	6,6kV
	1	1,5	6,6kV
	3	1	6,6kV
Container ship	1	3	6,6kV
Ro-pax ship	1	2	11kV
Oil tanker	1	3	6,6kV

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2.4 Regulations Review

2.4.1 General Overview

In this subchapter, the applicable SSE regulations per vessel type will be summarised as the relevant regulatory elements that need to be identified for facilitating the adaptation/connectivity of ship to shore-side electricity facilities. The identification of the relevant regulatory elements referring to each vessel types could facilitate the adaptation/connectivity of ships to SSE in the under-study TEN-T Core and Comprehensive ports of the EALING Action. The applicable regulations and key parameters that influence directly or indirectly SSE installations onboard will be analyzed for the description of the indicative case studies of the selected and most usual vessel types calling at the maritime ports of the project.

The European Union has set itself the binding goal of achieving climate neutrality by 2050 through the **European Climate Law**, as part of the **European Green Deal**. A significant reduction in current greenhouse gas emissions over the next few decades will be required also by maritime transport. As an intermediate step on the road to climate neutrality, the EU has committed to reducing its emissions by at least 55% by 2030. The European Union has currently revised its climate, energy, and transport-related legislation as part of the so-called **Fit for 55 Package** aiming to align the current rules with the 2030 and 2050 targets. Regarding SSE, in European maritime ports and installations onboard vessels, the provisions have been made fully consistent with the **Fuel EU Maritime proposal**. Despite the progress in recent years, maritime transport including all vessel types calling at European ports still relies almost exclusively on fossil fuels and constitutes a significant source of greenhouse gases and other harmful pollutants. Following the data collected within the framework of **Regulation (EU) 2015/757** in 2018, **containerships and passenger ships (including cruise ships)** constitute the two vessel types which are producing the highest amount of GHG emissions per ship while moored at the quayside.

Other applicable regulations that could influence indirectly SSE installations onboard per vessel type constitute the **revised EU Emission Trading Scheme** that applies to large ships above 5.000 gross tons (GT) regardless of their vessel type and the **revised Energy Taxation Directive** that will apply to all vessel types. In particular, the revised EU ETS directive will come into effect in 2024 for vessels above 5.000 GT, which are liable for 40% of the total CO2 emissions of the shipping sector and in 2026 it will come into effect for all types of vessels, that are liable for 100% of the total CO2 emissions of the shipping sector. As concerns the revised Energy Taxation Directive, this will incentivize the use of alternative fuels by all vessel types, as it will end the tax exemptions for bunkers sold (gasoil and Heavy Fuel Oil) for voyages of vessels in the EU. Except for these directives, the **revised Effort Sharing Regulation** which includes domestic shipping comprised of all existing vessel types in the national GHG reduction emission targets should be referred to as another regulation affecting indirectly SSE installations onboard per vessel type.

Based on the above, the **revised Alternative Fuels Infrastructure Regulation (Directive 2014/94/EU)** set the targets for the development of SSE facilities at European TEN-T Core and Comprehensive ports for certain **container and passenger ships (including Ro-ro passenger vessels, high-speed passenger craft and cruise ships)** calling at these ports for increasing their interoperability. Its objective is to ensure that there is a sufficient infrastructure network in EU ports for all existing vessel types with alternative fuels and to provide alternative solutions so that the vessels at berth do not need to keep their engines running. This regulation will play an important role in speeding up the deployment of this infrastructure so that the adoption of zero and low-emission ships will not be impeded, initiating a virtuous circle for the maritime sector, and delivering on the targets of the European Climate Law. This revised Directive will be the initial step for the supply of electricity to ships at the quayside in ports, requirements applicable from 2030.

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Moreover, concerning the SSE in the TEN-T Core and Comprehensive EU ports, the provisions are now fully consistent with the recently agreed **FuelEU Maritime Regulation** and common standards and technical specifications have been issued for the development of the related alternative fuels infrastructure dedicated to all the existing vessel types. The **FuelEU Maritime Regulation** introduces reduction targets for the **Greenhouse Gas Intensity of Energy Used Onboard** by all ship types operating in the region of the European Union. Additionally, it should be mentioned that it will amend the requirements for SSE and provisions relating to zero-emission technologies based on the underlying principle that the system should be coherent with the Alternative Fuel Infrastructure Regulation (AFIR) to enable the maritime sector in the EU to contribute in the reduction of the total net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to the achievement of climate neutrality in 2050 through the uptake of low carbon fuels by the maritime sector.

As for the recent updates in the related regulatory framework, considering **Directive (EU) 2023/959** extending from January 1, 2024 the established EU Emissions Trading System (EU ETS) to maritime transport, the Commission shall also adopt by October 1, 2023 delegated acts to amend Articles 6, 7 and 10 of Regulation (EU) 2015/757 as regards the rules contained in those Articles for monitoring plans, to take into account the inclusion of methane CH4 and nitrous oxide N2O emissions, as well as the inclusion of greenhouse gas emissions from offshore ships, within the scope of the EU MRV Regulation.

In particular, except for the replacement of the term CO_2 by greenhouse gas in **the Directive (EU) 2023/959**, companies shall for each of their ships by April 1, 2024 submit to their administering authority responsible and to Commission a verified monitoring plan that reflects the inclusion of methane CH_4 and nitrous oxide N_2O emissions for the entire reporting period of the previous year within the scope of EU MRV Regulation based on the same principles and methods for monitoring CO_2 emissions. Furthermore, as for the reporting processes, from January 1, 2024, the amendments for the inclusion of CH_4 and N_2O emissions will apply in the EU MRV Regulation and will be included in the EU ETS from 2026. A main amendment refers to the extension of the application of the Directive, because from January 1, 2025, the EU MRV Regulation is extended to apply also to offshore ship above 400 GT and general cargo ships between 400 ≤ GT ≤ 5,000 and for offshore ships, the definition of port of call has been expanded to include ports where the crew is relieved. Hence, a port of call now refers to a port where ship stops to load or unload cargo, embark, or disembark passengers or relieve the crew. In the case of ships falling first time under EU MRV, companies shall submit a monitoring plan no later than 3 months after each ship's first call in a port under the jurisdiction of a Member State. Ultimately, ships that fail to comply with EU MRV requirements for two or more consecutive periods may be expelled and denied trading in the EU.

Following the respective provisions of **FuelEU Maritime Regulation**, specific limits on the greenhouse gas intensity of energy used on-board by all vessel types are defined for all the vessel types arriving at, staying within, or departing from ports under the jurisdiction of an EU Member State including their obligation to use SSE or zero emission technology in ports under the jurisdiction of a Member State. This Regulation applies to vessel types above a gross tonnage of 5.000 regardless of their flag in respect to the energy used during their stay within a port of call under the jurisdiction of a Member State, for the entirety of the energy used on voyages between EU ports and for the half of the energy used on voyages departing from or arriving to a port of call under the jurisdiction of a Member State, where the last or the next port of call is under the jurisdiction of a third country. This specific Regulation does not apply to warships, naval auxiliaries, fish-catching or fish-processing ships, wooden ships of primitive build, ships not propelled by mechanical means or government ships used for non-commercial purposes. This obligation is in force, especially for containerships and passenger ships at berth in EU ports, which from 1 January 2030 shall connect to SSE and use it for all their energy needs while at berth. For vessels that are at berth for less than two hours, vessels using zero-emission technologies or need to make an unscheduled port call for reasons of safety or saving life at sea, vessels

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that are incompatible with the SSE equipment or due to the unavailability of the port infrastructure and other emergencies, this regulation is not applicable.

The greenhouse gas intensity of the energy used onboard by a ship shall be calculated as the amount of greenhouse gas emissions per MJ of energy used onboard. Greenhouse Gas Emissions consider the release of carbon dioxide (CO2), methane (CH4) and nitrous oxides (N2O) into the atmosphere to reflect their global warming potential and are expressed in grams of CO2 equivalent established on a well-to-wake basis. Energy use means the amount of energy, expressed in megajoules (MJ), used by a ship for propulsion and the operation of any onboard equipment, at sea or when at berth.

The Well-to-Wake basis is a novel concept for the maritime industry since until now the emissions were reported to the Thetis MRV platform [4] on a Tank to Wake basis. Another difference is the measurement of the CO2 equivalent emissions since currently the CO2 emissions were only considered.

To calculate the greenhouse gas intensity limit of the energy used onboard a ship, the following formula is applied:

$$\text{GHGIE [gCO2eq/MJ]} = \frac{\text{Well to Tank gCO2eq}}{\text{Energy used on-board}} + \frac{\text{Tank to Wake gCO2eq}}{\text{Energy used on-board}} \quad (1)$$

Where:

$$\frac{\text{Well to Tank gCO2eq}}{\text{Energy used on-board}} = \frac{\sum_i^{nfuel} Mi \times CO_{2eqWtT,i} \times LCV_i + \sum_k^c E_k \times CO_{2eqElectricity,k}}{\sum_i^{nfuel} Mi \times LCV_i + \sum_k^c E_k} \quad (2)$$

$$\frac{\text{Tank to Wake gCO2eq}}{\text{Energy used on - board}} = \frac{\sum_i^{nfuel} \sum_j^{m\ engine} Mi,j \times [(1 - \frac{1}{100} C_{engine\ slip\ j}) \times (\mathrm{CO_{2eq,TtW,j}}) + (\frac{1}{100} C_{engine\ slip\ j} \times \mathrm{CO_{2eq,TtW,slippage,j}})}{\sum_i^{nfuel} Mi \times LCV_i + \sum_k^c E_k} \quad (3)$$

$$\mathrm{CO_{2eq,TtW,j}} = (C_{\mathrm{f\ CO2,j}} \times \mathrm{GWP_{CO2}} + C_{\mathrm{f\ CH4,j}} \times \mathrm{GWP_{CH4}} + C_{\mathrm{f\ N2O,j}} \times \mathrm{GWP_{N2O}})i \quad (4)$$

Reference is made to the methodologies specified in Annex I and Annex II of the FuelEU directive for more details.

The yearly average greenhouse gas intensity of the energy used onboard by a ship during a reporting period should not exceed the limits described in the Table below. In the Table below, both the reduction percentages stated in the FuelEu Initiative, as of the date the report is written, and the reduction percentages stated in the provisional political agreement between the Council and the European Parliament on 23 March 2023 are included.

The reference baseline value corresponds to the fleet average greenhouse gas intensity of the energy used onboard by ships in 2020, determined based on the data monitored and reported in the framework of Regulation (EU) 2015/757 and using the methodology described above. The GHG intensity requirements are set as a percentage reduction relative to a reference value of 91.16 gCO2eq/MJ.

[4] https://mrv.emsa.europa.eu/#public/emission-report

Table 5: GHGIE reduction limits

	As stated in FuelEU Maritime		Provisional agreement	
Year	**Reduction factor**	**GHGIE target [gCO2eq/MJ]**	**Reduction factor**	**GHGIE target [gCO2eq/MJ]**
2020	(Baseline)	91.16	(Baseline)	91.16
2025	2.0%	89.3	2.0%	89.3
2030	6.0%	85.7	6.0%	85.7
2035	13.0%	79.3	14.5%	77.9
2040	26.0%	67.5	31.0%	62.9
2045	59.0%	37.4	62.0%	34.6
2050~	75.0%	22.8	80.0%	18.2

Moreover, applicable regulations issued in the previous years that could influence indirectly SSE installation onboard vessels are the **EU Directive 2005/33/EC** on the sulphur content of marine fuels applies to all vessel types, while the **IMO interim Guidelines on Safe Operation of On-shore Power Supply** (**OPS**) which focuses on the operation of the SSE Systems for High Voltage Shore Connections (HVSC) and Low Voltage Shore Connections (LVSC) in ports that apply to all ship types engaged on international voyages except for vessels with liquid cargo.

Relevant provisions to SSE installations onboard vessels are included also in **EMSA Guidance to Port Authorities and Administrations for Shore-Side Electricity Part 2 – "Planning, Operations and Safety"** for Low Voltage connections with references to the number of cables that need to be considered for each connection and ship type and incompatibility between 50 and 60 Hz will have to be solved by installing a frequency converter. In particular, it is mentioned in the Guidance that the least preferred solution related to the power demand estimation strategies for all the vessel types calling at EU ports is the applicability of IEC/IEEE 80005 Annexes which include the indicative power demand by ship type.

The relevant applicable international standards for all vessel types including provisions for the connection and compatibility of SSE equipment onboard vessels with the high or low-voltage shore connection systems are referred to below:

- IEC/IEEE 80005-1 - Utility connections in port - Part 1: High Voltage Shore Connection (HVSC) Systems – General Requirements
- IEC/IEEE 80005-2 - Utility connections in port – Part 2: High and Low Voltage Shore Connection Systems – Data and communication for monitoring and control
- IEC/PAS 80005-3 - Utility connections in port - Low Voltage Shore Connection (LVSC) Systems – General Requirements
- IEC 62613 – 1 (2019) – Plugs, socket-outlets and ship couplers for High-Voltage Shore Connection (HVSC) Systems – General Requirements
- IEC 62613 – 2 (2016) – Plugs, socket outlets and ship couplers for High-Voltage Shore Connection (HVSC) Systems
- IEC 60309 - 5 (2017) - Plugs, socket outlets, ship connectors and ship inlets for Low-Voltage Shore Connection (LVSC) Systems – Dimensional Compatibility and Interchangeability Requirements

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In particular, as was aforementioned the recently issued applicable international standard that affects directly SSE installations onboard per vessel type constitutes the **IEC/ISO/IEEE** 80005 International Standard. Especially, the **International Standard IEC/IEEE 80005 -1 -** Part 1: High Voltage Shore Connection (HVSC) Systems – General Requirements recommending High Voltage Shore Connection for all vessel types with a power demand higher than 1 MVA, the **IEC/IEEE 80005-2 -** Utility connections in port – Part 2: High and Low Voltage Shore Connection Systems – Data and communication for monitoring and control, the **IEC/PAS 80005-3** - Low Voltage Shore Connection (LVSC) Systems – General Requirements as well as **the IEC 62613** – Plugs, socket-outlets and ship couplers for High-Voltage Shore Connection (HVSC) Systems focusing on the SSE systems and addressing the needs of plugs, socket-outlets and ship couplers include all the technical prerequisites for the connection of all vessel types to the respective SSE facilities at ports.

Based on the above, it should be mentioned that the standard IEC/ISO/IEEE 80005-1 - Utility Connection in Port – Part 1 – High Voltage Shore Connection Systems (HVSC) sets the requirements for compatibility between ships and high voltage shore connection systems and is designed to guarantee standard, straightforward connection, eliminating the need for ships to make adaptations to their equipment at different ports. Therefore, ships that do not comply with the standard may find it impossible to connect to compliant shore supplies. This standard is supported by IEC-62613- 1 & 2, which sets standards for high-voltage plugs, socket outlets and ship couplers for HVSC systems. The standard IEC-62613-1 (2019) - General Requirements applies to accessories which have rated currents not exceeding 500 A and rated operating voltages not exceeding 12 kV 50/60 Hz, while the standard IEC-62613-2 (2016) applies to accessories of HVSC systems up to 12 kV, 500 A, 50/60 Hz and includes the dimensional compatibility and interchangeability requirements for accessories to be used by various types of ships, that will be presented in detail. Concerning the respective accessories for low voltage shore connection (LVSC) systems (plugs, socket-outlets, ship connectors and ship inlets) intended to connect ships to dedicated shore supply systems described in IEC/IEEE 80005-3, these are regulated by the standard IEC 60309-5 (2017).[5]

To be more specific, the standard IEC/ISO/IEEE 80005-1 describes high voltage shore connection systems (HVSC) onboard the ship and on shore, to supply the ship with electrical power from shore including provisions for ship distribution systems and it is expected that HVSC systems will have practicable applications for all vessel types requiring 1 MVA or more or ships with HV main supply. As regards the low voltage shore connection systems (LVSC) onboard the ship applicable for ships requiring up to 1 MVA at berth and the LVSC systems exceeding 250 A, equal or exceeding 400 V AC nominal voltage, they are covered by the international standard IEC/IEEE 80005-3.

As concerns the connection of the different ship types with SSE installations in European maritime ports, the ship-specific standards for interconnectivity and interoperability per ship type, which are considered applicable international standards directly affecting SSE installations onboard vessels are summarized in the below table[6]:

[5] EMSA Guidance on SSE to Port Authorities and Administrations – Part 2: Planning, Operations and Safety

[6] EMSA Guidance on SSE to Port Authorities and Administrations – Part 2: Planning, Operations and Safety

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Table 6: Applicable international standards directly affecting SSE installations onboard vessels

Ship Type	IEC /IEEE Standards – Operability & Connectivity	
	LVSC	HVSC
Oil tankers	(80005-3 – Annex D) IEC 60309-5	(80005-1 – Annex F) 62613-2 – Annex I
Chemical/Product Tankers	(80005-3 – Annex D) IEC 60309-5	(80005-1 – Annex F) 62613-2 – Annex I
Gas Tankers	(not defined) IEC 60309-5	(80005-1 – Annex E) 62613-2 – Annex I
Bulk Carriers	(not defined) IEC 60309-5	(not defined) 62613-2 – Annex I
General Cargo Vessels	(not defined) IEC 60309-5	(not defined) 62613-2 – as appropriate
Container Vessels	(80005-3 – Annex C) IEC 60309-5	(80005-1 – Annex D) 62613-2 – Annex I
Ro-Pax Vessels	(not defined) IEC 60309-5	(80005-1 – Annex B) 62613-2 – Annex J
Cruise Ships	(not defined) IEC 60309-5	(80005-1 – Annex B) 62613-2 – Annex H
Offshore Supply Vessels	(80005/3 – Annex B) (IEC 60309-5)	(not defined) 62613-2 – as appropriate
Fishing Vessels	(not defined) IEC 60309-5	(not defined) 62613-2 – as appropriate

Furthermore, as for the shore power connector and their applicable standards for interconnectivity and electrical safety for all ranges of SSE voltage ratings, it should be mentioned that for high voltage shore connections (HVSC) the SSE standard IEC/IEEE 80005-1 and the standard IEC 62613-1 related to the connector are applicable for cruise ships, tankers, containerships, Ro-pax vessels and LNG carriers, while for low voltage shore connections, the SSE standard IEC/IEEE 80005-3 and the standards IEC 60309-1 for general requirements and IEC 60309-5 for technical requirements and geometry/dimensions related to the connector are applicable for service ships (Offshore Support Vessels, other), containerships and tankers. However, ships not yet equipped with SSE, a newbuild installation or existing ship conversion should follow the technical requirements in IEC/IEEE 800051/1 (2019). The standard IEC/IEEE 80005-2 – Utility Connections in Port – Part 2: High and low voltage shore connection systems – Data Communication for Monitoring and Control specifies the interface descriptions addresses and data type as well as communication requirements on cruise ships, in Annex A.

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Hence, It is also important to note that as IEC/IEEE 800051/1 (2019) – High Voltage Shore Connection (HVSC) and the IMO Safety Guidelines on OPS (2020) are very recent references, ships equipped with SSE systems compliant with either the previous version of the IEC standard (2012) or with other best practice/standard reference will also be operating and requiring to be brought into the new technical/reference framework for achieving also harmonization.

As for the draft interim **Guidelines on safe operation of onshore power supply (OPS) service in port for ships engaged on international voyages,** they include provisions related to the ship systems and equipment, namely the ship-side installations for accepting shore power. It is clearly stated that the standards IEC/IEEE 80005-1:2019 Part 1 and IEC 62613-1:2019 provide the technical design, installation, and testing requirements for the SSE systems onboard vessels for high-voltage shore connection systems. The previous standards also include the requirements for the initial integration and function tests at the first call at a shore supply point to ensure the compatibility of both shore and shipside for high-voltage connections. Similarly, the respective tests at repeated calls of shore supply point for vessel's compatibility with the SSE port installations meet the standards IEC/IEEE 80005-1 and IEC 62613-1:2019. A reference is also included in the guidelines for personnels training and certification processes that are performed in full accordance with STCW regulation I/4, that was previously analysed.

Except for the provisions included in the previous standards and regulations, the interim IMO Safety Guidelines on SSE which directly affect the SSE installations onboard vessels by regulating the following aspects:

- reliable communication processes during the connection of the SSE equipment onboard vessels with the related SSE port installations
- operational requirements including the obligation of the respective personnel to wear the personal protective equipment as required by ship safety management system (ship-side)
- pre-connection and connection and disconnection safety inspections and checks for high and low-voltage shore power connections (such as definition of restricted access areas on ship-side, inspections on ship-side circuit breakers, check of non-existence of safety-critical operations on ships, inspection of the shipboard generators' operation and synchronization, transfer or increase of load for ship's generators etc.) for confirming the suitability of the ship-side and shore-side SSE arrangements
- safety precautions before maintenance procedures and the required documentation for SSE operation procedures (circuit diagrams and instructions for the operation of ship installations, description of ship power restoration procedures and of operational limitations during berthing)

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2.4.2 Impact of SSE use to environmental compliance

In this section, the Greenhouse Gas Intensity of the Energy used onboard a ship (GHGIE) is calculated and compared with the theoretically attained GHGIE, if SSE was used while the vessel was at berth.

To provide a straightforward comparison between the different ship types calling to EU ports the following assumptions were made:

- Data from the 2019 Thetis EU MRV are used. FuelEU Maritime considers 2020 as the baseline for the estimated reductions needed. However, to account for the undue influence of the COVID-19 global pandemic, the annual data for 2019 were retrieved and used.
- The average annual fuel consumption and the average CO_2 emissions which occurred within ports under a Member State jurisdiction at berth per ship type were used from the 2019 Thetis EU MRV.
- All fuel consumptions reported are assumed to be Heavy Fuel Oil for simplicity.
- The vessels are assumed to be moored at port and not at the anchorage.
- The following HFO properties were used:

Table 7: HFO Properties

Fuel	WtT		TtW			
	LCV	CO2eq_WtT	Cf_CO2	Cf_CH4	Cf_N2O	CO2eq_TtW,j
	(MJ/gFuel)	(gCO2eq/MJ)	(gCO2/gFuel)	(gCH4/gFuel)	(gN2O/gFuel)	(gCO2eq/gFuel)
HFO	0,0405	13,5	3,114	0,00005	0,00018	3,1631

- The fuel delivered to the vessel is considered equal to the fuel consumed. The Remaining On Board (ROB) quantity is equal to zero.

Based on the above assumptions the following were calculated.

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Table 8: Average Energy use at berth per ship type, Thetis MRV 2019

Ship type	Number of Ships	Average of Total fuel consumption [m tonnes]	Average of Fuel consumption within ports under a MS jurisdiction at berth [m tonnes]	Average of Energy used at berth [GJ]
Bulk carrier	2643	1,638.79	85.73	3,471.90
Chemical tanker	1030	2,370.70	253.70	10,275.00
Combination carrier	10	3,471.72	267.38	10,828.80
Container ship	1582	7,427.43	296.05	11,990.10
Container/ro-ro cargo ship	75	6,443.81	711.42	28,812.40
Gas carrier	235	3,043.19	279.10	11,303.40
General cargo ship	1150	1,755.02	84.77	3,433.20
LNG carrier	189	11,716.06	351.68	14,243.00
Oil tanker	1511	3,366.24	385.08	15,595.60
Other ship types	110	2,999.22	200.73	8,129.60
Passenger ship	149	13,180.38	1,556.27	63,029.10
Refrigerated cargo carrier	135	3,593.52	128.46	5,202.50
Ro-pax ship	381	12,066.93	889.88	36,040.20
Ro-ro ship	252	7,152.32	353.74	14,326.40
Vehicle carrier	389	3,530.33	158.28	6,410.40

The Fuel consumption at berth is calculated from the average CO_2 emissions which occurred within ports under a Member State jurisdiction at berth. Based on this and the Lower Calorific Value of the HFO, the average Energy used at berth per ship type is shown. It should be noted that since there is no sorting of the data according to vessel size, the data are meant to provide only an indication.

The below are used:

- The $\sum_k^c E_k \times CO_{2eqElectricity,k}$ is set equal to zero, as stated in FuelEU Maritime, Annex I.
- The following GWP values were used:

Table 9: Global Warming Potential of 100 years of Greenhouse gases (GHGs)

CO2	CH4	N2O
1	28	265

- $C_{engine\ slip\ j} = 0$

The GHG intensity requirements are set as a percentage reduction relative to a reference value of 91.16 gCO2e/MJ. To allow for an indicative comparison, it was assumed that the energy produced from fossil fuel (HFO) at berth could be replaced by the electrical energy, provided by the shore. The GHGIE was then again calculated, as shown in the Table below.

Table 10: Estimated achieved GHGIE with the use of SSE per ship type

Ship type	Average GHGIE (with SSE)	Difference
Bulk carrier	86,72	-4.44
Chemical tanker	82,22	**-8.94**
Combination carrier	85,69	-5.47
Container ship	87,07	-4.09
Container/Ro-Ro cargo ship	82,75	**-8.41**
Gas carrier	83,45	**-7.71**
General cargo ship	86,90	-4.26
LNG carrier	88,97	-2.19
Oil tanker	81,61	**-9.55**
Other ship types	84,14	**-7.02**
Passenger ship	79,58	**-11.58**
Refrigerated cargo carrier	86,56	-4.60
Ro-Pax ship	83,19	**-7.97**
Ro-Ro ship	86,49	-4.67
Vehicle carrier	87,60	-3.56

Marked with bold are shown the ship types that indicatively achieve the GHGIE 2030 limit of 6% reduction.

From the above table it is shown that bulk carriers are the most common vessel type calling to EU ports. When considering that the energy profile of a general cargo vessel – the fourth most common vessel type calling to EU ports – is similar to the energy profile of a bulk carrier, we can arrive to the

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conclusion that these types of vessels present a significant potential for reduction of the GHG emissions in EU, averaging a more than 4% reduction per vessel. Containerships are shown to be a very common commercial vessel type in EU, with reduction potential also averaging in 4%.

Oil tankers and chemical tankers grouped together, represent also one of the most common vessel types berthing to EU ports. They have a high potential for reduction (about 9%) of the GHG emissions.

Passenger vessels and Ropax vessels have high reduction potential, 11.58% and 7.97% respectively.

Container/ro-ro cargo ships, other ship types and Gas carriers, shown to achieve the GHGIE 2030 limit of 6% reduction, are, however, not very common in EU ports (low number of vessels).

A detailed analysis of the Thetis MRV data is provided in section 2.4.3.

Table 11: Average Reduction in EU ETS compliance cost (Euro) if SSE was used at berth

Ship type	Annual Average of Fuel consumption at berth [m tonnes]	Annual Average of CO2 emissions at berth [m tonnes]	Annual Average Reduction in EU ETS compliance cost (Euro) (with SSE)
Bulk carrier	85.73	266.96	24,026.69
Chemical tanker	253.70	790.02	71,101.96
Combination carrier	267.38	832.62	74,935.92
Container ship	296.05	921.90	82,970.97
Container/ro-ro cargo ship	711.42	2,215.36	199,382.57
Gas carrier	279.10	869.12	78,220.57
General cargo ship	84.77	263.97	23,757.64
LNG carrier	351.68	1,095.13	98,561.84
Oil tanker	385.08	1,199.14	107,922.52
Other ship types	200.73	625.07	56,256.59
Passenger ship	1,556.27	4,846.22	436,160.23
Refrigerated cargo carrier	128.46	400.02	36,002.20
Ro-pax ship	889.88	2,771.09	249,397.77
Ro-ro ship	353.74	1,101.55	99,139.17
Vehicle carrier	158.28	492.88	44,359.55

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In Table 11, the potential of reduction in the EU ETS compliance costs for a ship owner is shown, when SSE is used at berth. The CO2 emission tonnes, T_{CO2}, are calculated by multiplying the fuel tonnes consumed when at berth with the HFO Carbon Factor (CF= 3.114).

The allowances to be surrendered are calculated based on the following equation:

$$ETS_{Cost} = T_{CO2} \times C_P$$

Where Cp is the price of carbon permits on the EU carbon market. Currently, the price of carbon permits on the EU carbon market is 90 € per tonne of CO2 and is expected to potentially increase in the future.

2.4.3 Analysis of Thetis MRV 2019 data

A statistical analysis has been performed on the data of Thetis MRV repository for the year 2019, to observe the correlations between the CO2 emissions reported at berth and the characteristics of the vessels, per ship type. The year 2019 has been chosen as a Business-as-Usual scenario, before the effect of the COVID 19 pandemic.

The following figure depicts the boxplot analysis for the repository, classifying the vessels per type. As can be seen in the Figure, there are 15 types of vessels that recorded emissions at Thetis MRV for year 2019.

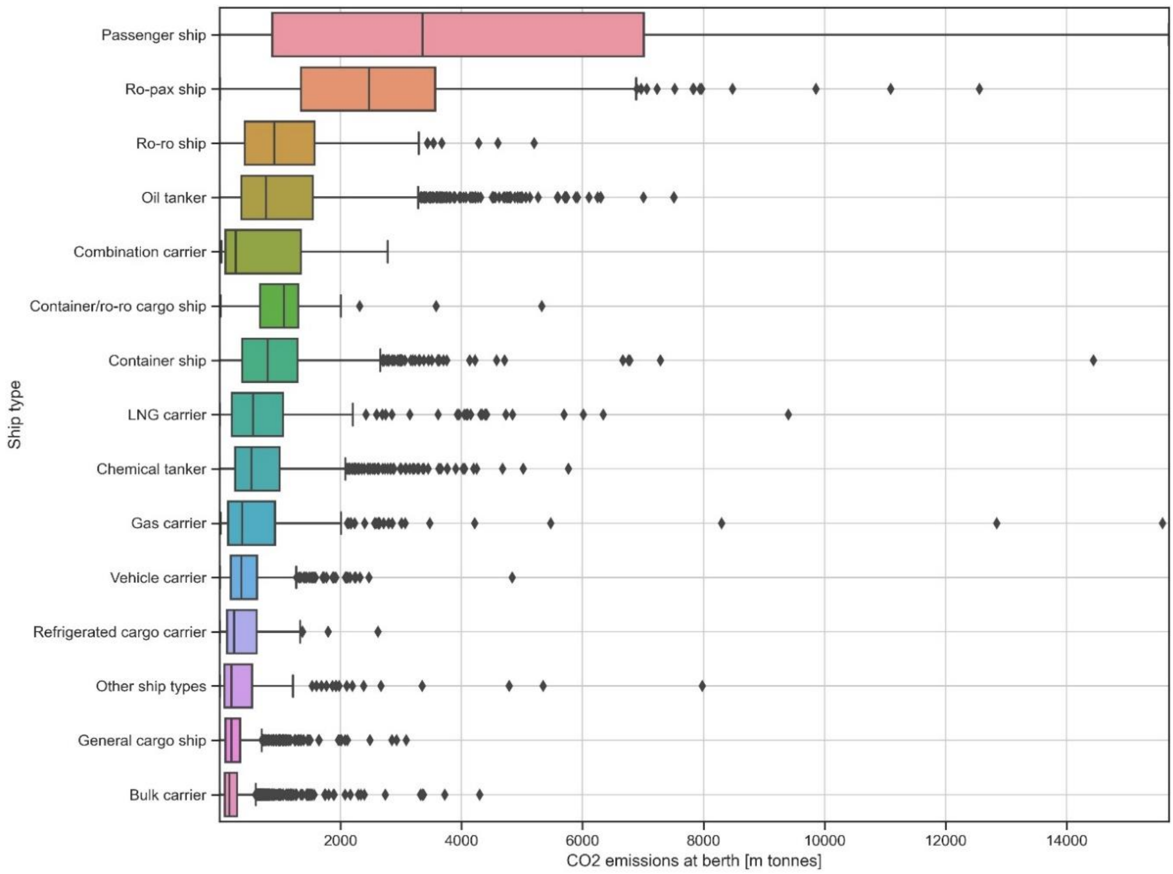

Figure 2: Boxplot of CO2 emissions per vessel, classified per ship type, Thetis MRV year 2019 repository

The boxplot analysis depicts, per type of vessel, a box that corresponds to percentiles 25 and 75 of each dataset, being the black line inside the box the value of percentile 50, or the median. Dots outside the whiskers are considered outliers, or non-representative values. This analysis indicates that the

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vessels with highest emissions are passenger ships, i.e. cruise ships, followed by ro-paxes and ro-ro ships. Then, cargo vessels follow in the list, starting with oil tankers. The vessels with the lowest emissions were bulk carriers. Container ships rank in the 7th position of highest emitters.

The following chart illustrates the distribution of the total emissions, per ship type. As can be seen, the highest values of emissions are reported by the group of oil tankers, followed by container ships and ro-pax ships.

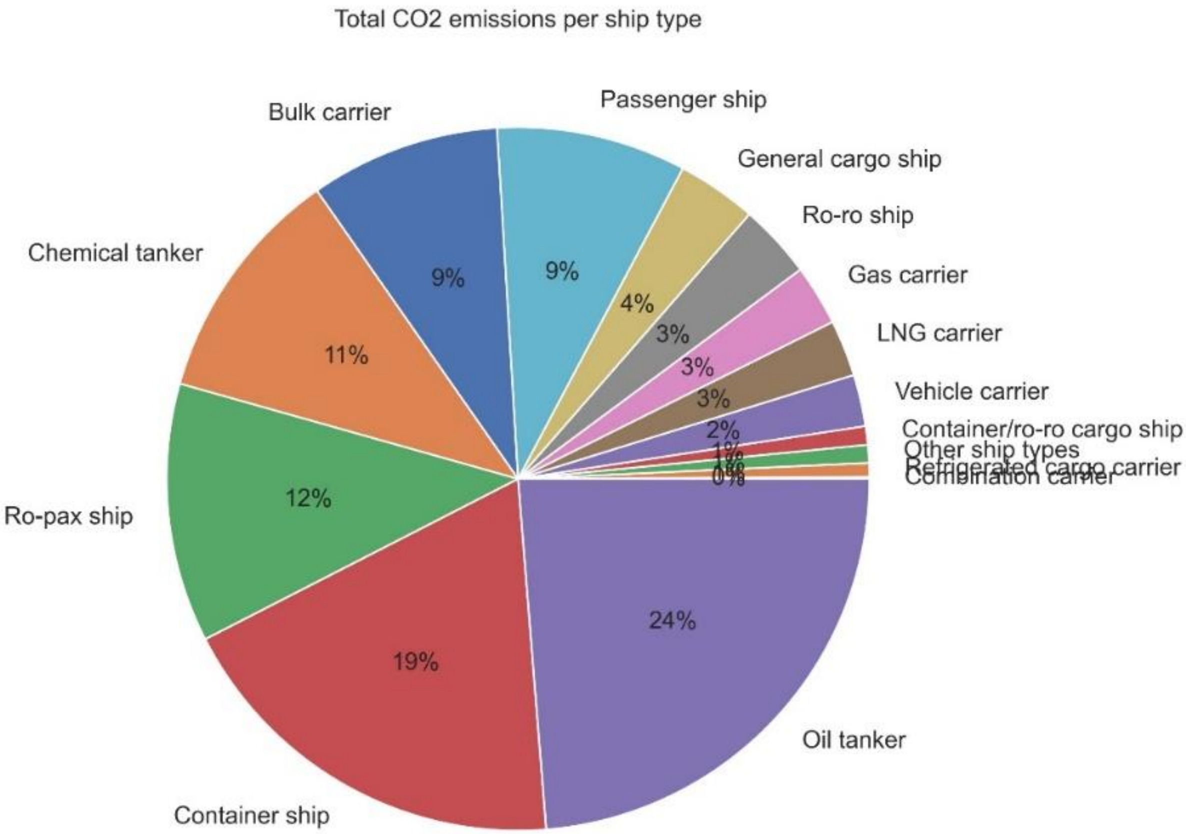

Figure 3: Total CO2 emissions per ship type, in percentage

These results are highly influenced by the total number of vessels of each type. The following bar plots depict the contribution per ship type in emissions and number of vessels.

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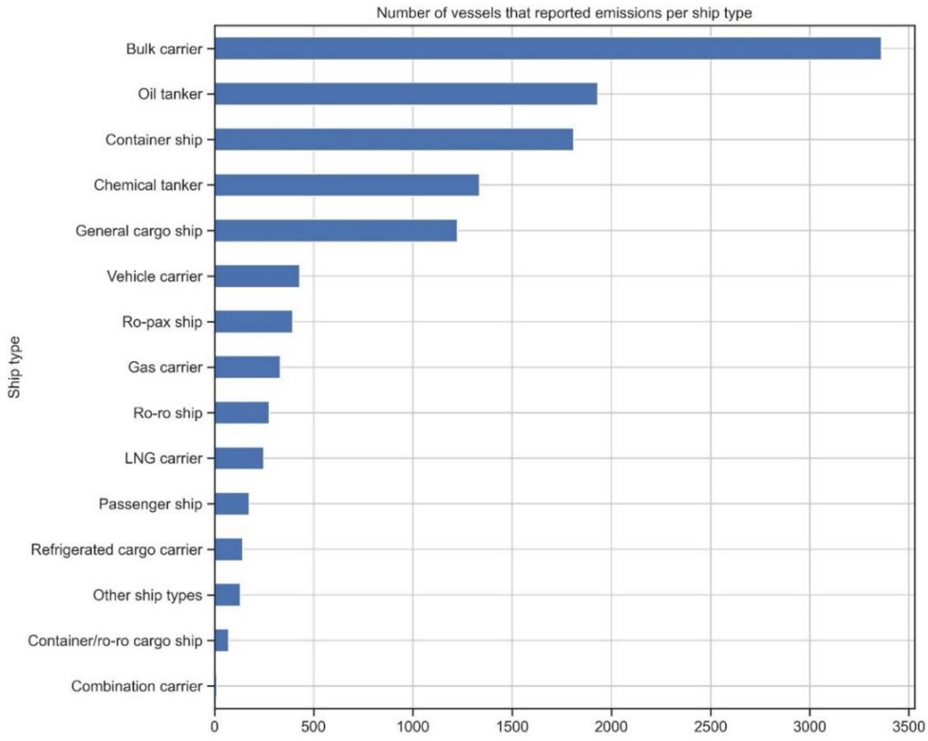

Figure 4: Number of vessels per ship type

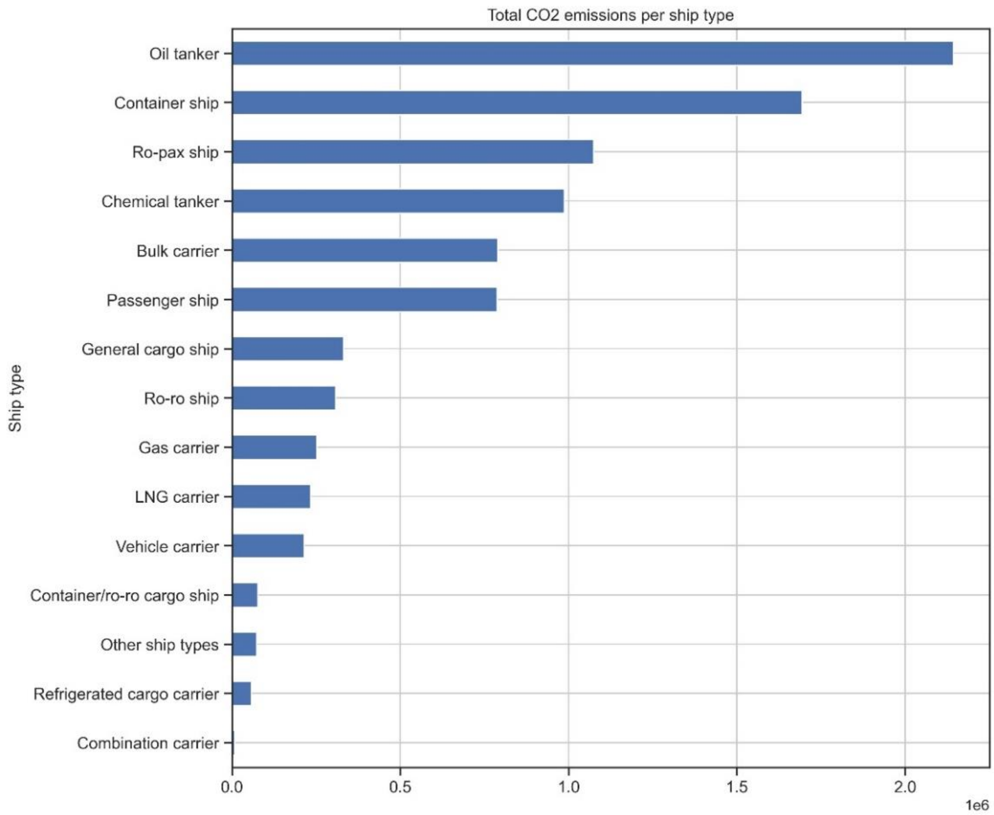

Figure 5: Total CO2 emissions per ship type

From these previous graphs, it is interesting to note that passenger and ro-pax ships represent only 21% of the total contribution of emissions, but they have the highest rates of CO_2 emission per vessel. Their contribution to the total is lower because they are outnumbered by other types of cargo vessels, such as tankers, bulk carriers and container ships.

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In the following scatter plot matrix, the data of emissions at berth from Thetis MRV is combined with characteristics of the vessels, such as GT or Length, extracted from the Maritime Portal[7]. A more or less direct correlation can be observed among all these variables, being clearer for some type of vessels than others.

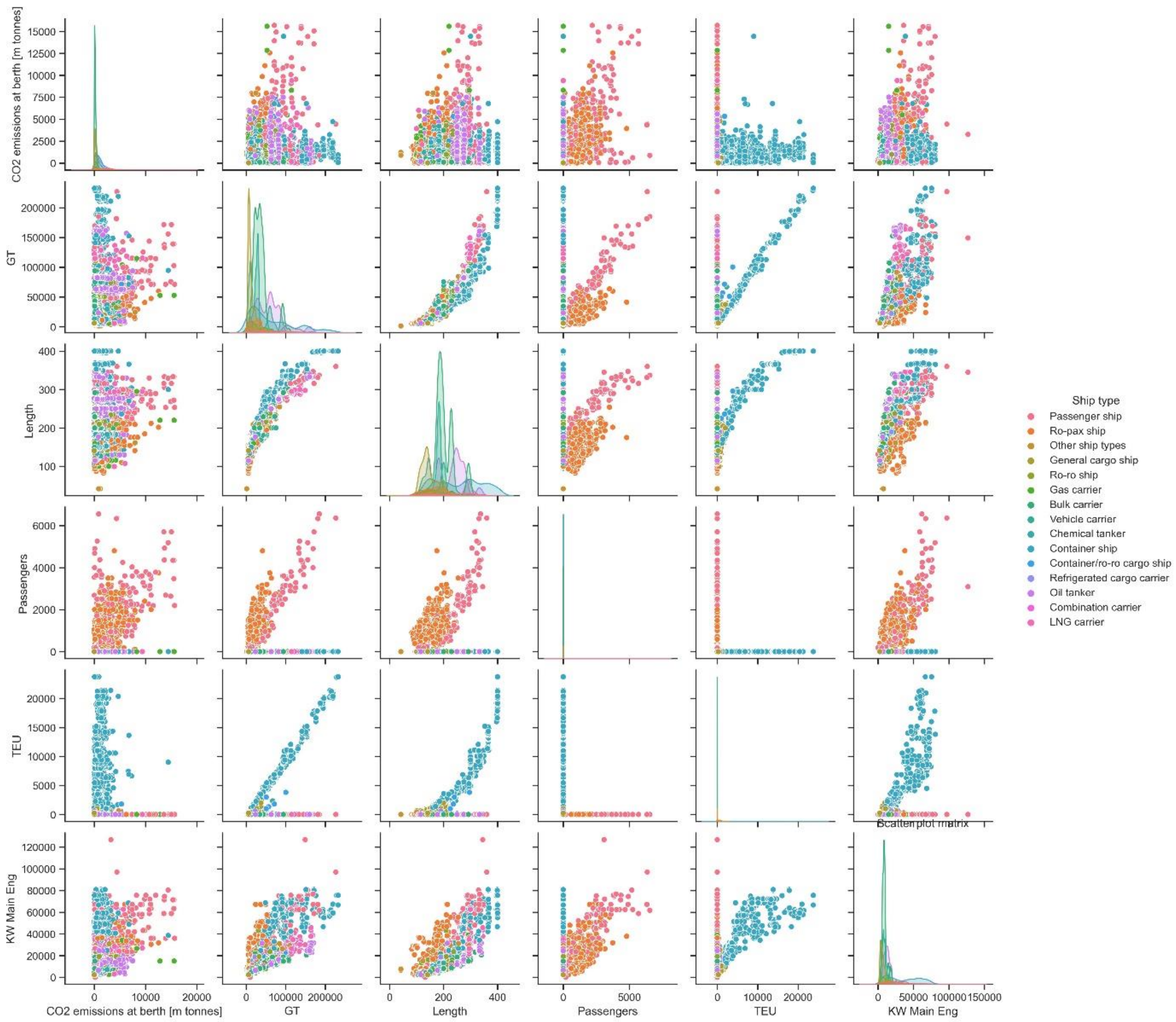

Figure 6: Scatter plot matrix, emissions at berth plus vessels' characteristics

Based on this information and the previous one from the type of vessels that are the objective of the SSE supply at the EALING ports, a further statistical analysis is performed in the next sections, by type of vessels, for the following types:

- Passenger ships
- Ro-pax ships
- Container ships
- Tankers
- Bulk carriers

[7] https://maritime.ihs.com/

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2.4.3.1 *Cruise ships*

The following scatter plot matrix depicts the relation between the different variables.

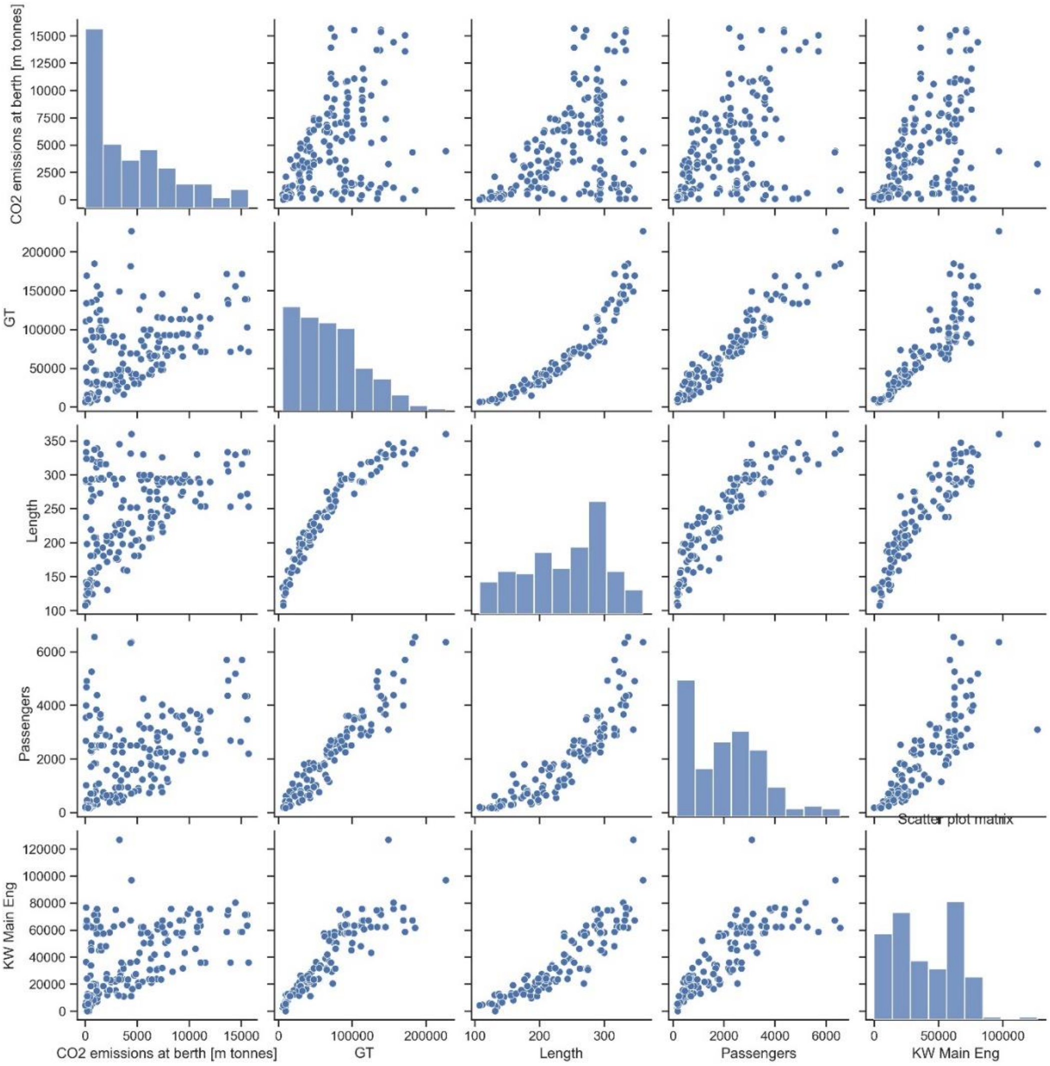

Figure 7: Scatter plot matrix for Passenger ships

The CO2 emissions at berth correspond to the first row or column in the graph. A more or less clear correlation can be observed with all the other variables, i.e. GT, Length, Passengers, and Main Engine Power. The following density plots depict this relationship for GT, Length and number of passengers.

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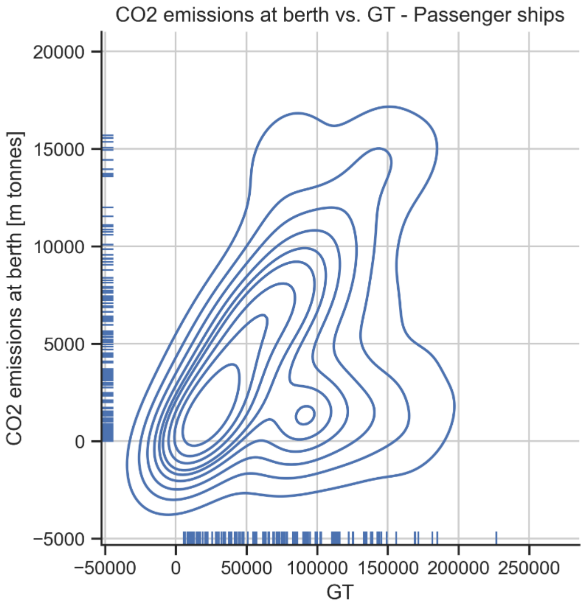

Figure 8: GT vs. CO2 emissions for Passenger ships

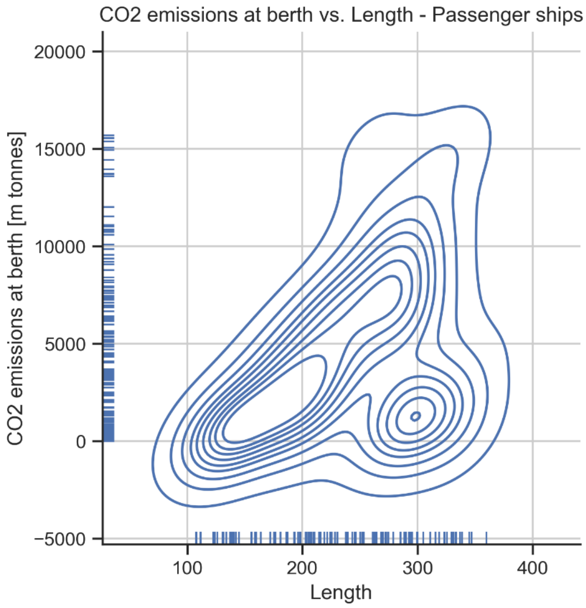

Figure 10: Length vs. CO2 emissions for Passenger ships

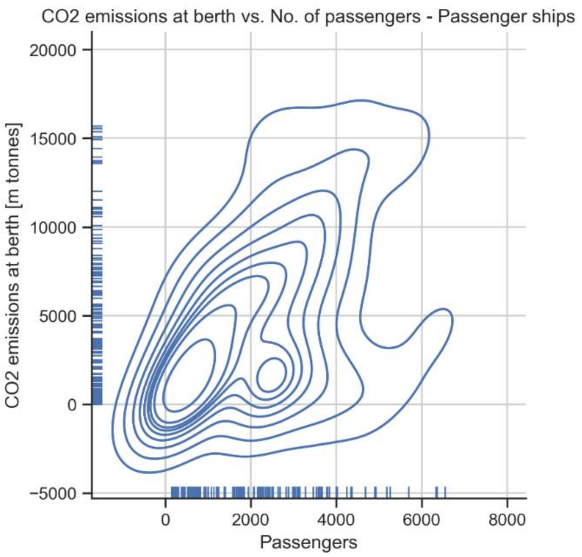

Figure 9: Number of passengers vs. CO2 emissions for Passenger ships

The following histograms depict the contribution, in percentage, of each segment or group to the total, in terms of number vessels in the same segment, and CO2 emissions.

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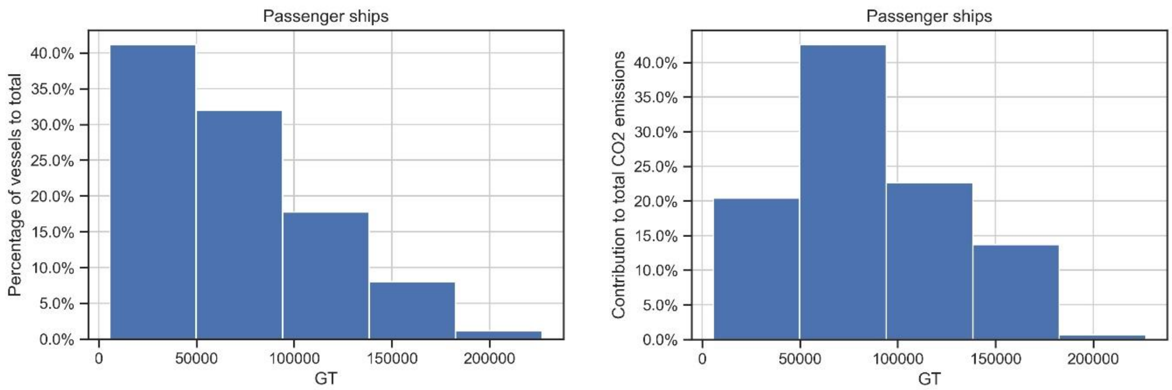

Figure 11: Number of vessels per GT segment (left) and contribution to CO2 emissions per GT (right) for Passenger ships

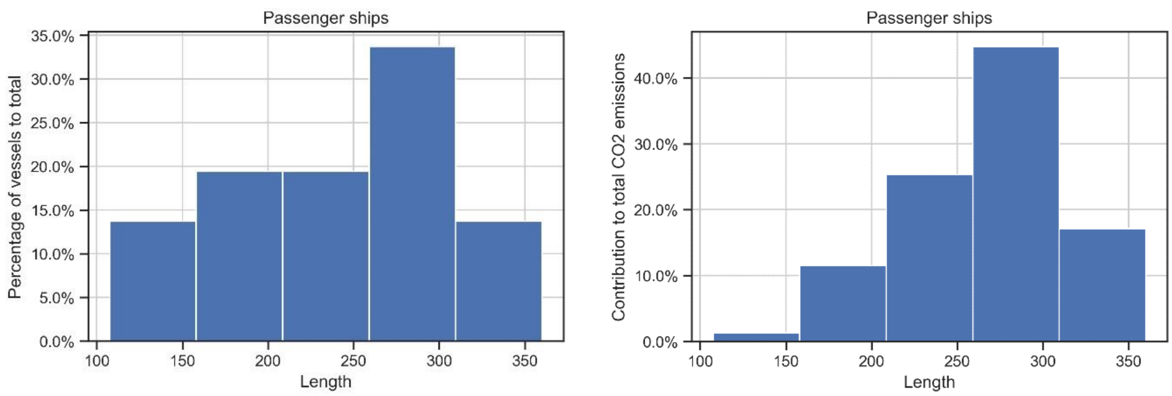

Figure 12: Number of vessels per Length segment (left) and contribution to CO2 emissions per Length (right) for Passenger ships

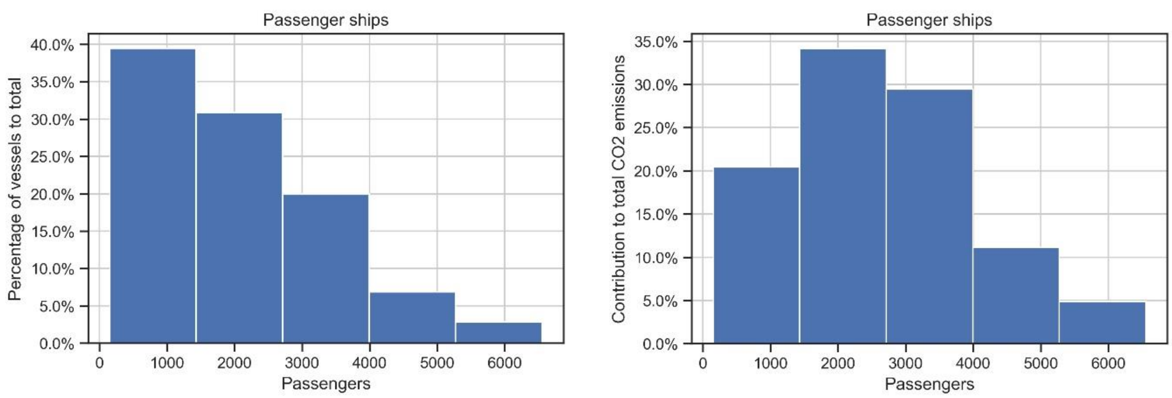

Figure 13: Number of vessels per Passengers segment (left) and contribution to CO2 emissions per number of passengers (right) for Passenger ships

2.4.3.2 *Ro-pax ships*

The following scatter plot matrix depicts the relation between the different variables.

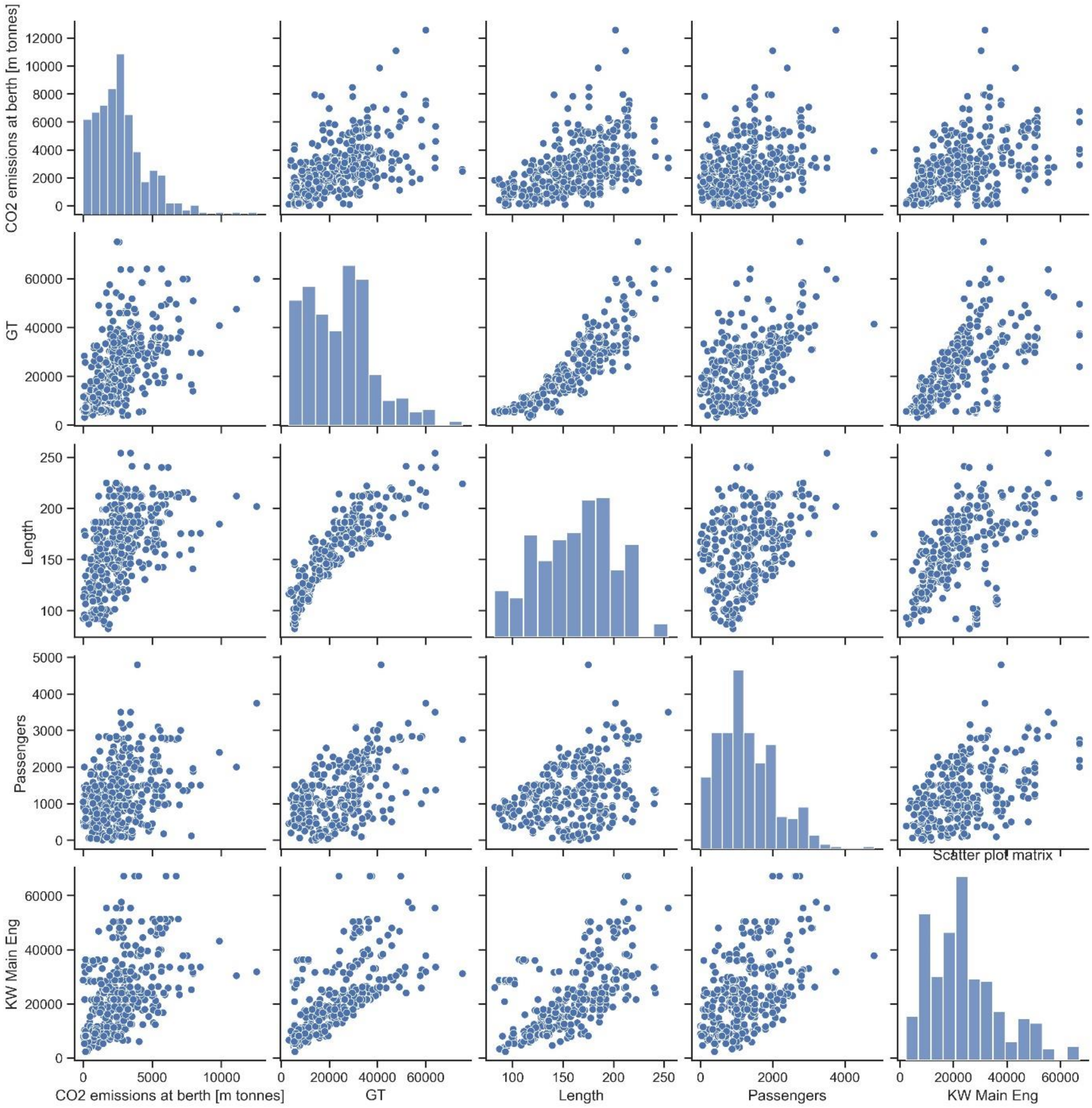

Figure 14: Scatter plot matrix for Ro-pax ships

The CO2 emissions correspond to the first row or column in the graph. A more or less clear correlation can be observed with all the other variables, i.e. GT, Lemgth, Passengers, and Main Engine Power. The following density plots depict this relationship for GT, Length and number of passengers.

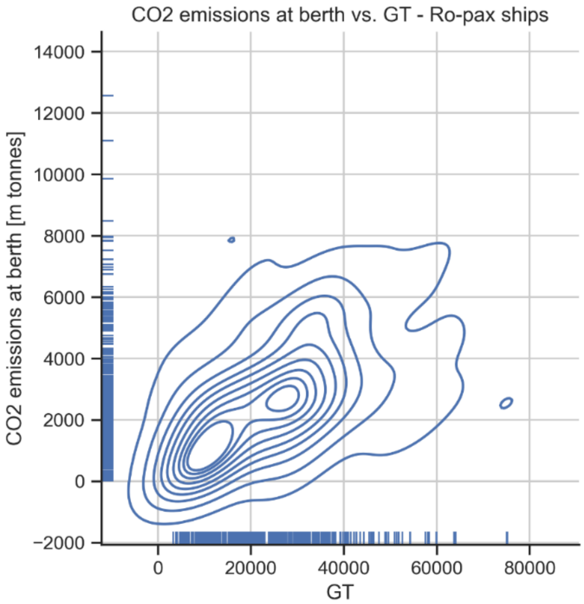

Figure 15: GT vs. CO2 emissions for Ro-pax ships

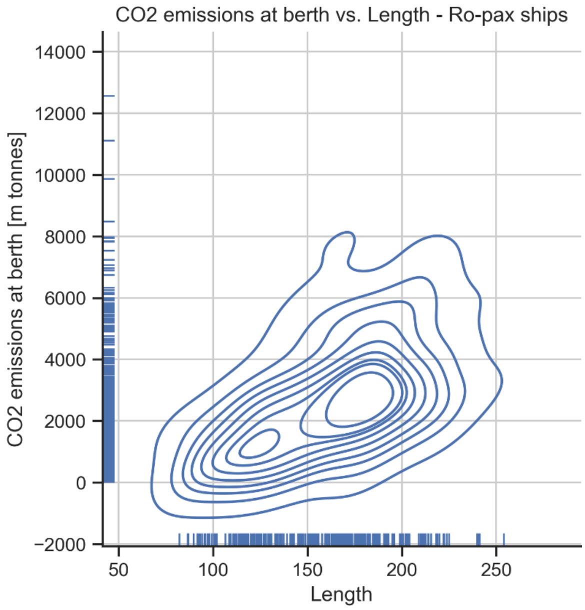

Figure 17: Length vs. CO2 emissions for Ro-pax ships

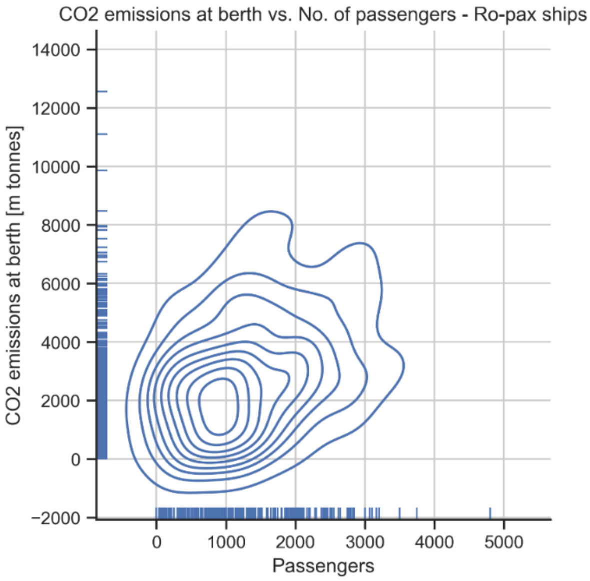

Figure 16: Number of passengers vs. CO2 emissions for Ro-pax ships

The following histograms depict the contribution, in percentage, of each segment or group to the total, in terms of number vessels in the same segment, and CO2 emissions.

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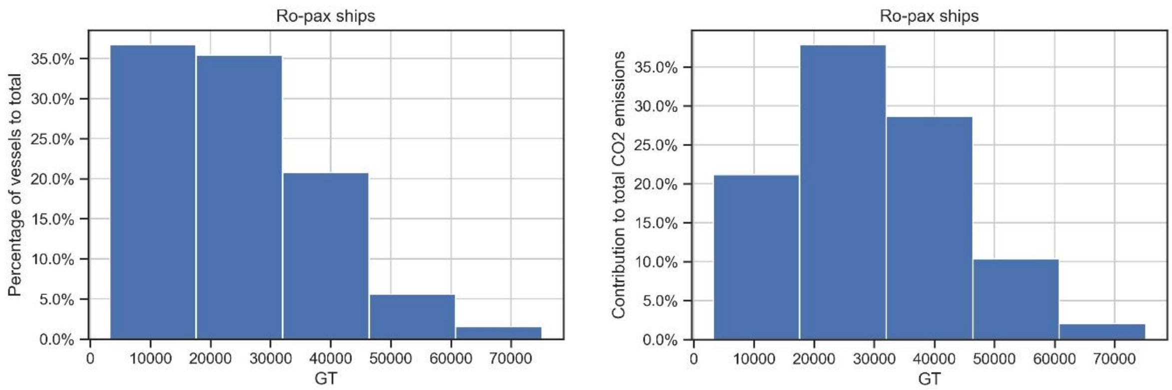

Figure 18: Number of vessels per GT segment (left) and contribution to CO2 emissions per GT (right) for Ro-pax ships

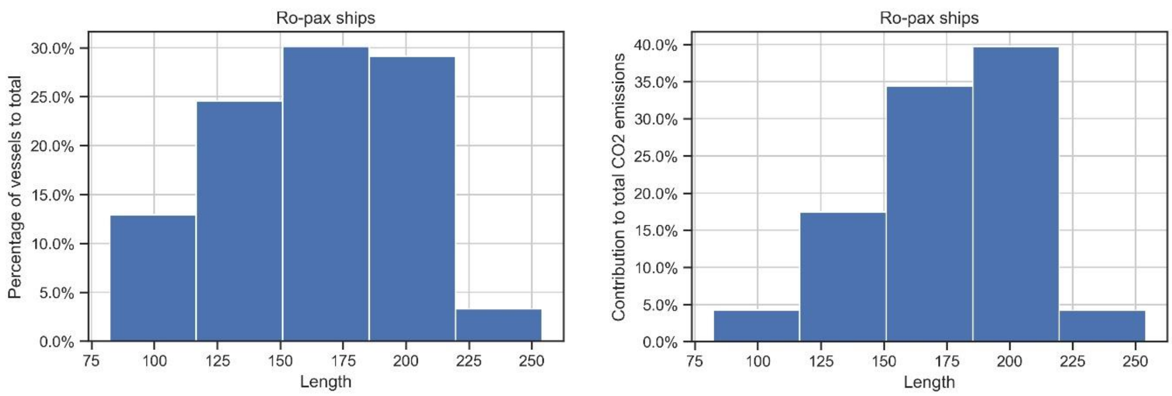

Figure 19: Number of vessels per Length segment (left) and contribution to CO2 emissions per Length (right) for Ropax ships

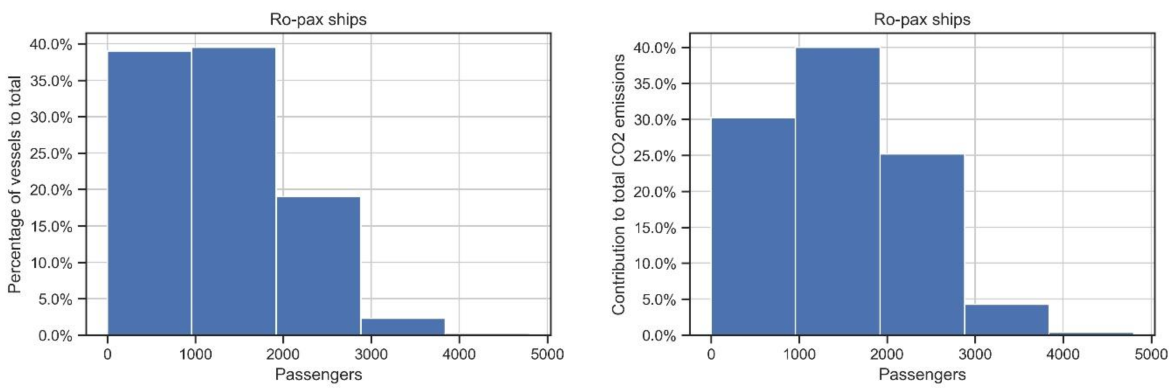

Figure 20: Number of vessels per Passengers segment (left) and contribution to CO2 emissions per number of passengers (right) for Ro-pax ships

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2.4.3.3 *Container ships*

The following scatter plot matrix depicts the relation between the different variables for the case of container ships.

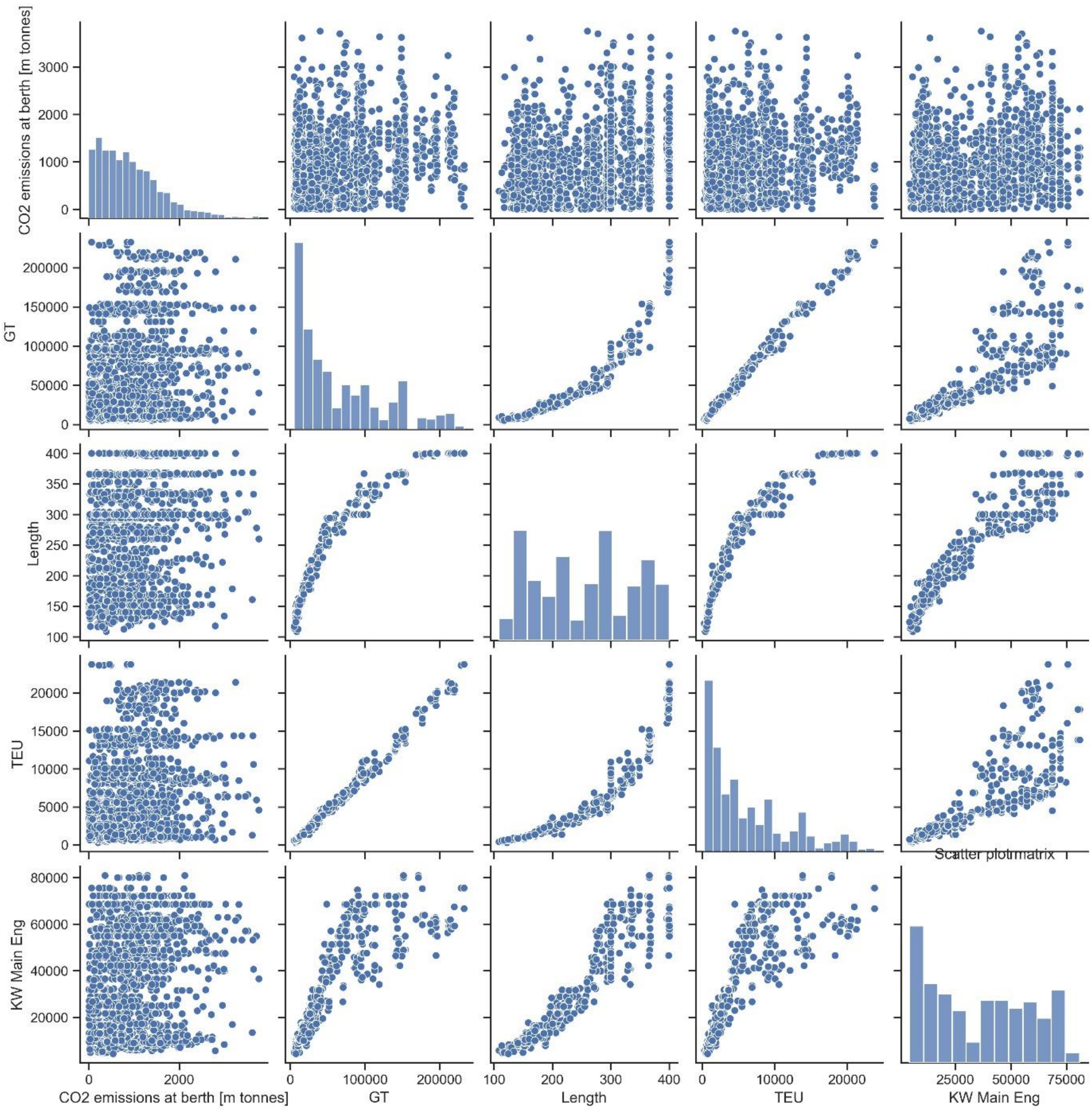

Figure 21: Scatter plot matrix for Container ships

The CO2 emissions correspond to the first row or column in the graph. As can be seen, the correlation is not as visible as in the previous types, between emissions at berth and the rest of variables; however, it can be appreciated in the following density diagrams that depict the relation between CO2 emissions at berth and GT, Length and TEU capacity.

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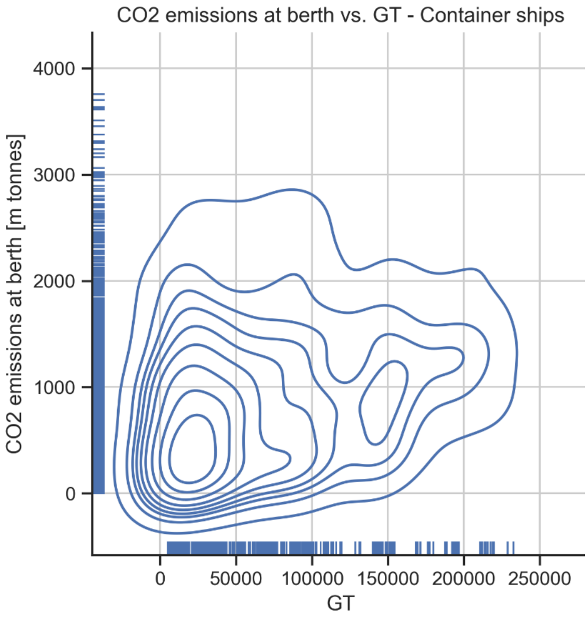

Figure 22: GT vs. CO2 emissions for Containerships

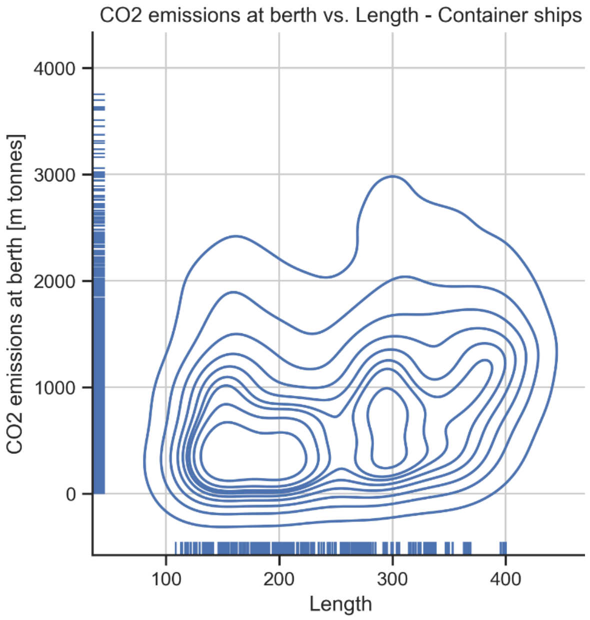

Figure 24: Length vs. CO2 emissions for Containerships

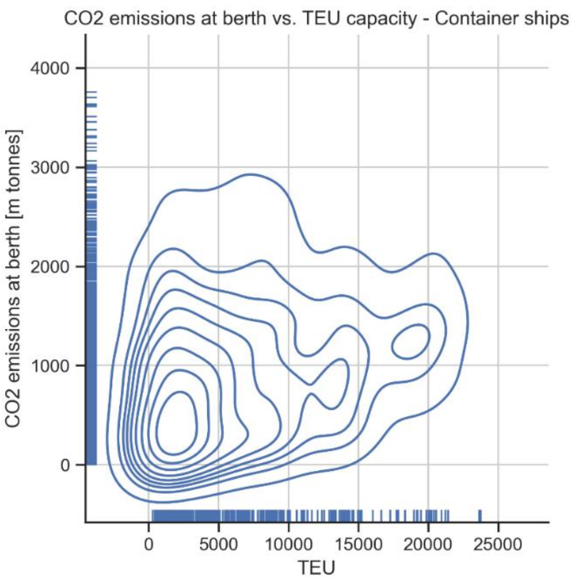

Figure 23: TEU capacity vs. CO2 emissions for Containerships

The following histograms depict the contribution, in percentage, of each segment or group to the total, in terms of number vessels in the same segment, and CO_2 emissions.

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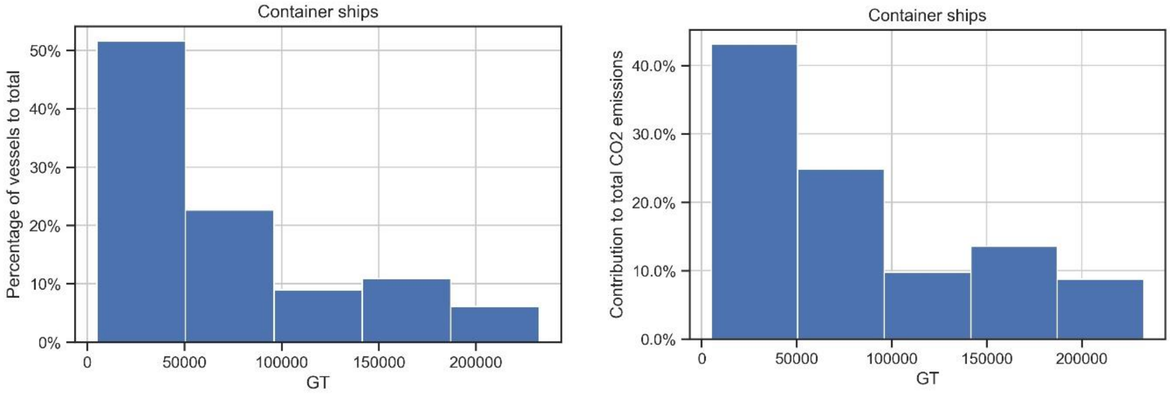

Figure 25: Number of vessels per GT segment (left) and contribution to CO2 emissions per GT (right) for Containerships

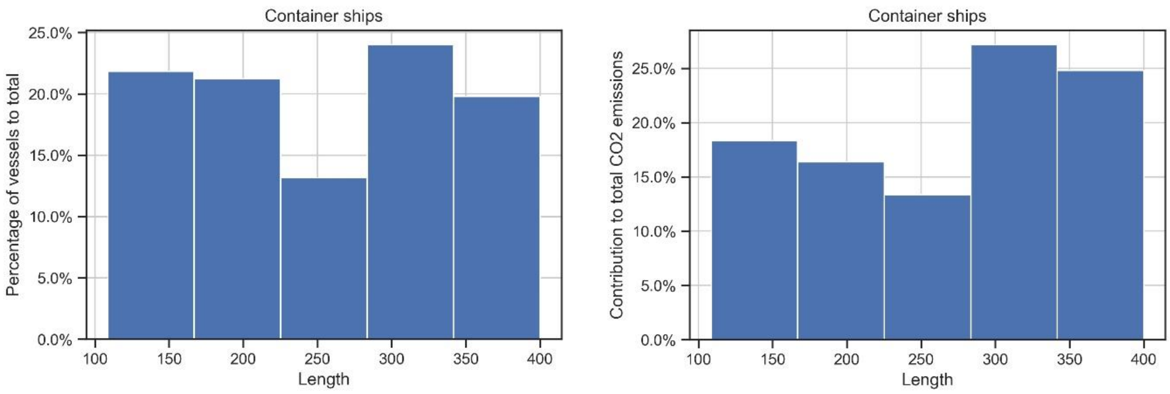

Figure 26: Number of vessels per Length segment (left) and contribution to CO2 emissions per Length (right) for Containerships

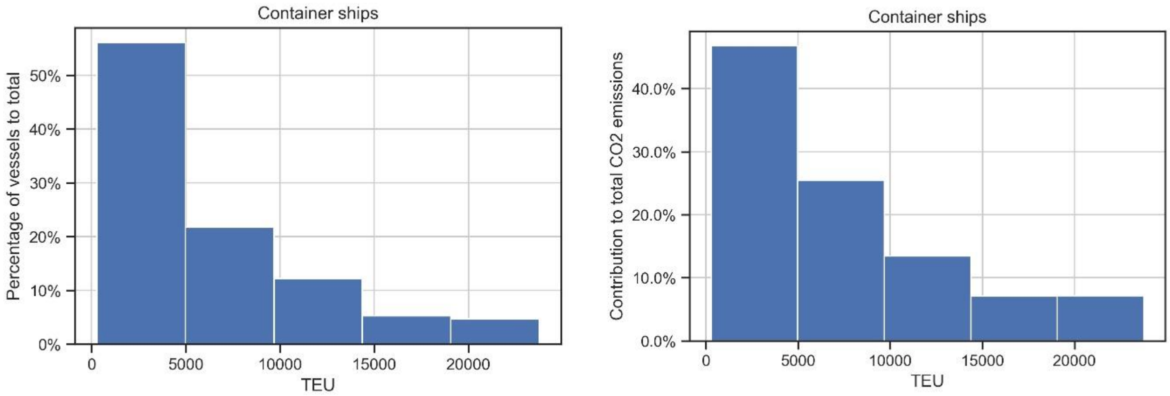

Figure 27: Number of vessels per TEU capacity segment (left) and contribution to CO2 emissions per TEU capacity (right) for Containerships

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2.4.3.4 Tankers

The group analysed corresponds to two types of vessels grouped together: oil tankers and chemical tankers. The resulting scatter plot matrix can be observed in the following Figure.

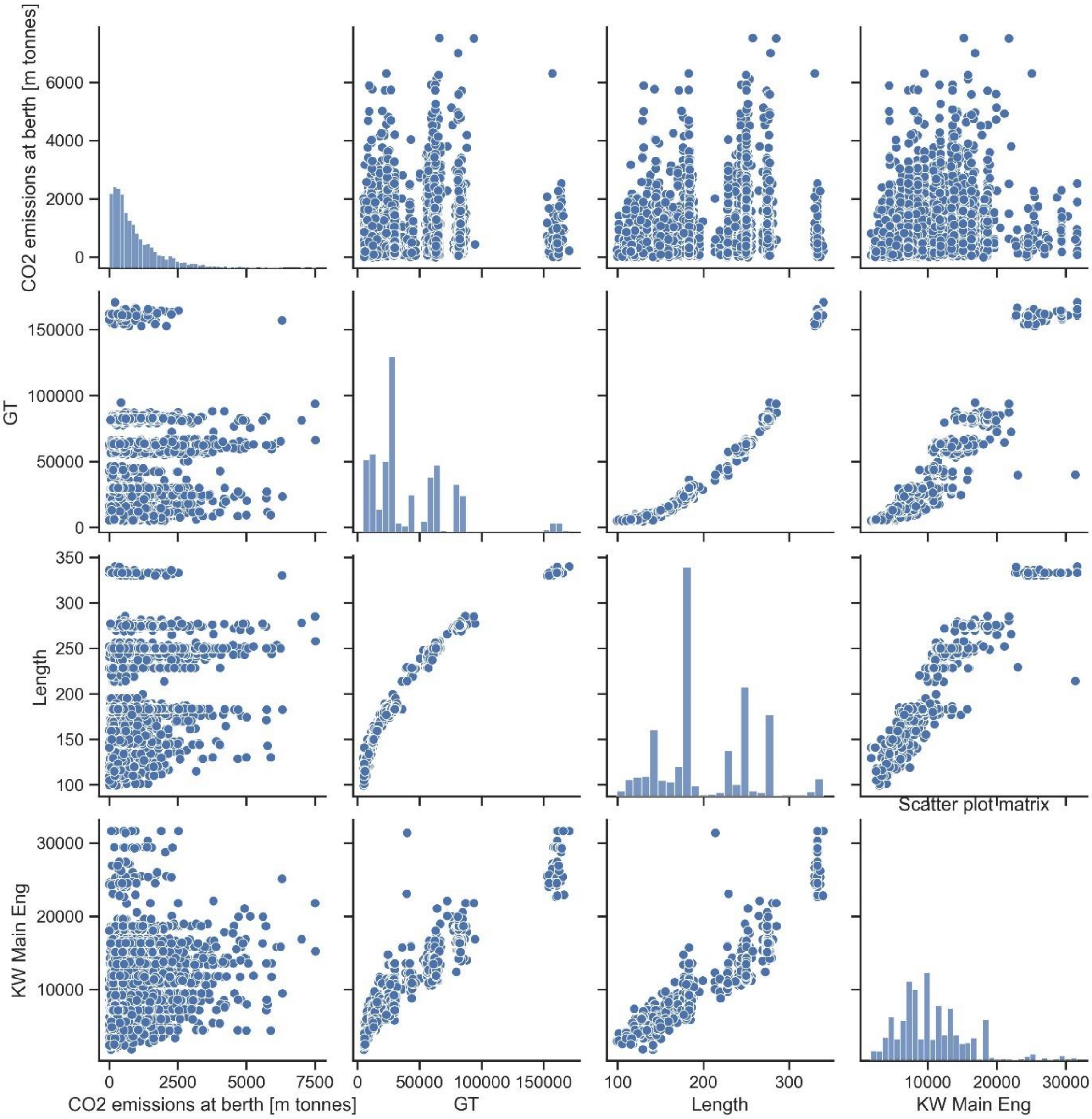

Figure 28: Scatter plot matrix for Tankers

The CO2 emissions correspond to the first row or column in the graph. The correlation with the emissions is not again as visible as with passenger ships. However, some slight correlation can still be appreciated in the following density diagrams that depict the relation between CO2 emissions at berth and GT, Length and Main engine power.

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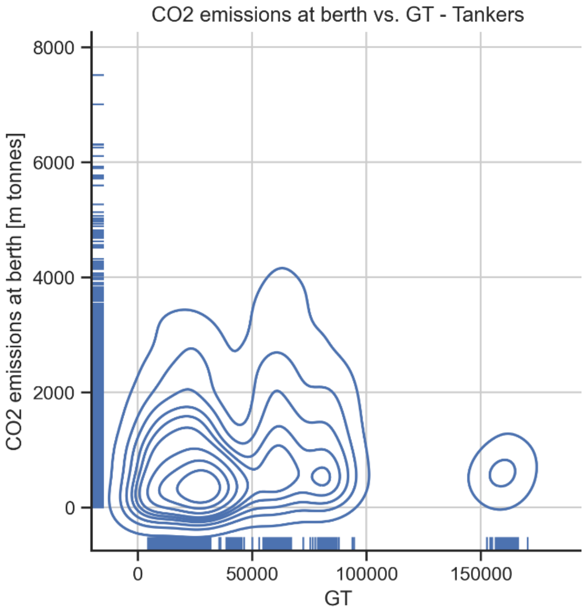

Figure 29: GT vs. CO2 emissions for Tankers

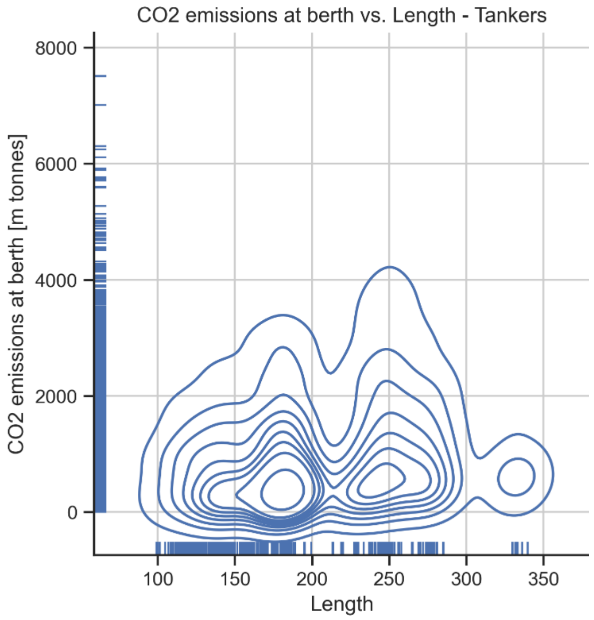

Figure 31: Length vs. CO2 emissions for Tankers

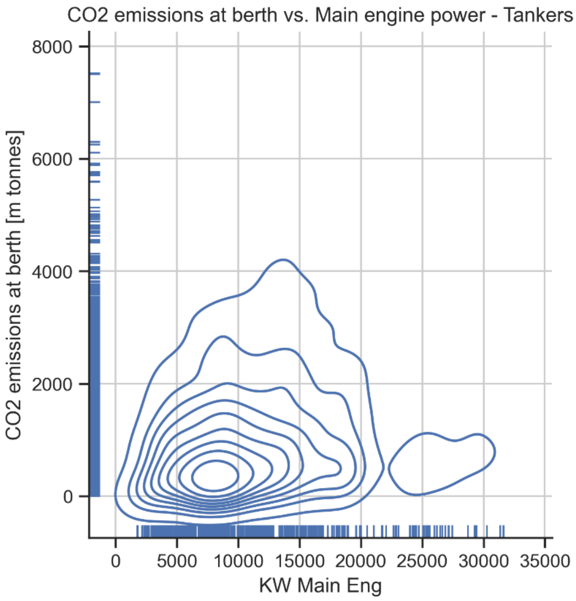

Figure 30: Main engine power vs. CO2 emissions for Tankers

The following histograms depict the contribution, in percentage, of each segment or group to the total, in terms of number vessels in the same segment, and CO2 emissions.

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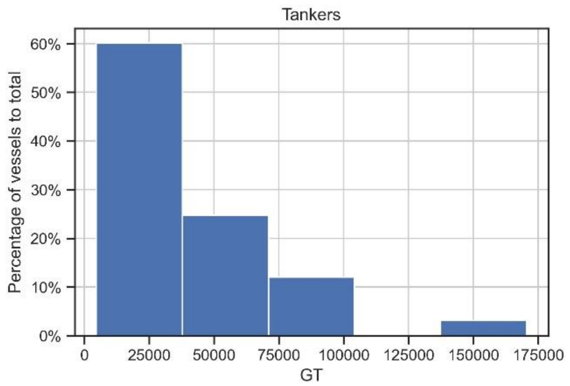


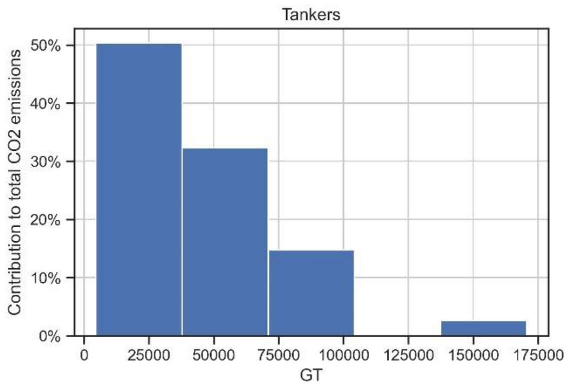
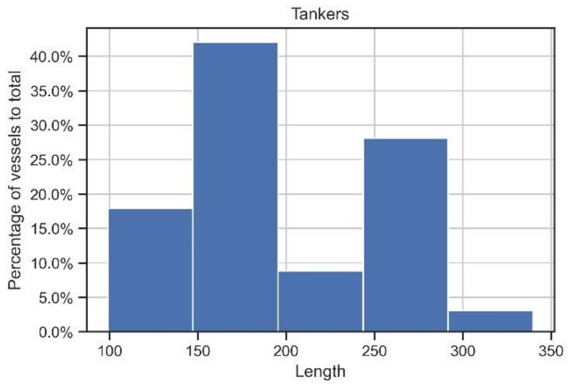


Figure 32: Number of vessels per GT segment (left) and contribution to CO2 emissions per GT (right) for Tankers



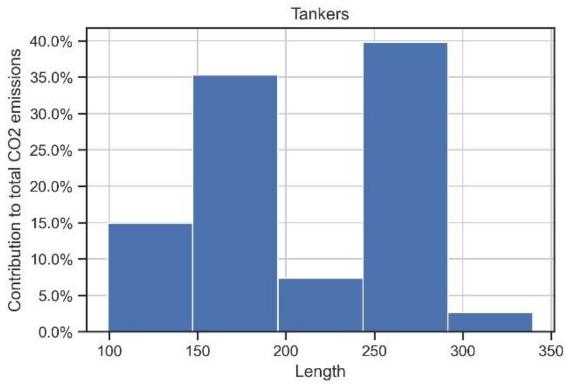
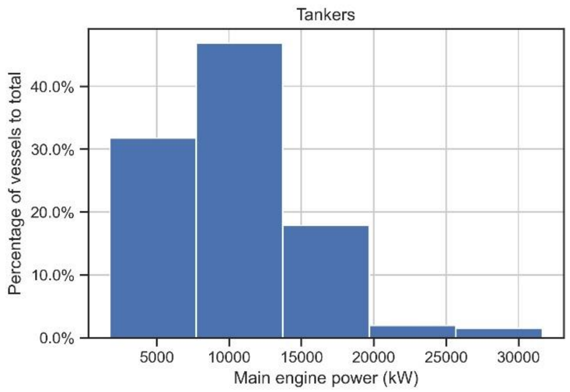


Figure 33: Number of vessels per Length segment (left) and contribution to CO2 emissions per Length (right) for Tankers



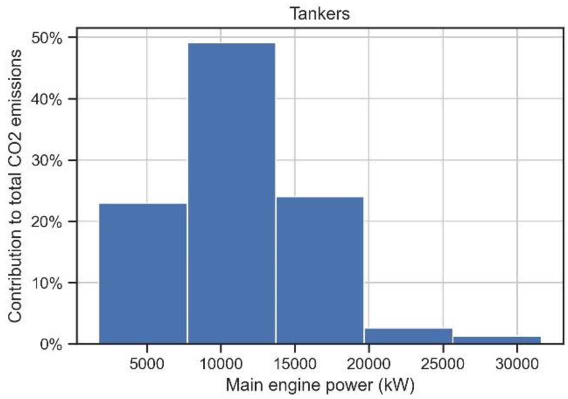


Figure 34: Number of vessels per main engine capacity segment (left) and contribution to CO2 emissions per main engine capacity segment (right) for Tankers

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2.4.3.5 Bulk carriers

Following, the scatter plot matrix is depicted for the case of bulk carriers.

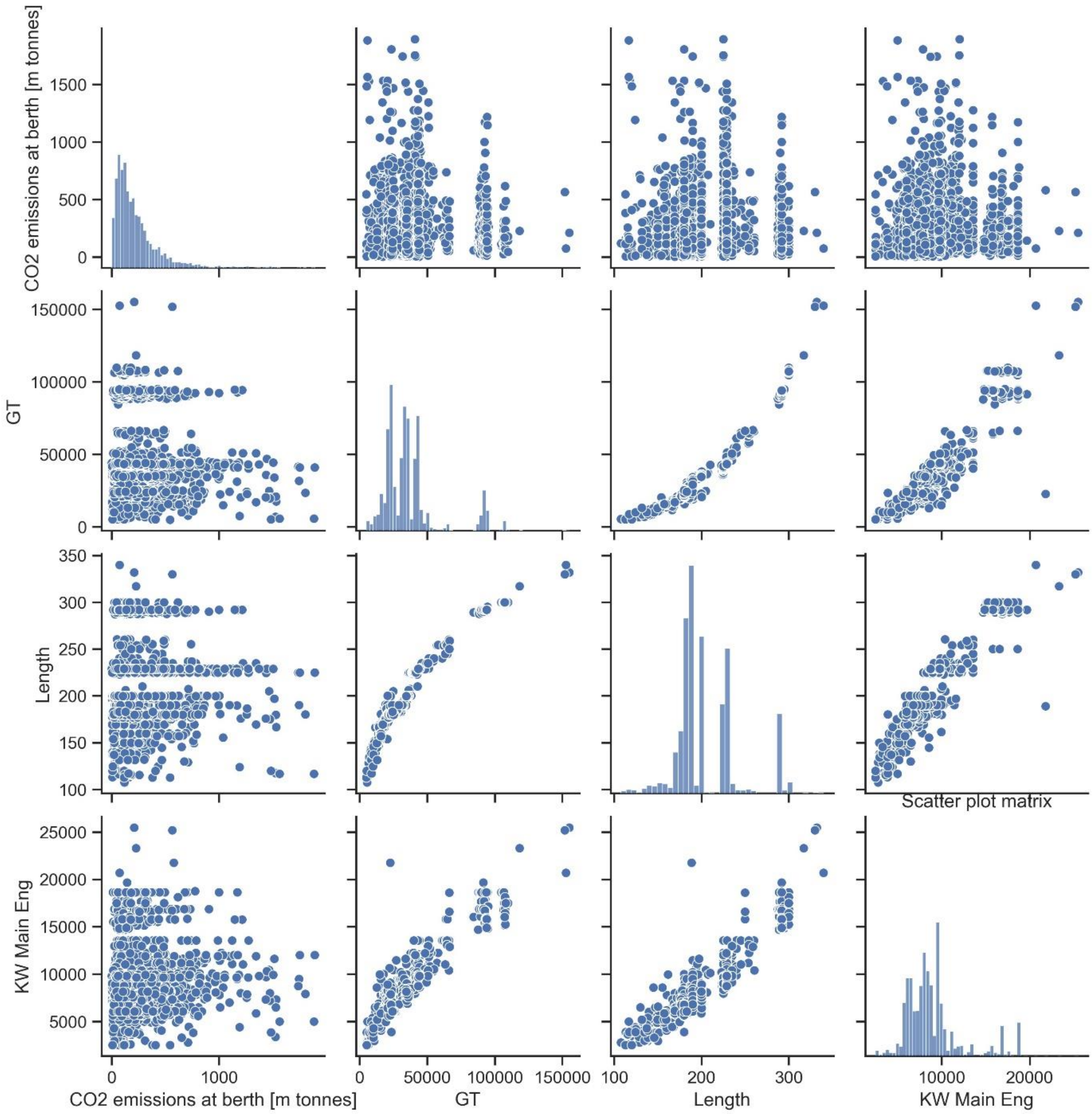

Figure 35: Scatter plot matrix for Bulk carriers

The CO2 emissions correspond to the first row or column in the graph. The correlation with the emissions is in this case very low or not existent at all. This can also be seen in the following density diagrams that depict the relation between CO2 emissions at berth and GT, Length and Main engine power.

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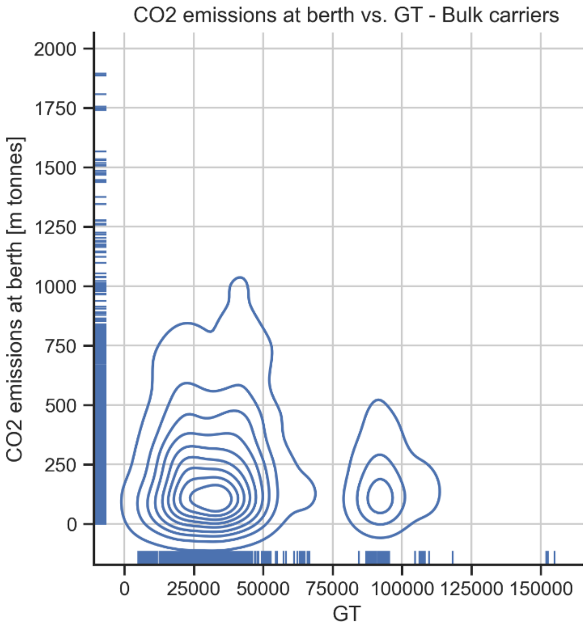

Figure 36: GT vs. CO2 emissions for Bulk carriers

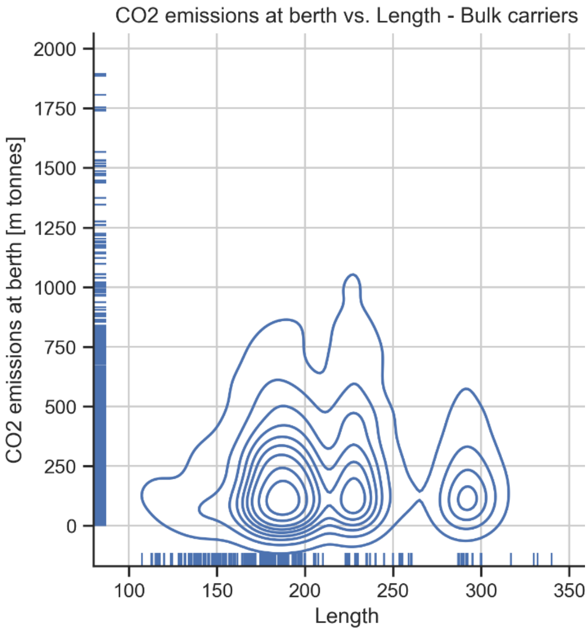

Figure 38: Length vs. CO2 emissions for Bulk carriers

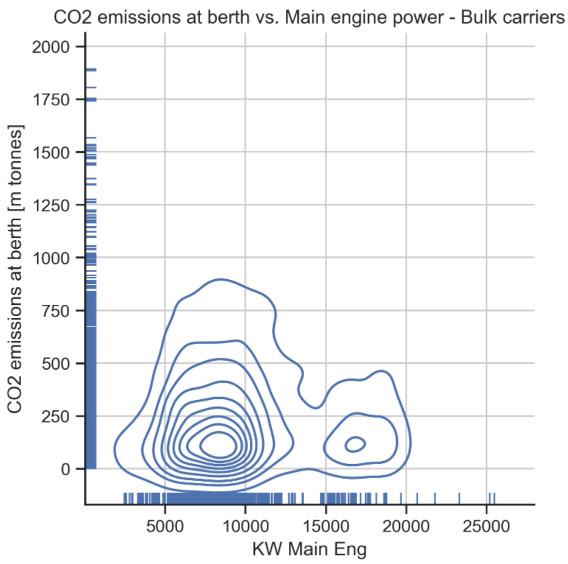

Figure 37: Main engine power vs. CO2 emissions for Bulk Carriers

The following histograms depict the contribution, in percentage, of each segment or group to the total, in terms of number vessels in the same segment, and CO2 emissions.

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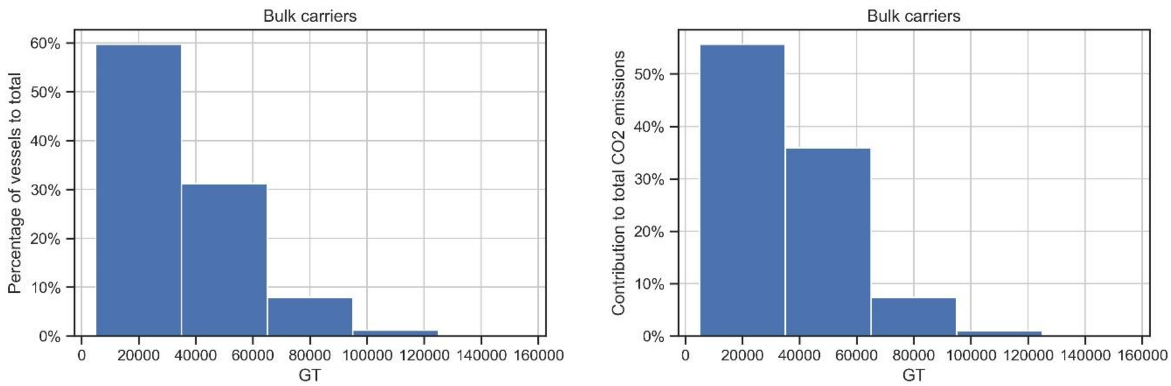

Figure 39: Number of vessels per GT segment (left) and contribution to CO2 emissions per GT (right) for Bulk Carriers

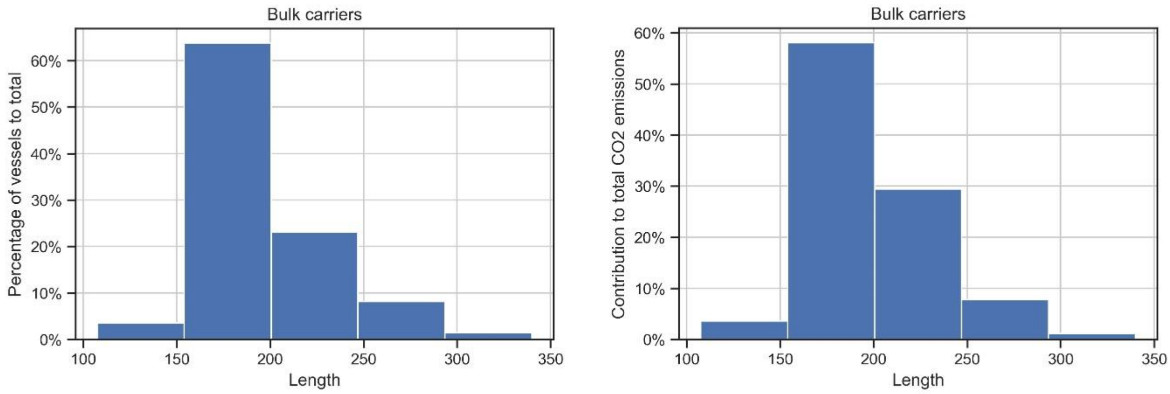

Figure 40: Number of vessels per Length segment (left) and contribution to CO2 emissions per Length (right) for Bulk Carriers

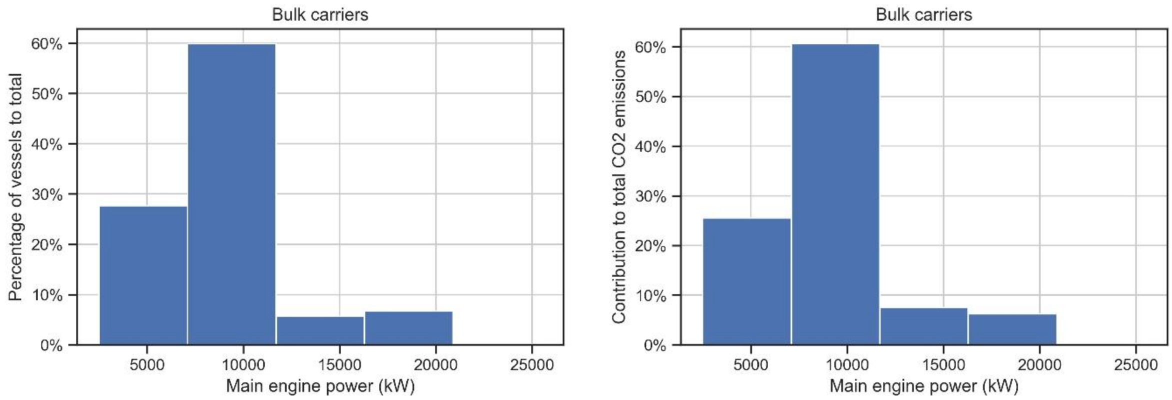

Figure 41: Number of vessels per main engine capacity segment (left) and contribution to CO2 emissions per main engine capacity segment (right) for Bulk Carriers

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2.5 Identification of case studies

A multifaceted analysis based on several technical, regulatory, and market-based parameters was performed as part of this chapter. The scope was to examine the issue of connecting the maritime fleet to the SSE and conclude to which vessel types should be further examined as case studies.

The Questionnaire responses from shipping companies, classification societies, and flag administrations were analysed. The purpose was to provide insights into the various aspects of the SSE, as seen from the shipping industry major stakeholders' side. At the same time, the results from the waterborne traffic on six participating EALING ports, were used to identify the most common vessel types berthing in EU ports.

Finally, a review of the applicable regulations was performed, resulting into a projection of the impact of the usage of SSE and a comprehensive statistical analysis on previously submitted and verified emissions to EU's dedicated platform Thetis MRV for different types of vessels.

Based on the provided information, five vessel types were considered as use cases for SSE installations and will be further analysed within the scope of this report, in the next chapters:

1. **Cruise ships:** Cruise ships are highlighted in the provided information as vessel types frequently berthing at ports. These ships were shown to produce the highest amount of polluting emissions while at berth. Implementing SSE on passenger ships can help addressing their substantial energy demands and significantly reducing emissions from auxiliary power units and systems.
2. **Ro-pax vessels:** Ro-pax vessels are commonly used by the enquired shipping companies. They are also one of the most frequent vessel types berthing at the studied EALING ports. Implementing SSE on ro-pax vessels can have multiple benefits since they were shown to produce the second largest number of polluting emissions while at berth. These vessels often operate on short-distance routes, making them suitable for SSE installations as they frequently return to the same port. Reducing their emissions through SSE can contribute to improved air quality and reduced environmental impact in densely populated coastal areas.

Both Cruise ships and Ropax vessels were shown to achieve the 2030 GHGs reduction limit with the use of SSE. They were also specifically targeted in the FuelEU Maritime regulation as vessel types suitable for SSE adoption.

3. **Containerships:** Containerships are another vessel type frequently berthing at EU ports. They were also specifically targeted in the FuelEU Maritime regulation as vessel types suitable for SSE adoption. These vessels carry large volumes of cargo, and their operation contributes significantly to greenhouse gas emissions in the maritime sector. Implementing SSE on containerships can lead to substantial emission reductions during their berthed periods, as they often remain stationary for extended periods of time during cargo loading and unloading operations. SSE installations can also help to address the power demand requirements of containerships, considering the potential high energy consumption associated with cooling and refrigeration systems for reefer containers.
4. **Bulk carriers:** Bulk carriers are the most common ship type berthing at EU ports. They are commonly used for transporting unpackaged bulk cargo, such as coal, grain, and ore. Given their size and capacity, bulk carriers often spend considerable time at ports for loading and unloading operations. SSE installations on bulk carriers can contribute to emission reductions during these berthed periods, which can be significant considering the energy demand

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associated with cargo handling equipment, such as cranes. Moreover, bulk carriers are frequently used in the transportation of raw materials for industrial processes and reducing their emissions through SSE can have an indirect positive impact on the carbon footprint of various industries.

5. **Tankers:** Tankers represent also one of the most common vessel types calling to EU ports. They have a high potential for reduction of the GHG emissions. By connecting to SSE, tankers can eliminate the need for onboard generator operation during berthing periods, leading to substantial fuel cost savings. The installation of SSE equipment both at tanker terminals and onboard the vessels present technical challenges because of the nature of the cargo. Special consideration arises due to the assigned dangerous areas onboard the tankers and suitable arrangements should be provided.

Several parameters can affect the implementation and effectiveness of shore-side electricity. Sufficient power capacity must be available to meet the demand of the vessels at different conditions. Vessels also have specific voltage requirements for their electrical systems, making the availability and quality of the port infrastructure significant in the provision of shore-side electricity. Ports need to ensure that the shore-side electricity matches these requirements to enable vessels to connect seamlessly. Exploring the several combinations of case studies that arise from those considerations is essential to ensure that various vessels with different electrical systems can access shore-side electricity in various ports.

Based on the above, five (5) specific vessels were chosen as the EALING Case Studies:

- A 140,000 GT Cruise Ship, requiring more than 1MVA, with 11kV power distribution system.
- A 18,600 GT Ro-ro passenger ship (Ropax) requiring more than 1MVA, with 380V power distribution system.
- A 10,000 TEU Containership, requiring more than 1MVA, with 6.6kV power distribution system and with SSE infrastructure already installed. However, the SSE system was installed during the construction of the vessel in 2010, before the establishment of the applicable standards.
- An 87,000 DWT Bulk Carrier, requiring less than 1MVA, with 440V power distribution system.
- A 50,000 DWT Tanker, with 440V power distribution system, requiring more than 1MVA during loading/unloading condition and less than 1MVA during port stay.

The analysis of the EALING Case Studies is performed in the next chapter.

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3. ANALYSIS OF EALING CASE STUDY VESSELS

In this Chapter, the five case study vessels, identified in the previous chapter, will be examined:

A. a 140,000 GT Cruise Ship

B. an 18,600 GT Ro-ro passenger ship (Ropax)

C. a 10,000 TEU Containership

D. an 87,000 DWT Bulk Carrier

E. a 50,000 DWT Tanker

The scope is to provide an engineering assessment of the SSE installation and operation onboard the selected case study vessels. By following the process described in the Figure 42, shown below, the aim of this deliverable is to showcase the technical elements that will facilitate, or hinder respectively, the widespread adoption of the SSE from the maritime industry.

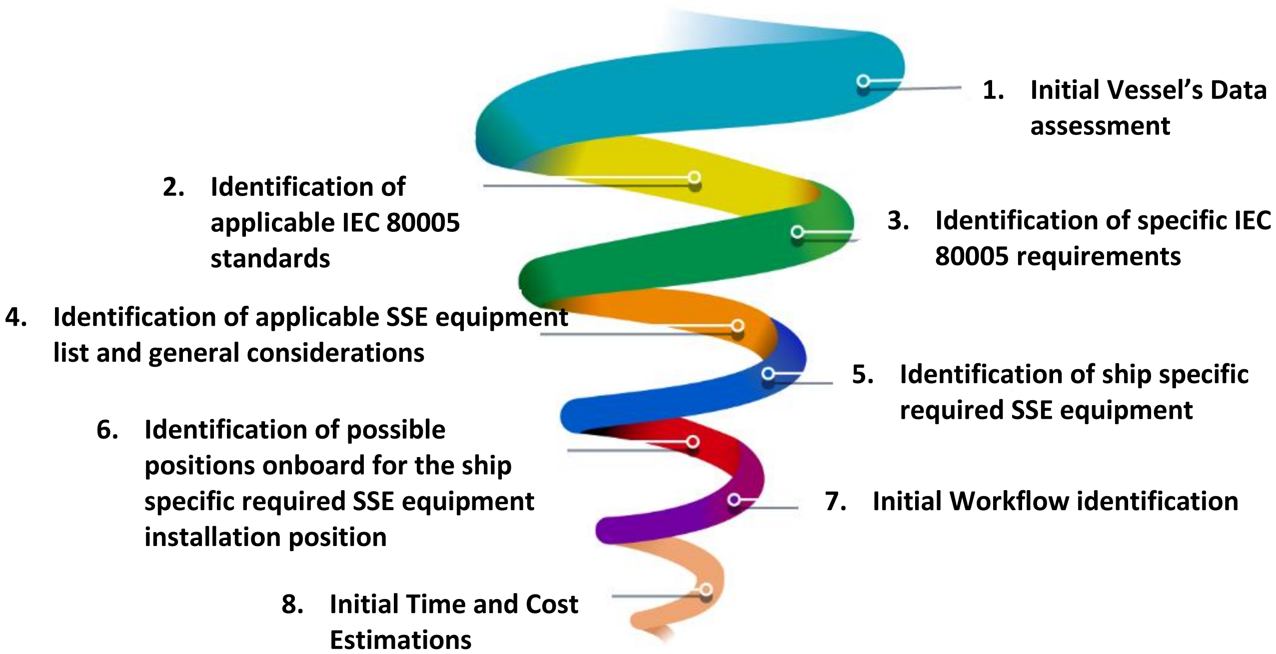

Figure 42: Process steps to perform an assessment for the SSE installation onboard a vessel

The process described above will be further analysed in the next Chapters 3 and 4. In the following Chapter 3, the factors that affect the SSE installation onboard will be first described and then they will be applied specifically to the five vessels that have been identified as case studies, based on the Chapter 2. The steps 7 and 8 will be further analysed in Chapter 4, based on the results of the present chapter.

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3.1 Factors affecting the SSE installation onboard

3.1.1 Preliminary considerations

The preliminary analysis of SSE connection for the case study vessels involves an assessment of various factors to determine the feasibility and requirements for implementing SSE during vessels' port stays. In general, performing a detailed study and consulting with electrical engineers, marine engineers and experts in SSE systems is highly recommended to ensure a safe and reliable installation. In this section, a preliminary analysis of the special Shore Side Electricity (SSE) considerations will be conducted. The key factors that need to be considered when evaluating SSE implementation onboard all the assessed types of vessels will be examined.

Analytically, the analysis process includes:

- Ship Type and Power Requirements:
  - Understanding the characteristics and power demands of each vessel type.
  - Assessing the vessel's power consumption patterns during port stays.
- Cable Sizing and Receiving Point:
  - Analyzing the power transmission requirements and determining the appropriate cable sizing to meet the vessel's power demands.
  - Assessing the best location for the receiving point to facilitate efficient cable routing and minimize power losses.
  - Identifying the type of receiving point (e.g., power pedestal, shore connection box) suitable for each vessel type.
- Data Communication and Monitoring:
  - Evaluating the need for data communication systems between the vessel and the shore for monitoring and control purposes.
  - Assessing the communication requirements for real-time information exchange, power management, and system monitoring.
- Voltage Requirements and Transformers:
  - Verifying the voltage provided at the berthing positions.
  - Assessing if voltage transformers are needed to match the vessel's requirements and ensure compatibility with the onboard systems.
- Circuit Breaker Capability:
  - Determining the breaking capacity of the circuit breaker onboard each commercial vessel to ensure safe and efficient operation.
  - Ensuring that the circuit breaker can handle the maximum loads of the vessel during port stays, including peak power demands providing both overload and short circuit protection.
- Cost-Benefit Analysis:
  - Conducting a preliminary cost-benefit analysis to evaluate the financial feasibility of implementing SSE for each vessel type.
  - Considering the potential emission reductions, operational efficiency, regulatory compliance, and long-term sustainability benefits.

The **first step** of the preliminary SSE analysis includes an assessment of the vessel's existing condition. The main inputs used to carry out the analysis for the installation of the SSE connection facility of the chosen vessels are:

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- The **Electrical Load Balance (or Electric Load Analysis – ELA)** is a calculation of the maximum loads that the electrical system is designed for, based on the installed electrical consumers installed onboard for different vessel conditions, like the port stay and navigation condition, for example. The Electrical Load Balance is assessed to identify the designed electrical load consumption for harbour staying. During port stay, the main electrical needs are the vessel's hotel loads. However, the port stay may also include cargo operations that will require higher power inputs, so any installed equipment will need to be able to handle these power load. It may also include different vessel-type specific conditions for when the vessel is at port that need to be assessed. The actual electrical loads during port stay are usually lower than the ones described in the ELA.
- The **Single line diagram,** also sometimes called one-line diagram, is the simplest symbolic representation of an electric power system. It has the form of a block diagram, graphically depicting the paths for power flow between the different consumers of the system. Elements on the diagram do not represent the physical size or location of the electrical equipment, but it is a common convention to organize the diagram with the same left-to-right, top-to-bottom sequence as the switchgear or other apparatus represented. Additional to providing a simplified depiction of the installed electrical system onboard, it also states the Diesel Generators', and Main Switchboard's respectively, nominal voltage and operating frequency.
- The **General Arrangement (GA) plan** gives information on the arrangement of the vessel, its main dimensions and some main equipment onboard. The GA plan depicts the division and arrangement of the ship by providing a side view, plan views of the most important decks and some cross-sections, mostly the midship section. The GA is fundamental for two reasons. The first one is to identify the location of the existing equipment and infrastructure onboard that will affect the future installation of the SSE. The second one to identify the possible space onboard to install the SSE equipment and the required modifications resulting from such installation.

Once the vessel's condition has been analysed, the electrical loads that are required to be supplied by the port to the vessel, the voltage, and the frequency it operates, and an initial condition assessment of its spatial arrangement are known. The accurate estimation of the ship's electrical needs is crucial since based on the vessel's electrical requirements, the **applicable IEC/IEEE 80005 standard** is identified. IEC/IEEE 80005 -1 is applicable for HVSC systems for ships requiring 1 MVA or more or ships with HV main supply, while the provisional IEC/PAS 80005 -3 is applicable for LVSC systems for ships requiring up to 1 MVA.
When planning to use SSE, the vessel will be directed to the respective berthing positions that can provide the required power capacity. Further to the IEC/IEEE 80005-1 or IEC/PAS 80005-3, whichever is applicable, **additional specific electrical considerations and sizing requirements** are provided in the annexes. Depending on the ship's type and applicable IEC/IEEE 80005 standard, so, both the port side and the vessel side SSE installations will be differentiated.

A summary of the main electrical requirements for High Voltage Shore Connection according to the IEC/IEEE 80005-1 standard annexes is presented in Table 11.

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Table 12: Main electrical requirements for High Voltage Shore Connection as per IEC/IEEE 80005-1 standard

	RO-PAX	CRUISE	CONTAINER	LNGC	TANKER
Nominal Voltage provided by the shore	11 V 6,6 kV may be applicable only for regional waterborne transportation	11 and/or 6,6 kV	6,6 kV	6,6 kV	6,6 kV
Power rating provided	Up to 6,5 MVA	Minimum 16 MVA (20 MVA is recommended)	Up to 7,5 MVA	Up to 10,7 MVA	Equal to 10,8 MVA
Power cables	1 (3ph+earth)	4 (3ph @500A, @250A)	2 (3ph+earth)	3 (3ph+earth)	3 (3ph+earth)
Short circuit withstand current	16 kA RMS (1s)	25 kA RMS (1s)	16 kA RMS (1s)	25 kA RMS (1s)	16 kA RMS (1s)
Short circuit max peak current	40 kA	63 kA	40 kA	63 kA	40 kA
Prospective short circuit contribution	16 kA (both sides)	25 kA (both sides)	16 kA (both sides)	25 kA (both sides)	16 kA (both sides)
Galvanic isolation	May not be required if supplies only ships with galvanic isolation onboard	Galvanically separated from the shore distribution system	Galvanically separated from the shore distribution system	Galvanically separated from the shore distribution system	Galvanically separated from the shore distribution system
Earthing system	Shore side transformer (if used) star point earthed with 335/200 Ohms NGR	Shore side transformer star point earthed with 540 Ohms NGR	Shore side transformer star point earthed with 200 Ohms NGR	Shore side transformer unearthed where LNGC compliant IEC 60092-502	Other earthing arrangements may be allowed because of the need to limit earth fault current in hazardous areas
Location of CMS	At Berth	At Berth	Onboard the Ship	At Berth	At Berth

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The following information is included in the table above:

- **Nominal Voltage**: The nominal voltage refers to the specified voltage level provided be the shore connection. It is typically defined as the voltage at which the system is designed to operate and is directly determined based on the applicable IEC standard since 6.6 kV or 11 kV can be used for HVSC. For LVSC the provided voltage may be 690, 440 or 400 Volts of AC, as shown in Table 12. However, more specific arrangements regarding voltage may be required according to ship type, as shown above.
- **Power Rating**: The power rating of the HV shore connection system indicates the maximum amount of electrical power that can be supplied to the connected vessel. It is typically expressed in real power measured megawatts (MW) or in apparent power measured in megavolt-amperes (MVA). The power dimensioning depends on the specific requirements of the port and the vessels it serves. The relationship between real power and apparent power is described by the power factor. The power factor is an important consideration in SSE systems. The power factor is a measure of how effectively electrical power is being utilized. A poor power factor can lead to inefficient power usage and higher energy costs. For all the case studies a power factor of 0.8 will be considered by default.
- **Power Cables**: The power cables used for the HV shore connection systems must be designed to withstand the voltage and current levels involved. They should have appropriate insulation and conductor sizes to handle the power rating and ensure safe and reliable transmission of electricity between the shore and the vessel.
- **Short Circuit Withstand Current**: The short circuit withstand current is the maximum current that the HVSC system can safely handle during a short circuit event. It is crucial to ensure that the system components, such as circuit breakers and switchgear, can safely interrupt and withstand the high currents that may occur during fault conditions.
- **Short Circuit Max Peak Current**: The short circuit max peak current represents the peak value of the current during a short circuit event. It helps determine the capability of the system to handle high fault currents and protect the connected equipment from damage.
- **Prospective Short Circuit Contribution**: The prospective short circuit contribution refers to the contribution of the HV shore connection to the total short circuit current in the electrical network. It is important to assess and consider this contribution to ensure the overall stability and reliability of the electrical system.
- **Galvanic Isolation**: Galvanic isolation is a crucial requirement in the HVSC system to ensure the safety of personnel and equipment. It involves isolating the shore power supply from the vessel's electrical system, typically by use of transformers or other isolation devices, to prevent the flow of electrical currents through unwanted paths and eliminate the risk of electric shock.
- **Earthing System**: The earthing system of the shore connection system ensures the safe dissipation of fault currents and provides a reference potential for the system. It typically includes grounding electrodes, conductors, and protective earthing measures to minimize the risk of electrical hazards and ensure the proper functioning of protective devices.
- **Location of CMS**: The placement of the CMS depends on the vessel type only and not the power requirement that defines the applicable IEC standard. The cable management system shall be located onboard ship only in the case of containerships. In all the other ship types the installation shall be ashore. In general, the CMS should be strategically located for easy access,

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cable routing, and maintenance. It may include cable trays, conduits, and supports that are positioned in a manner that allows efficient cable management and ensures the integrity of the HVSC system.

Similar information is included in the Table 12 for the LVSC systems. Table 12 summarizes the main electrical requirements for Low Voltage Shore Connection according to the IEC/PAS 80005-3 standard annexes, providing same information as in the previous table. The case of the bulk carrier is not included in the annexes of the standard, so it is derived by the general IEC/PAS 80005-3 requirements.

Table 13: Main electrical requirements for Low Voltage Shore Connection as per IEC/PAS 80005-3 standard

	OSV	CONTAINER	TANKER	BULK CARRIER
Nominal Voltage provided by the shore	400/440/690 V	400/440/690 V	440 V	400/440/690 V
Power rating provided	< 1MVA	< 1MVA	< 1MVA	< 1MVA
Power cables	Up to 5 (3 phases + earth)	Up to 5 (3 phases + earth)	Up to 5 (3 phases + earth)	Up to 5 (3 phases + earth)
Short circuit withstand current	16 kA RMS (1s)	16 kA RMS (1s)	16 kA RMS (1s)	16 kA RMS (1s)
Short circuit max peak current	40 kA	40 kA	40 kA	40 kA
Prospective short circuit contribution	Not defined	Not defined	Not defined	Not defined
Galvanic isolation	Galvanically separated from the shore distribution system. Galvanic separation between the shore and on-board systems shall be provided on shore.	Galvanically separated from the shore distribution system. Galvanic separation between the shore and on-board systems shall be provided on shore.	Galvanically separated from the shore distribution system. Galvanic separation between the shore and on-board systems shall be provided on shore.	Galvanically separated from the shore distribution system. Galvanic separation between the shore and on-board systems shall be provided on shore.
Earthing system	Shore side transformer star point earthed with 25 Ohms NGR	Shore side transformer star point earthed with 25 Ohms NGR	Shore side transformer star point earthed with 25 Ohms NGR	Shore side transformer star point earthed with 25 Ohms NGR
Location of CMS	At Berth	Onboard the Ship	At Berth	At Berth

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For the Low Voltage Shore Connection according to the IEC/IEEE 80005-3 standard, the number of cables needed can be up to five (5). The actual number of cables depends on the power demand to be covered and the nominal voltage provided, as shown in the next Figure 43. The cable conductor size is 185 mm^2, as per standard.

Power demand kVA	Voltage (V)					
	400		440		690	
	Nr Connections	I_max/cable (A)	Nr Connections	I_max/cable (A)	Nr Connections	I_max/cable (A)
Up to 250	2	180	1	328	1	209
251 – 500	3	241	2	328	2	209
501 – 750	4	271	3	328	2	314
751 - 1000	5	289	4	328	3	279

Figure 43: Low Voltage Shore Connection - Number of Connections as a function of power demand and voltage

By following these steps, the specific vessel's type, existing design, and electrical needs are matched with the SSE requirements provided by the IEC standards. Based on the vessel's existing condition and the resulting initial assessment key factors including, but not limited to, cable sizing, connection (receiving) point type, data communication needed, voltage requirements and circuit breaker capability are determined.

The resulting electrical network that needs to be installed and interoperated can be complex and consisting by many parts, as showcased in the Figure below.

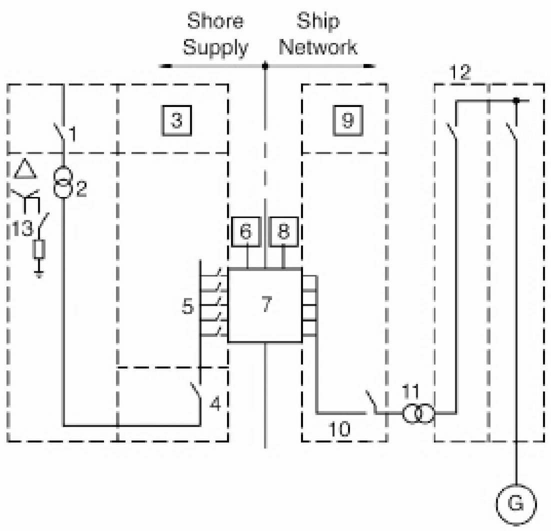

Figure 44: Low Voltage Shore Connection – LVSC block diagram

1) primary breaker, 2) substation transformer, 3) LV switchgear, 4) main breaker, 5) feeder breakers, 6) feeder cables to power receptacles, 7) plug and receptacle assemblies, 8) plug with a flexible cable, 9) ship onboard shore power panel, 10) ship-side circuit breaker, 11) optional ship onboard transformer, 12) synchronizing breaker, and 13) neutral resistor disconnect switch. G) grounding.

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In general, the required equipment that is installed onboard a vessel for the supply of SSE is:

1. The CMS (only in the case of containerships)
2. The Ship inlet – the receiving point (point 9 in Figure 44)
3. The receiving Circuit Breaker (point 10 in Figure 44)
4. The Power Cables, up to the transformer (if installed)
5. The Power Transformer (if required to match the voltage between the ship and the shore voltage - point 11 in Figure 44)
6. The Power Cables, from the Transformer (if installed) up to the MSB
7. The Circuit Breaker at the MSB, with relevant means for synchronization (point 12 in Figure 44)

Dedicated space should be found onboard to accommodate the new equipment. The positioning of the required equipment to be installed onboard the vessels is an important limitation, especially in the case of retrofitting installation. In this deliverable, we will consider the case of retrofitting vessels with the SSE-required equipment. In the case of newbuilds, the installation and interconnection of the SSE are easier to plan, and account for the required space, even if the equipment is not installed immediately. This is the case of the new building vessels being constructed SSE-ready, with some preliminary equipment installed onboard, but more importantly, with reserved space for the future installation of the SSE system.

The provided power (MVA) from the port, as was shown in the previous chapter, may be less than the maximum power determined by the applicable Standard. In this way over dimensioning of the cabling and the equipment is avoided, making the installation of the SSE equipment more cost effective for the port. The same principle applies for the vessel. Based on the load analysis, the SSE equipment may be sized accordingly. This includes selecting the appropriate capacity of the circuit breakers, transformers, and cables to handle the expected power demand without overloading the system. The sizing should consider factors like power factor, harmonics, and future expansion needs. However, it is usual practice to over dimension the ELA loads. As a rule of thumb, about 25-45% of the total generators' installed power, may actually be used when at port stay. This number is usually considerably lower than the one stated in the ELA. Especially for the installations onboard, additional to cost considerations, the weight of any installed equipment and the space that this equipment occupy are important limitations. So, the dimensioning of the equipment and the cabling is proposed to be performed according to the vessel's actual needs.

With those inputs and following the existing rules it is possible to assess the electrical technical specification for the dimensioning of the SSE equipment.

3.1.2 Ship-shore interface constraints

The first point of contact between the vessel and the port is the receiving point (Fig. 45). The number of power cables the power it is designed for, the applicable standard for its design are important parameters affecting the **compatibility between the port and the vessel**. To achieve this the number of cables and the connection sockets/plugs should always be designed according to the applicable standard. The sockets and plugs constitute the interface between the vessel and the port. Both in the port and in the ship side, they should be dimensioned for the maximum power as stated in the IEC/IEEE 80005 to ensure operability for every possible combination.

Assuming compatibility, as described above, the next important parameter affecting the receiving point is the installation position onboard.

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The position of the receiving point should be strategically determined to facilitate efficient cable routing and minimize power losses, the voltage drop and the required cables length, as well as to reduce the impact in the existing ship arrangement and operations. The last two depends on the type of the vessel mostly.

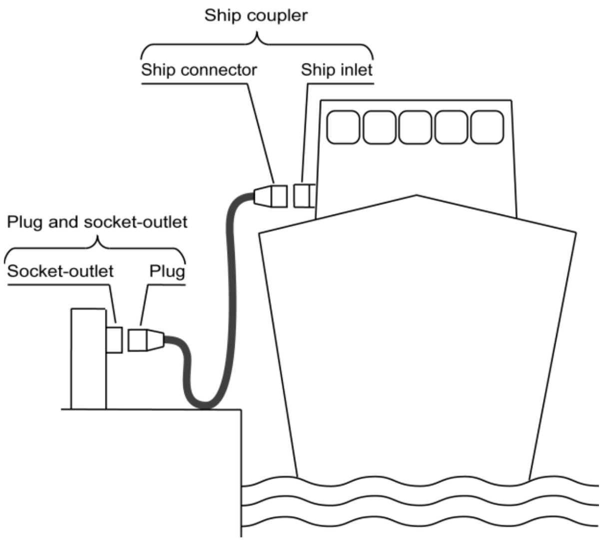

Figure 45: Ship coupler, source: IEC/PAS 80005-3 standard

To provide flexibility regarding the position of the vessel while at berth two receiving points, one for the port and one for the starboard side, are considered in the retrofitted scenarios in Chapter 4. The receiving point is the first point of contact onboard the vessel with the SSE equipment from ashore. The arrangement with two receiving points will not restrict the mooring positioning of the vessel while at the same time making it able to receive electricity from ashore. In general, the receiving points should be installed as close to the side shell as possible. They should also be installed above the bulkhead deck of the vessel to not endanger the watertight integrity of the vessel. The cables are to enter the enclosed vessel compartment (i.e. vessel accommodation) from the receiving points through openings with weathertight arrangements.

The position of the receiving point along the length of the vessel is also an issue that needs to be considered. The ship mooring arrangements onboard must not be hindered by the installation of the SSE equipment. Sufficient clearance needs to be ensured to accommodate both the ship's mooring equipment and the shore connection infrastructure (see Figure 46 as a reference for a cruise ship's stern mooring arrangement and Figure 47 as a reference for a tanker's mooring arrangement).

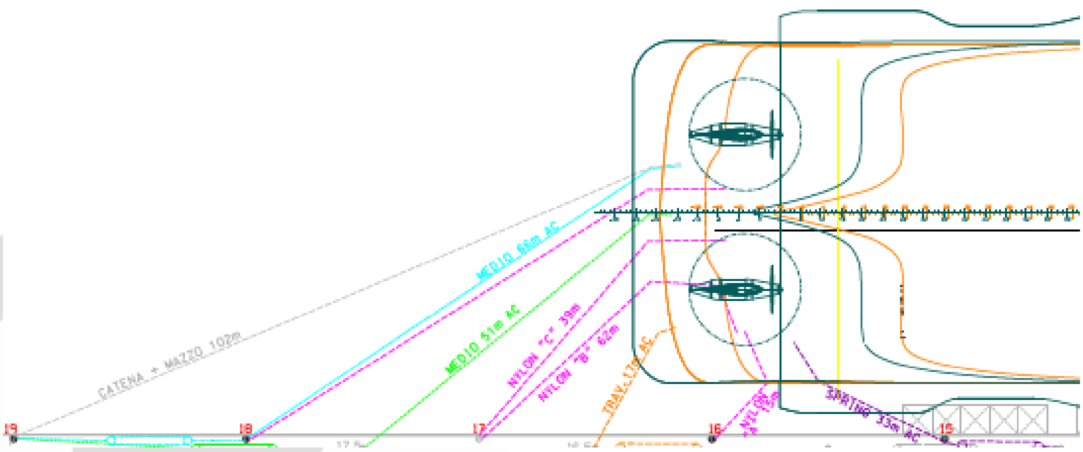

Figure 46: Plan view of a cruise ship stern mooring arrangement

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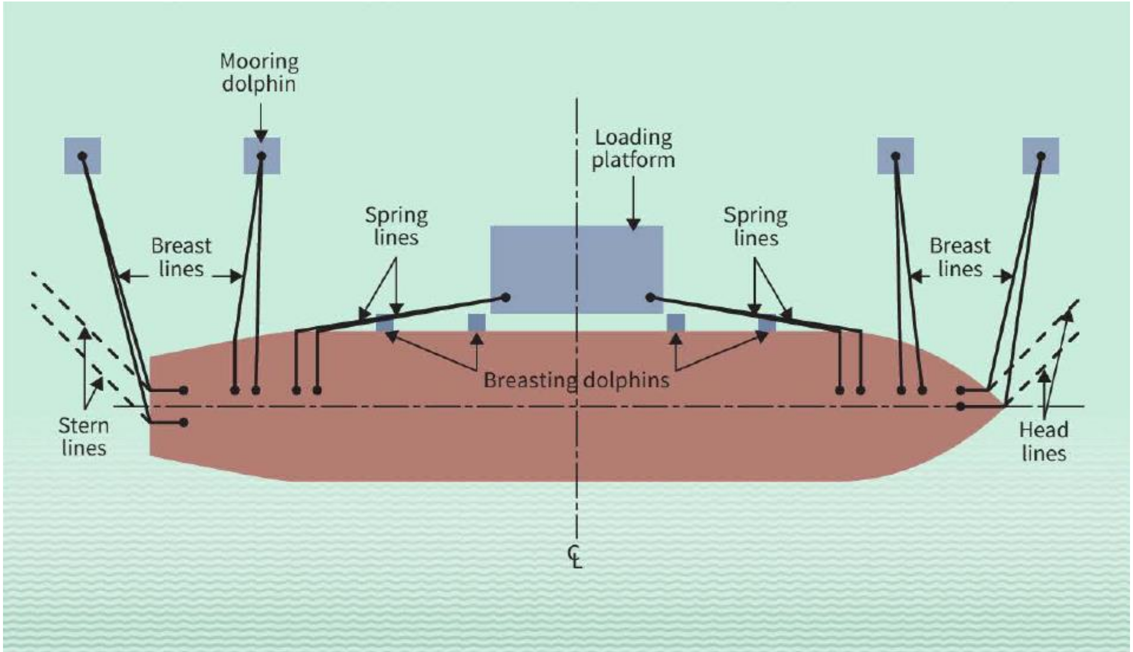

Figure 47: Typical mooring pattern at a conventional tanker terminal, source: MEG4, OCIMF

Another consideration is the fact that the SSE equipment, including the receiving point(s), is not to be located within a designated hazardous area, for example in tankers and gas carriers. If it is in a dangerous area, the equipment needs to be intrinsically safe and have the relevant documentation and/or be installed in compliance with relevant safety guidelines and regulations. Suitable arrangements also need to be provided for its connection with the safe areas onboard.

The type of receiving point, such as a power pedestal or a dedicated shore connection box, should be selected based on the vessel's requirements and the available space onboard the vessel. For example, in the case of cruise ships, it is common to have a large opening to the hull (vessel entry point) and connect the cables directly to a dedicated shore connection box, that includes the receiving Circuit Breaker.

However, in most cases a power pedestal (socket box most commonly referred), will probably be used due to space or other limitations. A separate panel that will include the receiving circuit breakers will be installed in an enclosed area of the vessel, providing more flexibility to the spatial arrangement.

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Figure 48: AMP socket box onboard a vessel, containing only the receiving socket for the connection of the cable from ashore

Regarding the CMS, special consideration will be given to this on the subchapter 3.4.

3.1.3 Other onboard considerations

There are however more things to be considered regarding the installation onboard once the type and position of the receiving point(s) is decided.

The power cables are an essential component of the SSE system. They are used to transfer electrical power from the shore to the ship. These cables should be protected at both ends by a dedicated circuit breaker. This ensures that in case of any faults or overloads, the circuit can be isolated and protected.

The breaking capacity of the new circuit breaker onboard should be carefully considered. The circuit breaker's capacity should be able to handle the maximum loads of the vessel while at the port, ensuring a safe and reliable power supply. Proper coordination with electrical engineers and classification societies is necessary to determine the appropriate breaking capacity.

Based on those considerations, the receiving points should be installed as close as possible to the MSB to reduce, for instance, the cable length, the voltage drop, and the power losses.

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In terms of voltage requirements, it is essential to ascertain the voltage provided at the berthing position. If the shore side voltage does not match the vessel's requirements (MSB voltage), a voltage transformer may need to be installed to convert the voltage to the appropriate voltage level.

The voltage level of the ship's electrical system may not always be compatible with the available shore power infrastructure. Different ports or terminals may have varying voltage requirements or standards. In most of the cases, a voltage transformer is installed onboard the vessels, so that it renders them flexible for SSE connection, while visiting different ports. For example, if a ship has a 440V electrical system, it may not be able to directly connect to shore power where this voltage level is not available, if such equipment is not installed.

Here, a transformer plays a crucial role. A transformer can step up or step down the voltage level to match the requirements of the ship's electrical system or the available shore power source. The IEC 80005 standards provide some restrictions to the voltage that the port will have to provide based on the ship type and the power demand. However, there are still many resulting voltage combinations, as will be shown below. In the case of a ship with a 440V system, for example, trying to connect to a shore power source with a different voltage, the transformer will adjust the voltage level, accordingly, enabling a safe and efficient connection.

In addition, it is important to note that not all ports have the infrastructure to provide every possible voltage level for shore power. Therefore, careful planning is required when selecting ports for a ship's berthing. Ships have different electrical systems and voltage requirements based on their design and specifications. Some ships may operate at 440V, while others may have different voltage levels such as 400V or 690V. Similarly, shore power facilities at different ports may have varying voltage capabilities. It is not feasible for every port to accommodate all possible voltage levels.

Due to this limitation, ship operators and planners need to consider the voltage requirements of their vessels and match them with the available shore power options at various ports. This requires careful coordination and communication between the ship's crew, port authorities, and power providers to ensure that the necessary voltage level is available for a successful shore power connection.

By considering the voltage compatibility between the ship and the port in advance, ship operators can effectively plan their routes and select ports that can provide the appropriate voltage for shore power. This proactive approach ensures that ships can optimize their use of shore power and minimize their environmental impact, while also avoiding operational disruptions or the need for additional voltage conversion equipment.

Nevertheless, ships gain the flexibility to connect to different shore power sources worldwide, regardless of the voltage variations by having a tap changer transformer for shore connection onboard. In detail, a tap changer transformer, also known as a voltage regulator transformer or simply a tap changer, is a type of transformer that allows for the adjustment of its output voltage by changing the tapping points on the transformer winding.

The primary purpose of a tap changer transformer is to maintain a consistent voltage level despite fluctuations in the input voltage or changes in the load conditions. The tap changer mechanism is usually located on the shore connection winding side of the transformer. It consists of a selector switch or a motor-driven mechanism that can move the connection point along the winding, thereby changing the turns ratio and adjusting the output voltage.

There are two main types of tap changer mechanisms: on-load tap changer (OnLTC) and off-load tap changer (OffLTC).

- On-load tap changer (OnLTC): This type of tap changer enables voltage adjustments while the transformer is energized and supplying power. It allows for seamless voltage regulation without interrupting the power flow. OnLTCs are commonly used in applications where voltage stability is critical, such as in power distribution networks or industrial systems with varying loads.

- Off-load tap changer: In contrast, an off-load tap changer requires the transformer to be de-energized during voltage adjustments. It involves manually or automatically changing the tapping points when the transformer is not supplying power. Off-load tap changers are typically used in applications where frequent voltage changes are not required, or where power interruption during tap changing is permissible, such for SSE purposes.

The tap changer mechanism provides flexibility in adjusting the output voltage to maintain a desired level, compensating for voltage variations and load fluctuations. This feature is especially valuable in scenarios where a stable and consistent voltage supply is crucial, such as in power transmission and distribution systems, industrial processes, or large-scale electrical installations.

When low voltage is used for the power transmission, the number and size of cabling is larger, making it harder to install as it needs more space and is heavier. It is also more expensive for the ship owners both from the perspective of acquisition costs and installation costs.

In this regard, the voltage transformer should be installed as close as possible to the MSB to avoid lengthy large sized cables to be installed.

Some more general but equally important electrical considerations are also given below:

- Voltage Drop Calculation: Voltage drop occurs when there is a significant distance between the SSE connection point and the ship's electrical distribution system. Voltage drop can lead to a decrease in voltage levels and affect the performance of electrical equipment. To mitigate voltage drop, proper cable sizing and routing should be done, considering the distance and electrical load.

- Grounding System: A robust grounding system is crucial for the safety of SSE installations. It provides a path for fault currents to flow safely to the ground. The grounding system should be designed and installed following relevant electrical codes and standards to ensure personnel safety and protection against electrical faults.

- Protection Systems: SSE installations should have appropriate protection systems in place to safeguard against electrical faults, overloads, and short circuits. This includes the use of circuit breakers, fuses, relays, and other protective devices. These devices ensure that in case of any abnormal conditions, the electrical system can be quickly isolated to prevent further damage.

Furthermore, if applicable, data communication systems for monitoring and control purposes should be established onboard specific ship types, allowing real-time information exchange between the vessel and the shore.

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3.1.4 Load transfer

The synchronization procedure is crucial for the safe and efficient operation of shore equipment installation onboard cruise ships. It guarantees a reliable and uninterrupted power supply during port stays, enabling the ship to access the required electrical power from the shore while maintaining the necessary electrical stability and synchronization.

In this regard, the blackout option for load transferring is generally not preferred in shore equipment installation onboard ships due to several reasons:

- Safety: During a blackout, there is a complete loss of electrical power. This can create hazardous situations, especially in critical areas such as passenger cabins, restaurants, or medical facilities. Essential systems, such as lighting, ventilation, and emergency equipment, rely on continuous power to ensure the safety and well-being of passengers and crew members. A blackout can significantly compromise these safety measures.
- Passenger Comfort: Cruise ships are designed to provide a comfortable and enjoyable experience for passengers, for instance. A blackout would disrupt the functioning of various amenities, including air conditioning, entertainment systems, and kitchen equipment. This can lead to discomfort and dissatisfaction among passengers, potentially affecting the reputation of the cruise line.
- Operational Continuity: Ships operate on tight schedules and itineraries, with numerous activities and services running simultaneously. A blackout would disrupt the seamless functioning of onboard operations, including navigation systems, communication equipment, and hotel services. It could lead to delays, cancellations, and inconvenience for both passengers and crew.
- Redundancy and Reliability: Ships typically have redundant power systems to ensure a reliable and uninterrupted power supply. These systems often include multiple generators, backup batteries, and emergency power sources. By utilizing synchro or alternative load transferring methods, cruise ships can distribute the electrical load across different power sources, ensuring redundancy and reducing the risk of complete power failure.
- Regulatory Compliance: The maritime industry has specific regulations and guidelines to ensure the safety and operational standards of ships. These regulations often require redundancy in power systems and backup options for load transferring. Utilizing blackout as a load transferring option may not comply with these regulations, leading to potential legal and regulatory issues.

All circuit breakers in the MSB should be equipped with synchronization instruments, as already stated. These synchronization instruments play a crucial role in the process of synchronizing the ship's electrical system with the shore power supply.

The MSB, located in the ship's electrical room, is a vital component that distributes electrical power throughout the vessel. It houses various circuit breakers that control and protect different electrical circuits. The inclusion of synchronization instruments in each circuit breaker allows for precise coordination and synchronization during the load transferring process.

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The synchronization instruments in the circuit breakers enable the ship's electrical system to synchronize its voltage, frequency, and phase with the shore power supply. This synchronization is essential to ensure a seamless and stable transfer of electrical load between the ship and the shore. By aligning these electrical parameters, the transition between the ship's power generation and the shore power supply can occur smoothly, minimizing the risk of power disruptions or imbalances.

The synchronization instruments typically consist of monitoring and control devices that provide real-time information about the voltage, frequency, and phase of the ship's electrical system. These instruments allow for accurate adjustments and fine-tuning of the ship's power parameters to match those of the shore power supply. In the next section, the synchronization procedure of a cruise ship with the shore will be detailed. This procedure will outline the step-by-step process of establishing synchronization, ensuring that the ship's electrical system is properly aligned with the shore power supply before initiating load transfer.

3.1.5 Engineering Process Steps

Summarizing, before proceeding with the retrofit activities, a **detailed electrical system analysis** should be conducted to assess the vessel's existing power distribution infrastructure. This analysis will help identify any potential limitations or modifications required for the successful integration of the shore side equipment. The **selection of shore side electricity equipment** should be based on the vessel's power requirements and compatibility with the existing electrical system. The following recommendations should be considered:

- Voltage and Frequency: Ensure that the shore side equipment is designed to be compatible with the vessel's frequency (typically 60 Hz) and voltage
- Power Capacity: Determine the required power capacity based on the vessel's load profile and anticipated power demand during port stays. Select shore side equipment that can handle the maximum anticipated load.
- Protection Devices: Install appropriate protection devices, such as circuit breakers, fuses, and relays, to safeguard the shore side equipment and the vessel's electrical system from overloads, short circuits, and other electrical faults.

Certain **Electrical System Modifications** to the vessel's electrical system may be necessary to accommodate the shore side equipment. The following recommendations should be considered:

- Switchboard Upgrades: Evaluate the existing switchboard's capacity and consider upgrading it if required to handle the additional shore side equipment.
- Power Distribution: Determine the optimal power distribution configuration to ensure efficient integration of the shore side equipment with the vessel's electrical system. This may involve rearranging the distribution panels or adding new ones.
- Cable Routing and Sizing: Assess the existing cable routing and sizing to accommodate the shore side equipment's power requirements. Ensure that the cables are properly rated for voltage, current, and environmental conditions.

Once the retrofit activities are completed, thorough **commissioning and testing** should be conducted to verify the proper functioning of the shore side equipment. The following recommendations should be followed:

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- Pre-Commissioning Checks: Perform a series of pre-commissioning checks, including insulation resistance tests, continuity checks, and functionality tests, to ensure that all equipment and systems are ready for operation.
- System Integration Testing: Conduct comprehensive system integration testing to verify the seamless integration of the shore side equipment with the vessel's electrical system. This includes testing the shore-to-ship power transfer, load sharing, and synchronization functions.
- Performance Evaluation: Monitor and evaluate the performance of the shore side equipment during normal operation and under varying load conditions. This will help identify any operational issues or inefficiencies that need to be addressed.

Proper **documentation and training** are essential for the successful operation and maintenance of the shore side equipment. The following recommendations should be considered:

- As-Built Documentation: Prepare accurate as-built documentation, including updated electrical schematics, equipment specifications, and operating manuals, reflecting the retrofit activities and changes made to the vessel's electrical system.
- Training Programs: Develop comprehensive training programs for the vessel's crew members and maintenance personnel, covering the operation, troubleshooting, and maintenance procedures specific to the shore side equipment.
- Emergency Response Planning: Incorporate the shore side equipment into the vessel's emergency response plans and conduct drills to ensure that the crew is prepared to handle any contingencies or electrical emergencies related to the retrofit activities.

Safety Considerations should be a top priority during the retrofit process. The following recommendations should be followed:

- Hazard Analysis: Conduct a comprehensive hazard analysis to identify potential risks associated with the retrofit activities. Mitigation measures should be implemented accordingly.
- Personnel Safety: Provide appropriate personal protective equipment (PPE) for personnel involved in the retrofit process. Ensure that all personnel are adequately trained and aware of the safety procedures and protocols.
- Lockout/Tagout Procedures: Develop and implement lockout/tagout procedures to safely isolate and de-energize the relevant electrical systems during the retrofit activities.

By following the process outlined above the retrofitting of shore side electricity equipment onboard vessels can be carried out safely and effectively. Adhering to the IEC 80005 standards and considering the specific requirements of the vessel's electrical system will help ensure a successful integration of the SSE equipment, enabling efficient and reliable power supply during port stays.

In conclusion, addressing SSE considerations for the five case study vessels requires careful evaluation of cable sizing, receiving point positions and types, data communication systems, voltage requirements, and circuit breaker capacities. Accurate assessment of the power requirements and thorough coordination with port authorities, the marine and the electrical engineers are crucial to ensure efficient SSE integration and reliable power supply while the vessels are at port.

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3.2 Case study A – Cruise Ship

In this section the engineering and interoperability with the port assessment of the installation of a SSE supply system onboard a 140,000 GT Cruise Ship is performed.

3.2.1 Initial Assessment

The existing principal data of the Cruise vessel that is used as a case study are shown in Table 14 below. In the same table the total number and electrical characteristics of diesel generators installed onboard and the power requirements of the vessel, as states in the ELA, are described. This vessel has five (5) generators installed with a total installed electrical capacity of 56.25 MW. Cruise ships have a significant demand for various energy sources, including electricity, heating, and cooling, during their time in port. These energy requirements are essential to power the ship's systems, maintain passenger comfort, and support onboard operations. The maximum loads, while at port, are calculated for the summer condition.

It's important to note that the specific configuration and layout of the electrical system may vary depending on the ship's design and requirements. The single line diagram in Figure 49 provides an overview of the main electrical components and their connections, allowing for a clear understanding of the power distribution system on the cruise ship. The specific vessel's power single line diagram is shown above. The vessel is operating at a high nominal voltage of 11KV at 60 Hz frequency.

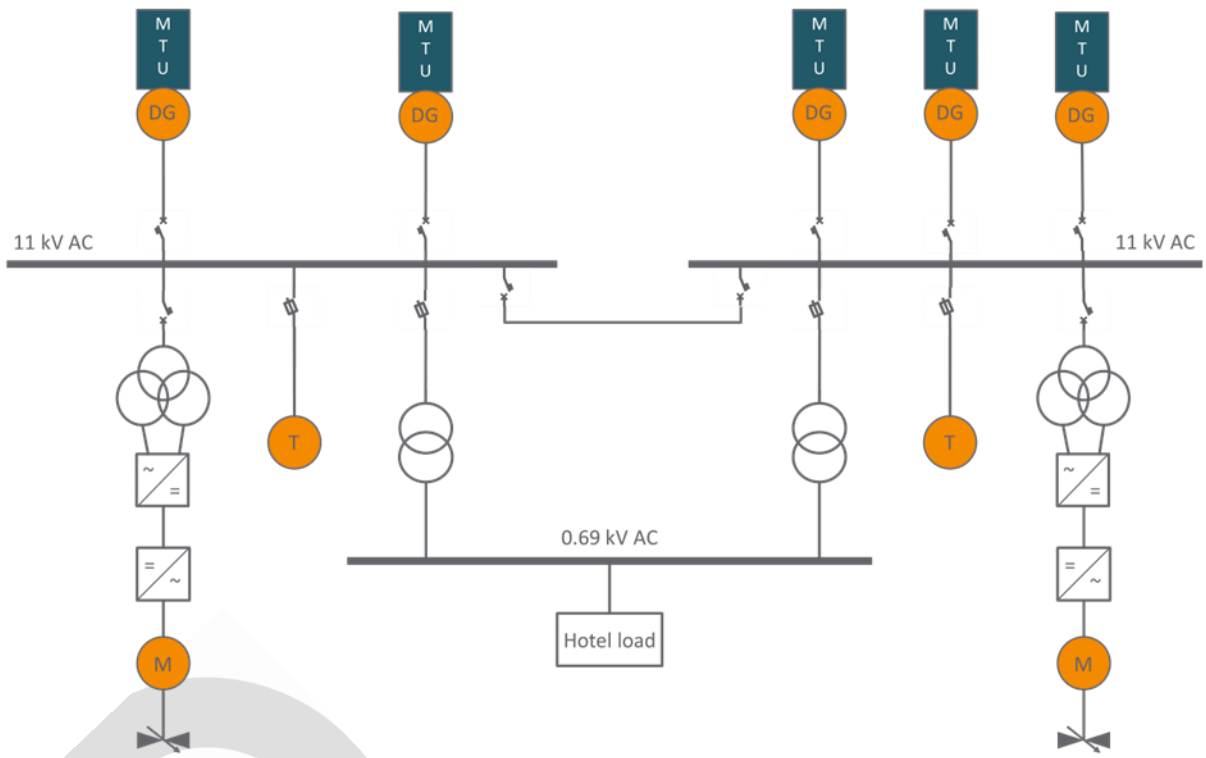

Figure 49 - Single line diagram before SSE installation

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Table 14: Main data of Case study A – Cruise ship

Ship Data		
Length overall	294	m
Length BP	278	m
Breadth	44	m
Depth	11.7	m
Draft (summer)	8.5	m
Deadweight	9500	tons
Gross Tonnage	140.000	m3
Passenger/Crew carrying capacity	3215 Passengers 1500 Crew	
Installed equipment onboard		
Cargo cranes	N/A	
Ballast water treatment system (BWTS)	Yes	
Exhaust Gas Cleaning System (EGCS)	Yes	
Installed electrical power		
Generators	3 sets x 9350 KW 2 sets x 14100 KW	
Frequency (Hz)	60	
Nominal Voltage (V)	11KV	
Maximum Electrical power used when at port – Electric Load Analysis data		
Generator used	Main Diesel Generators	
Condition	Summer Condition	Winter Condition
D/Gs running	1	1
Total load (kW)	9950	8300

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The ship's deck plans are organized and labelled according to the arrangement shown in Figure 50. Each deck is assigned a specific designation based on its purpose and location within the ship's structure. In this arrangement, there are two key decks mentioned: Deck B and Deck A.

Deck B is the deck that houses the ship's two main electrical power stations. These power stations serve as the primary sources of electrical power for the entire ship. They contain essential equipment and machinery responsible for generating and distributing electricity throughout the vessel. It also accommodates the two MSBs, which control the distribution of electrical power to various systems and areas on the ship.

Deck A is the designated deck where the SSE equipment should be installed. This deck is located above the waterline.

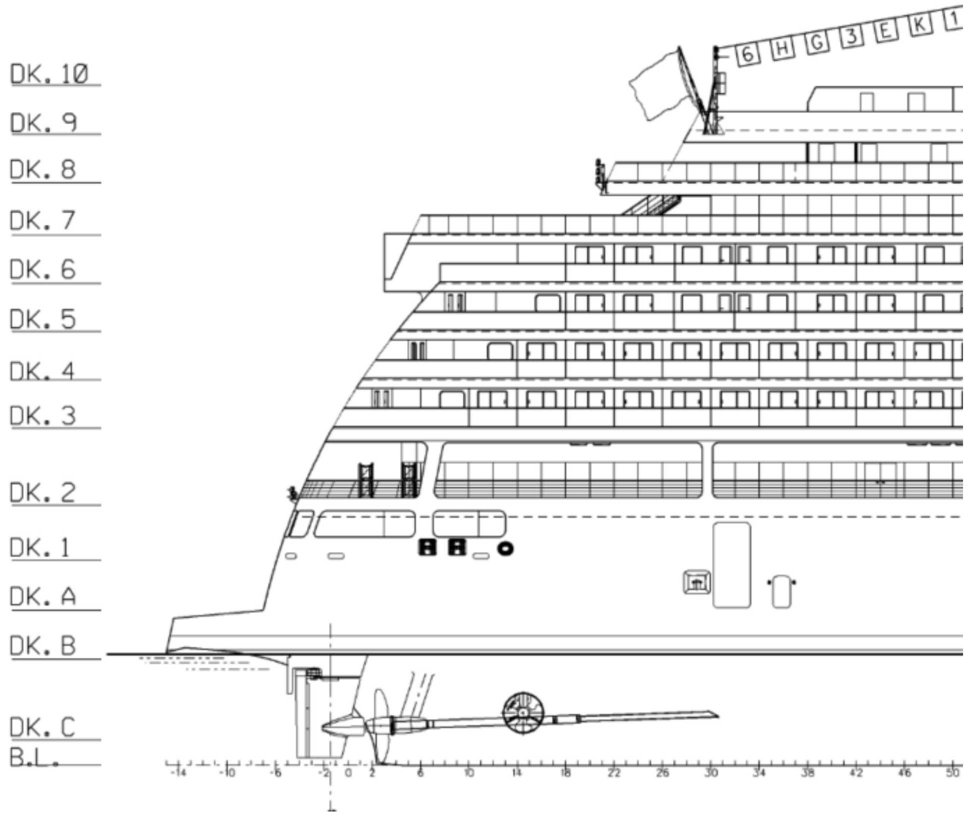

Figure 50: External view of the Cruise Ship highlighting the Decks' numbering

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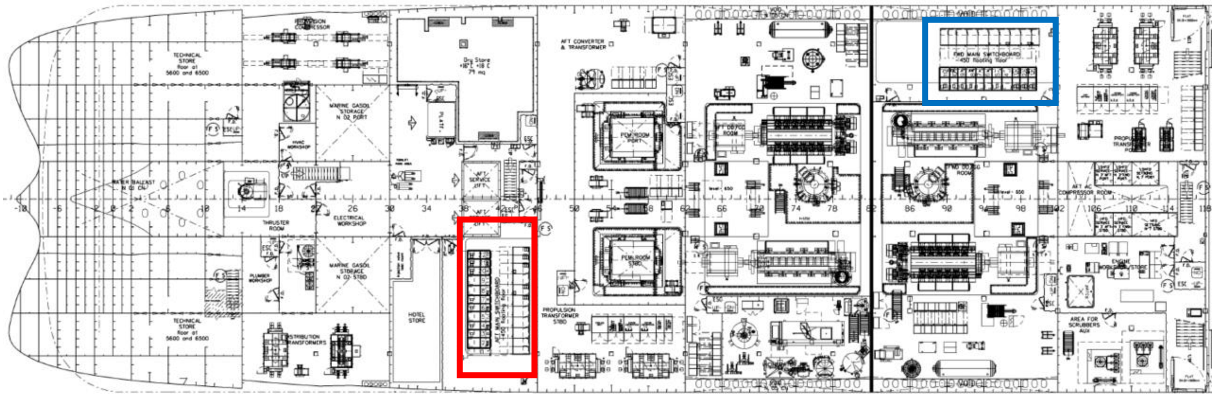

Figure 51: Plan view of the Deck B of the cruise ship, showing the location of the two MSBs (aft in red, fore in blue)

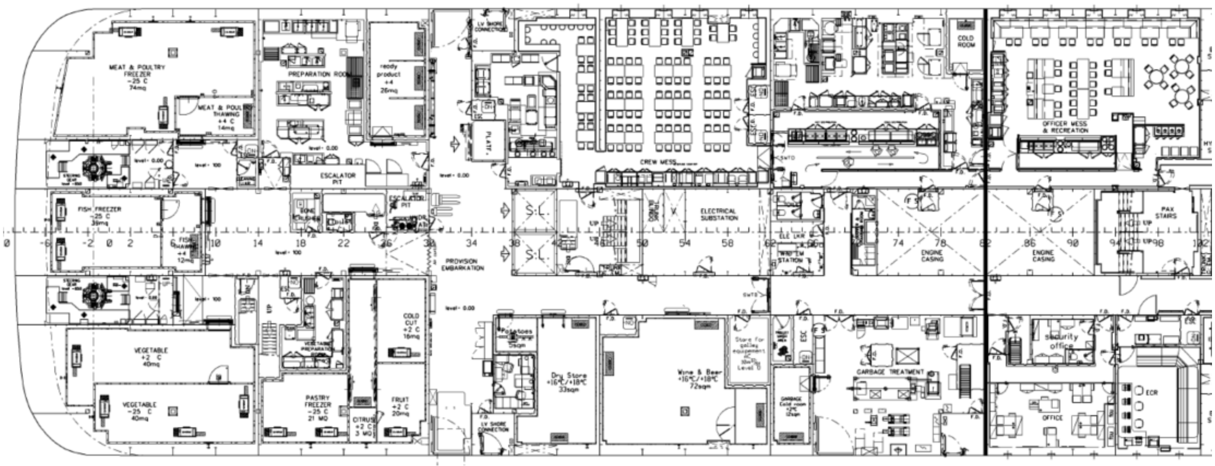

Figure 52: Plan view of the Deck A of the cruise ship, highlighting the same area as per Deck B

3.2.2 Preliminary Analysis

The table below is presenting the requirements that the standard states for the HVSC for cruise ships compared to the case study cruise ship's electrical energy needs. The main data of the Cruise ship are shown in the table below. For the Cruise ship case study, IEC/IEEE 80005-1 is applicable since it requires more than 1MVA of power to be provided by the shore side. Additional requirements for Cruise ships are also applicable.

Table 15: Summary of HVSC requirements for cruise ships and corresponding Cruise ship Case Study condition

Shore Side - HVSC		Ship Side - HV		
Max Power provided	up to 20 MVA	**Max Power required (kVA)**	**Summer**	12437,5
			Winter	10375
Voltage provided	11000 VAC	**Voltage required**		11000 VAC

For the refitting of the cruise ship in the given case study, it will be necessary to find space onboard for the following components, as stated in the previous subchapter:

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- Shore Connection Switchboard (Figure 53): A Shore Connection Switchboard, which includes one circuit breaker and the necessary outlets for the shore power cables, will need to be installed. This panel is responsible for managing the connection to the shore and providing a safe and reliable interface for the shore power cables. To ensure the compatibility and interoperability between the vessel and the visited ports, the connection equipment (receiving point) should be designed as follows:
  - ✓ Cruise ships shall utilize four (4) power 3-phase connectors, each rated 500 A and one neutral single pole connector rated 250 A, according to the Annex C of the applicable IEC/IEEE 80005-1.
  - ✓ General arrangement of ship plug and shore socket-outlet shall be in accordance with IEC 62613-2:2016, Annex G - 12 kV 500 A three-phase accessories with two pilot contacts. The neutral connector and inlet shall be in accordance with IEC 62613-2:2016, Annex H - 7,2 kV 250 A single-pole (neutral) accessories.
  - ✓ The power rating of the ship plug and shore socket-outlet to be 20MVA, which is the maximum stated rate for the cruise ships as per IEC standard.
- Cable Connection: An appropriate cable connection between the circuit breaker in the main switchboard room and Shore Connection Switchboard needs to be prepared. This will involve selecting and installing suitable cables to establish the electrical connection between these two panels.
- Additional Vacuum Circuit Breaker cubicle in the Main Switchboard: To accommodate the shore connection equipment, an additional circuit breaker will need to be installed in the main switchboard room. This circuit breaker will act as a dedicated protection device for the shore power connection.

The onboard SSE equipment for the cruise ship has been sized at 16,5 MVA as detailed discussed in the next subchapter. This sizing takes into consideration the estimated power requirements of the ship's electrical systems, equipment, and services while connected to shore power. It provides more than 30% extra power capacity compared to its maximum required. The decision to size the SSE system with extra capacity ensures that there is room for future electrical installations on board the cruise ship. This allows for potential expansions, upgrades, or additions to the ship's electrical systems as required in the future. By providing this flexibility, the ship can accommodate new technologies, increased power demands, or additional electrical equipment that may be necessary as the ship undergoes modifications or improvements over time.

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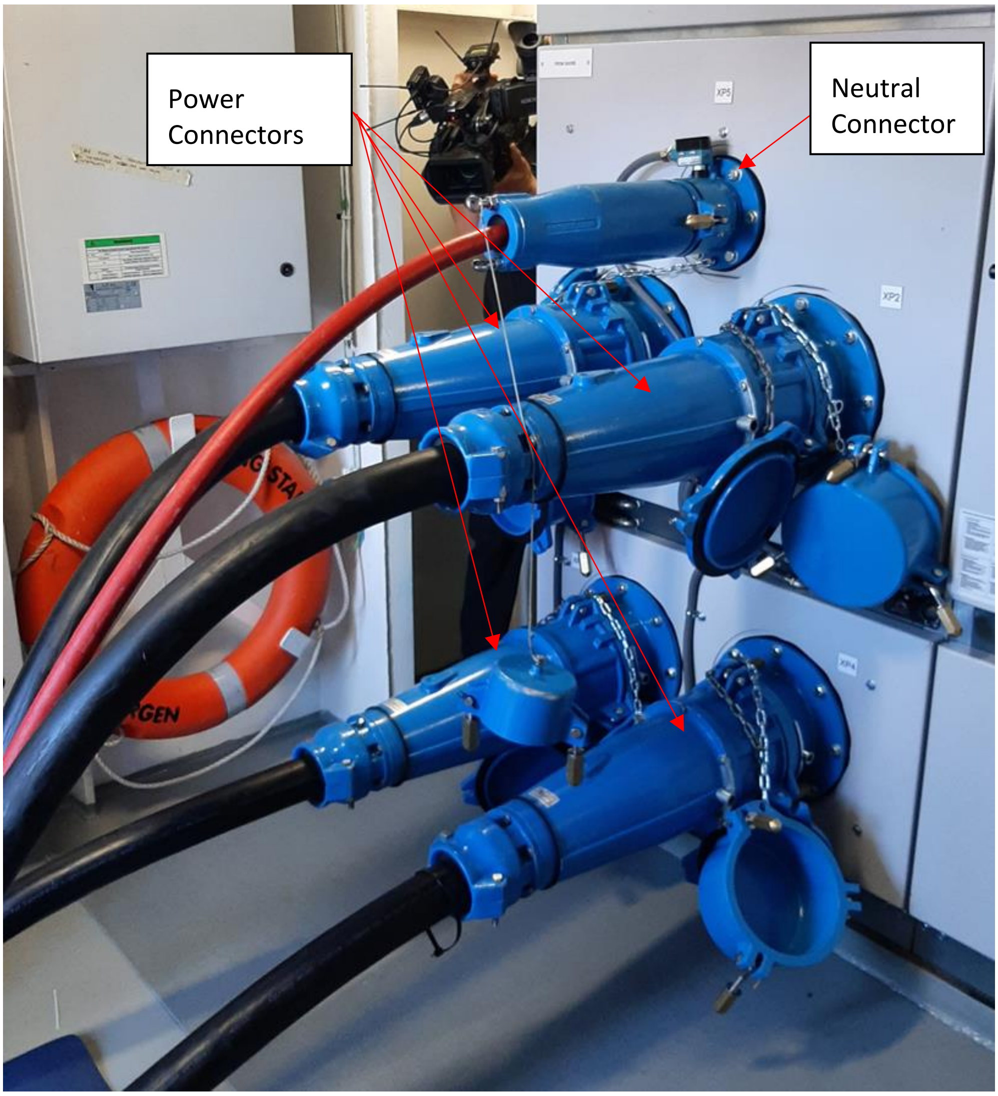

Figure 53: Cables connected to the onboard Shore Connection Switchboard

Another consideration is the physical positioning of the equipment onboard. The interconnection of a cruise ship to a shore connection can face several challenges. Here are some of the major impediments involved:

- Mooring Equipment Clearance: Cruise ships are equipped with various mooring equipment, such as bollards, cleats, and fairleads, which are used to secure the ship to the dock. This equipment may obstruct the path or interfere with the installation of the shore connection equipment.
- Retrofitting Challenges: Retrofitting existing cruise ships with shore connection capabilities can be more challenging compared to integrating them into new ship designs. Retrofitting may require modifications to the ship's electrical systems, structural changes, and additional equipment installation. These modifications should be carefully planned and executed to ensure compatibility, safety, and compliance with relevant regulations.

Addressing these impediments requires coordination and collaboration between the cruise ship operators, port authorities, electrical engineers, marine engineers, and other stakeholders involved. Thorough planning, feasibility studies, and proper engineering expertise are essential to overcome these challenges and establish effective shore connections for cruise ships.

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3.2.3 Vessels' Drawings update

Space must be found onboard for the following components, as shown in the figure below:

1. Vessel Entry Point
2. Shore Connection Switchboard
3. Cable Connection
4. Additional Circuit Breaker cubicle in Main Switchboard Room

The single-line diagram in Figure 54 illustrates the electrical connections and components within the ship's system. The SSE equipment is depicted as an additional connection point on the diagram, indicating its integration into the existing electrical infrastructure (highlighted in red).

This allows the ship to draw electrical power from the shore instead of relying solely on its onboard generators, reducing emissions and operating costs during periods of stationary operation.

By referencing Figure 54, one can understand the specific configuration and electrical pathways involved in connecting the shore power supply to the main switchboard, ensuring a comprehensive understanding of the ship's electrical infrastructure.

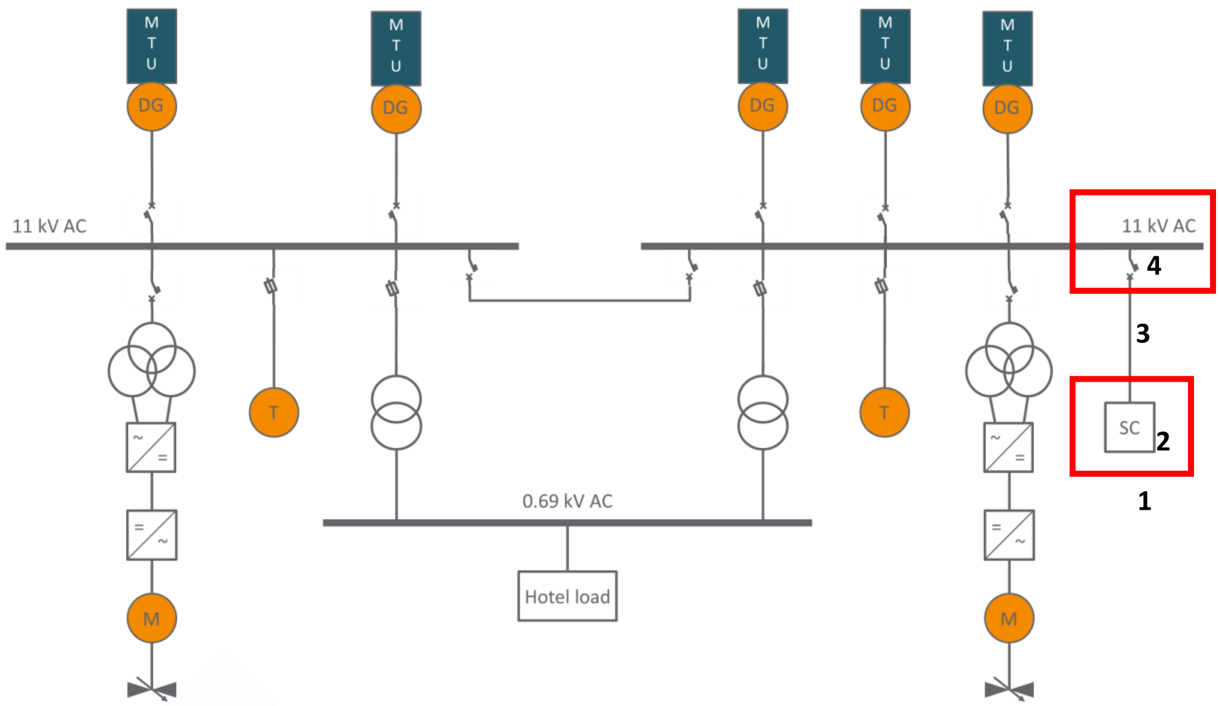

Figure 54: Single line diagram after SSE installation

In Table 16 are resumed the new equipment main data presenting the Shore Connection Switchboard main data and the data related to the new cubicle to be installed in the MSB room.

Table 16: SSE main data for a cruise vessel

Power Characteristics		
Power rating	16500	kVA
Rated Voltage	11	kV
Rated Current	866	A
Shore Connection Switchboard (SCS) main dimensions		
SC cubicle dimension (H x W x D)	2200 x 1600 x 1720	mm
SC cubicle weight	2700	kg
Additional Circuit Breaker cubicle in MSB main dimensions		
MSB cubicle dimension (H x W x D)	2855 x 800 x 2000	mm
MSB cubicle weight	1500	kg

Regarding the general arrangement update, the space for the Vessel Entry Point and the Shore Connection Switchboard room has been identified on Deck A, as highlighted in Figure 55 and Figure 56, for the following reasons:

- there was already a room available for a low voltage shore connection
- the adjacent rooms were either sacrificial or could be reallocated.

The decision to locate the shore connection room on Deck A was driven by several factors. Firstly, it was crucial for the shore connection room to be situated adjacent to the ship's sides to minimize the distances of the connection cables from berth. This positioning facilitates a more efficient and direct connection between the ship and the shore power source.

Furthermore, the selected room on Deck A was found to be directly above the aft MSB. This proximity ensures convenience in terms of cable routing and connection between the shore connection room and the ship's main electrical distribution system.

In terms of space availability, the decision to utilize Deck A was made because there was already a room present for a low voltage shore connection. This existing room could be repurposed or upgraded to accommodate the requirements of the shore connection system. Additionally, the adjacent rooms on Deck A were either deemed sacrificial (not essential for the shore connection system) or could be reallocated to create sufficient space for the shore connection room.

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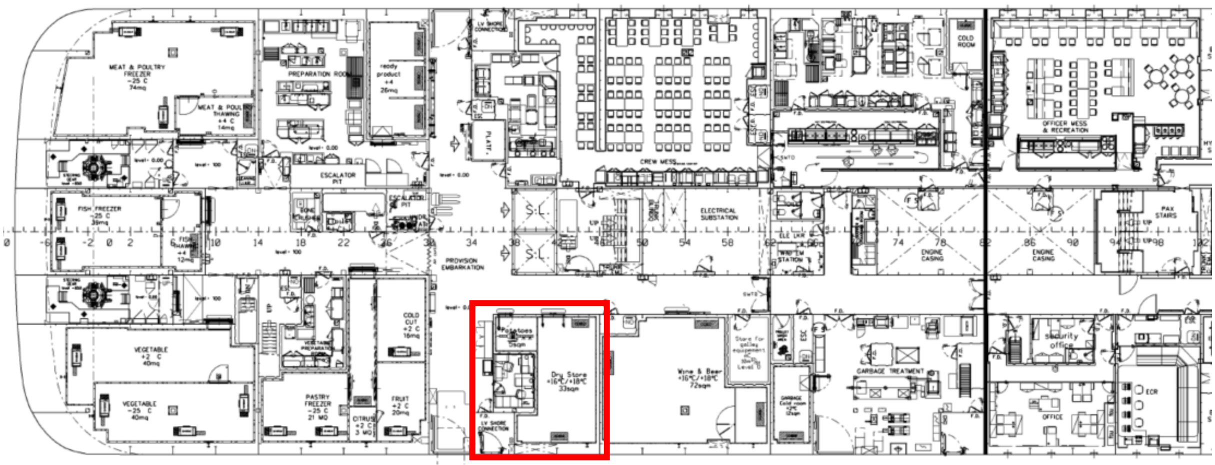

Figure 55: Plan view of the Deck A of the cruise ship, showing the location of the space to be refitted for SSE equipment installation

Figure 56: Outside view of the Cruise Case study vessel highlighting SSE cables entrance

In addition, an adjacent boarding bridge was available to facilitate the installation of the necessary equipment, as highlighted in Figure 57. The presence of an adjacent boarding bridge proved advantageous in the selection of the location for the shore connection room on Deck A. The boarding bridge provides a convenient access point for bringing in and installing the required equipment for the shore connection system.

The availability of the adjacent boarding bridge not only simplifies the logistical aspects but also contributes to the overall effectiveness and feasibility of establishing the shore connection system on Deck A. It facilitates the smooth integration of the necessary equipment, ensuring a well-coordinated and efficient installation process.

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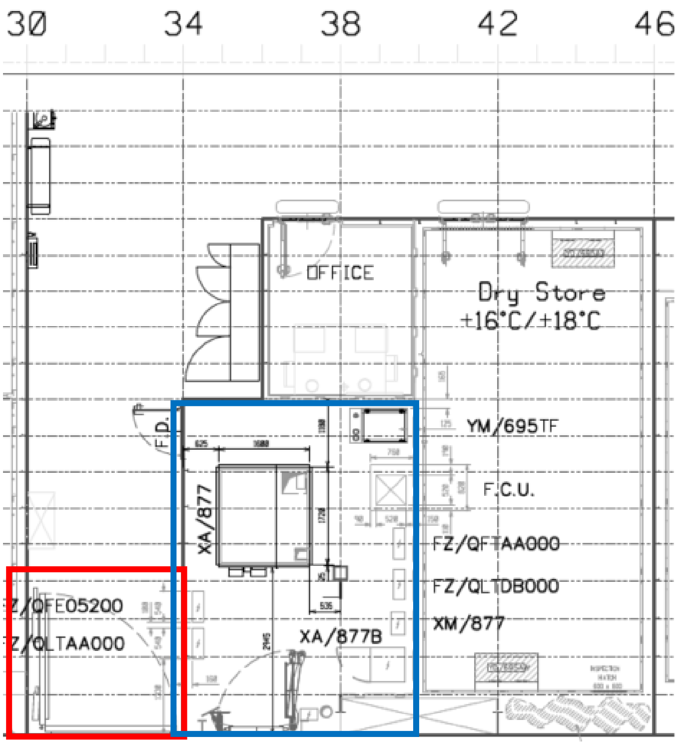

Figure 57: Plan view of the Deck A of the cruise ship, highlighting the boarding bridge (in red) and the new Shore Connection equipment room (in blue)

To facilitate the connection and removal of the cables on board, a suitably sized tool must be provided to support the cables on board the ship. The same must be equipped with a manual winch to allow you to adjust the height of the tool. The system will have to be equipped of suitable lift equipment in order to allow to the technicians to fix it to the ship and to facilitate of the handling (in Figure 58 an example).

In addition, at the entrance to the door of the local shore-connection board, it has to be provided a roller of support of the cables to prevent the friction between the sheath of the cables themselves and the mast of the hatch leads to early wear of the cable.

Moreover, there are two so-called tension bars (yellow/black) depicted in Figure 58, which provide two mechanical safety thresholds. These thresholds allow for the de-energization of the shore connection switchboard in the event of cable breakage due to severe weather conditions or mishandling during connection operations. They are designed to detect excessive tension or pulling forces on the cables that are part of the SSE equipment. This feature triggers the disconnection of the shore connection switchboard, effectively cutting off the electrical supply from the onshore source. By doing so, potential hazards and risks associated with damaged or compromised cables are mitigated, ensuring the safety of the ship and its electrical system.

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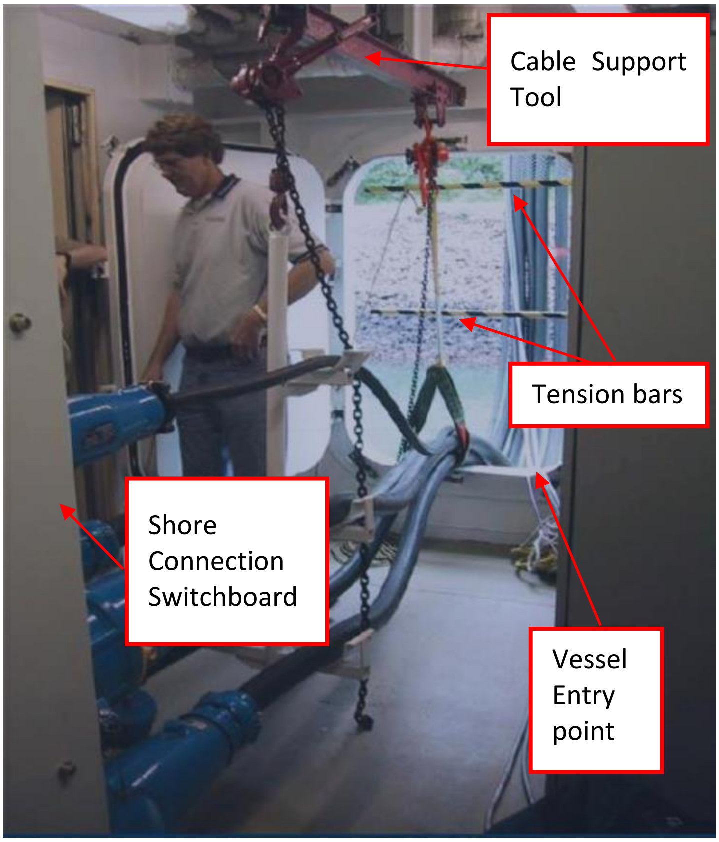

Figure 58: Additional tool for shore cables on board

Figure 59 displays the wiring diagram of the specific components involved in the new onboard system, focusing on the shore connection equipment. In detail:

- ACB "A" represents the circuit breaker related to the existing genset onboard
- ACB "B" represents the circuit breaker related to the additional cubicle installed in the MSB room (Figure 60)
- ACB "C" represents the circuit breaker related to the new shore connection cubicle (Figure 53)

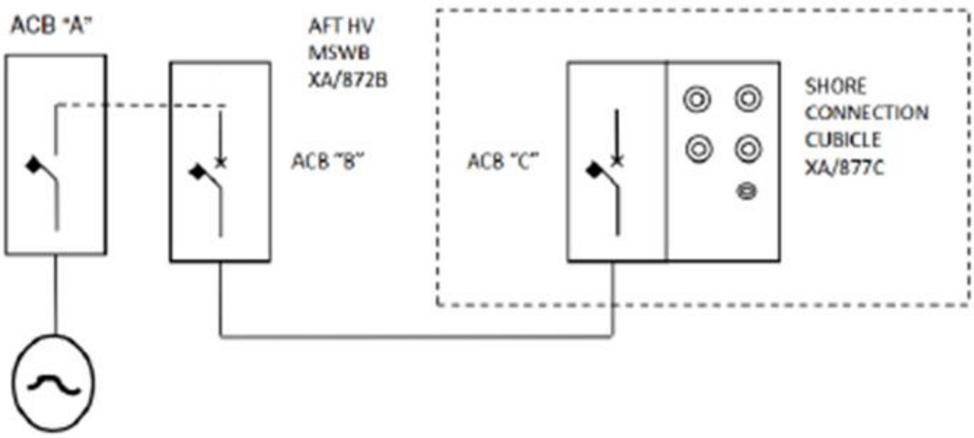

Figure 59: Detail for the Shore Connection equipment for a cruise ship

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In addition, Figure 60 illustrates the installation of the Shore connection cubicle containing the circuit breaker ACB "B". This cubicle is specifically located in the in the aft MSB room, as highlighted in red in the previous Figure 51.

Figure 60: Additional circuit breaker (ACB "B") installed in the MSB room

There is a need of 6 single core cables to connect the two cubicles with a cross section of 240 mm2 with an insulation rated capable to withstand the required 11 kV, as detailed in Table 17. This is the item 3, as shown in Figure 54.

Table 17: Cruise ship additional cables data

Cables connecting SCS and Additional Circuit Breaker cubicle in the MSB		
Power rating	16500	kVA
Voltage	11000	V
Current	866	A
Cable selection	6 cables X (1 x 240)	mm2
Total cables weight	23100	kg/km

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- Power Rating: This refers to the power capacity or rating of the cables. It indicates the total maximum amount of power that the cables can safely transmit without exceeding their designed limits.
- Voltage: This specifies the rated voltage level of the cables. It represents the voltage at which the cables are designed to operate.
- Current: This indicates the current capacity or rating of the cables in parallel. It represents the maximum current that the cables can carry without exceeding their designed limits.
- Cable Selection: This describes the specific type or model of cable selected. It provides information about the number of single core cables to be routed onboard. The number of cables selected is a multiple of 3, indicating that they are configured in a three-phase arrangement to accommodate the electrical power distribution requirements.
- Cable Weight: This denotes the total weight in kg/km of the cables. It is an important factor to consider for installation purposes and overall weight distribution on the vessel.

Finally, an important parameter is the load transferring process from the vessel's generators to the shore electrical network. The load transferring in cruise ships is performed with shore power transfer via parallel connection not blackout.

The synchronization procedure ensures a seamless integration and transfer of power from the shore connection to the ship's onboard electrical system. Here is a step-by-step description of the synchronization process where the power supply is transferred from ship Diesel Generator (DG) to HVSC with parallel changeover.

<u>Parallel Changeover from DG to HVSC</u>

HVSC panel is to be selected for the connection of ship's network to shore.

The earthing switch on the HV MSB and the earthing switch of the HVSCs must be open. This operation is interlocked with keys logics.

The HVSC informs the ship automation system (IAS) via a contact when it is ready; IAS has therefore the permission to start the connection sequence first by closing ACB C (shore connection panel) and then ACB B (HV MSB shore connection incoming) by means of automatic synchronizing device.

Thus, the sequence consists in:

- the IAS verifies that only one diesel generator is connected to the network and propulsion and thruster
- systems are interlocked and OFF;
- the IAS inhibits the start of another diesel generator;
- the IAS closes the ACB "C";
- the IAS gives a ship-to-shore sequence start command to the automatic synchronizing relay;
- the automatic synchronizing relay synchronizes frequency and voltage of the DG with the HVSC through
- the interfaces with the DG electronic governor (increase/decrease speed) and Automatic Voltage Regulator (AVR) (increase/decrease voltage);
- when the two networks are synchronized, the automatic synchronizer gives the command to close the ACB "B";

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- the automatic synchronizer unloads the DG active power acting on the DG electronic governor (increase/decrease speed commands); in the meantime, the automatic synchronizer acts on the AVR (through the increase/decrease voltage) in order to keep a constant power factor;
- when an active power threshold is reached, the automatic synchronizer gives an open command to the ACB "A" of the diesel generator.

3.2.4 Technical Recommendations for Cruise ships

Cruise ships typically rely on their own onboard systems, such as boilers, chillers, and air conditioning units, to meet their thermal load demands. These systems are designed to handle the large-scale heating and cooling requirements specific to the ship's infrastructure, passenger accommodations, and operational needs.

While shore-side electricity (SSE) is commonly used to provide electrical power to ships while they are docked, it is often insufficient to meet the high thermal load requirements of cruise ships. The thermal load refers to the energy needed for heating, cooling, and other temperature control functions on board. The main data regarding the electric and thermal loads during port stay are depicted in Table 15.

The SSE infrastructure at ports is designed to supply electricity. While it can provide the required energy for lighting, appliances, and other onboard functions, it is not feasible to use SSE as a source of energy to cover the significant thermal requirements.

The major risk is that cruise ships will continue to rely on their own onboard thermal systems (ie oil fired boilers), which often include the use of fossil fuels like diesel or liquefied natural gas (LNG) to generate heat and power the ship's energy-intensive processes. Efforts are being made to explore alternative energy sources and technologies, such as hybrid power systems, to reduce the environmental impact of cruise ship operations while meeting their thermal load requirements.

Table 18: Cruise ship main data

Cruise Ship main data	units	
VS	knots	20,5
Hotel load (port - summer)	kW	9950
Hotel load (port - winter)	kW	8300
Required steam heat (port)	kW	3039
Required HT heat (port)	kW	3728
Navigation hours per day	h	16,2
Port hours per day	h	7,8

Another issue that exacerbates the high thermal energy requirement of cruise ships, is the fact that no energy will be recovered from the Diesel Generators' operation while at port. Waste heat recovery is a way to improve the performance of both existing and new ships by avoiding waste of valuable heat. Waste Heat Recovery (WHR) systems have long been applied on ships. Having the ship's generators

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turned off while at port, changes the vessel's profile of energy use when at port, having large effects on waste heat quality and availability. Separate studies should be planned to examine the impact of the SSE and its effects on thermal energy availability, especially onboard cruise ships.

In summary, cruise ships rely on their onboard thermal systems, often powered by fossil fuels, to provide the necessary heating, cooling, and other temperature control functions, while docked. Due to the high thermal load demands of cruise ships, the sole used of SSE might be insufficient to meet the required energy loads during their stay in port.

3.3 Case study B – Ropax

In this section, a preliminary assessment of the SSE installation onboard a Ropax vessel will be conducted.

3.3.1 Initial Assessment

The existing condition of the Ropax vessel that is used as a case study is assessed as a first step. The main data of the Ropax vessel are shown in the table below. This vessel is designed to be used for both domestic voyages and short international voyages, however it is operating in domestic voyages.

This vessel has three (3) generators installed with a total installed electrical capacity of 3762 KW.

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Table 19: Main data of Case study B –Ropax

Ship Data		
Length overall	145.9	m
Length BP	133.5	m
Breadth	23.2	m
Depth	13.9	m
Draft (summer)	5.9	m
Deadweight	2700	tons
Gross Tonnage	18600	m3
Crew carrying capacity	87	
Passenger carrying capacity	2000	Domestic Voyages
	1282	Short International Voyages
Cargo carrying capacity	599 lane meters & 146 cars or 427 cars	
Installed equipment onboard		
Cargo cranes	N/A	
Ballast water treatment system (BWTS)	No	
Exhaust Gas Cleaning System (EGCS)	No	
Installed electrical power		
Main Diesel Generators	3 sets x 1254 KW	
Frequency (Hz)	50	
Nominal Voltage (V)	380	
Maximum Electrical power used when at port – Electric Load Analysis data		
Generator used	Main Diesel Generators	
Condition`	In Port Condition	Loading Condition
D/Gs running	2	3
Total load (kW)	973.6	1860.47

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The single line diagram shown below provides an overview of the main electrical components and their connection on the Ropax vessel. The vessel's operating high nominal voltage is 380V and the low nominal voltage is 115V. This vessel operates at a 50Hz frequency.

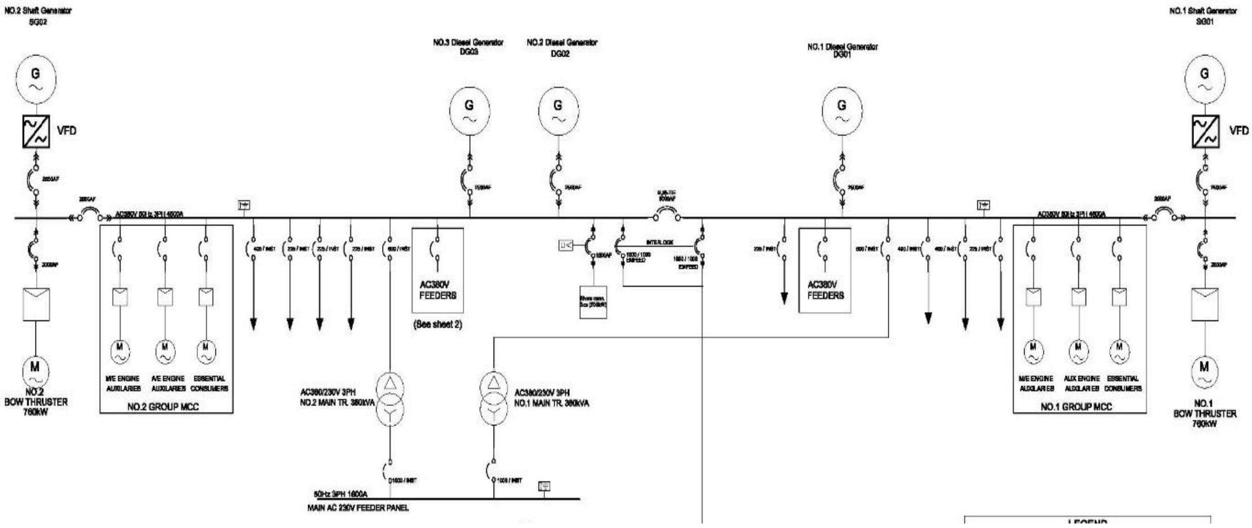

Figure 61: One line diagram of power of the Ropax case study vessel

On the figures below, sections of the General Arrangement plans were included for the applicable areas that SSE equipment could, potentially, be included. Ropax vessels typically perform aft side mooring to load and unload the passengers and the vehicles they carry via the stern doors, as shown in Figure 58. In Figure 60, the 2nd Deck of the vessel is shown. The MSB, where the SSE equipment will be finally connected to, is in this deck. The area that is considered to be the most appropriate for the installation of the receiving point is the aft side of the vessel.

However, this not always the case since there are Ropax ferries designed to load from the aft side and unload from the bow area, or vice versa. This is a case that needs to be further investigated.

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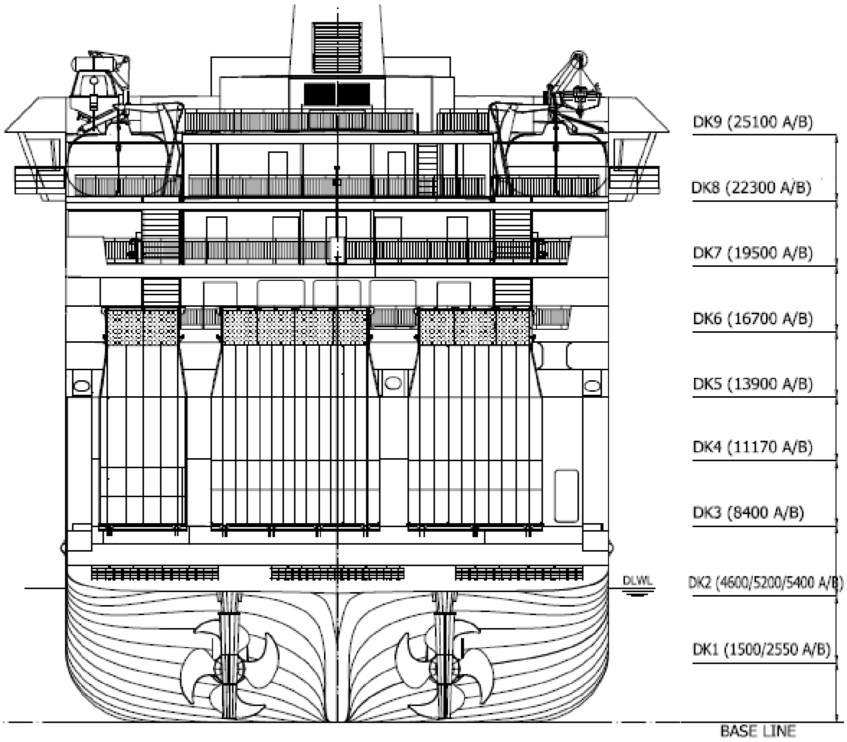

Figure 62: Stern view of the Ropax Case study vessel showing the ramps

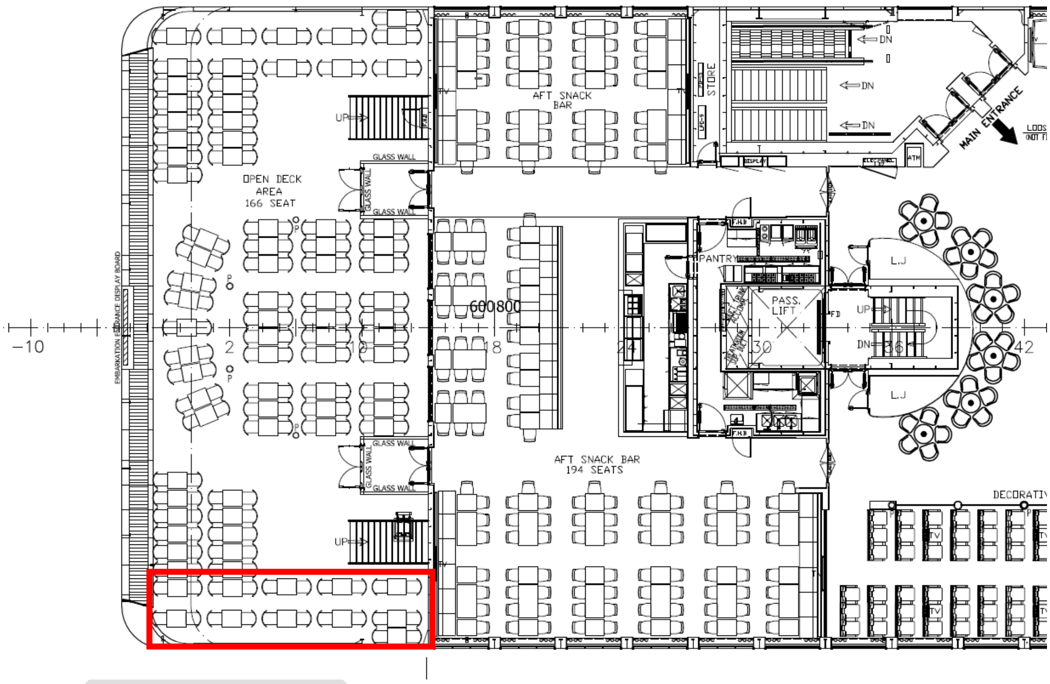

Figure 63: Plan view of the 6th deck, open deck with passenger seats

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3.3.2 Preliminary Analysis

For the Ropax Case study, IEC/IEEE 80005-1 is applicable, as well as additional requirements as described in the first section of this chapter. Table 20 is presenting the requirements that the standard states for the HVSC for Ropax ferries compared to the case study ship's electrical energy needs.

Table 20: Summary of HVSC requirements for Ropax vessels and corresponding Ropax Case Study condition

Shore Side - HVSC		**Ship Side - LV**		
Max Power provided	up to 6.5 MVA	**Max Power required (KVA)**	Loading	2325.0
			Port	1216.3
Voltage provided	6600 VAC- for regional transportation	**Voltage required**		380 VAC
	11000 VAC			

It is noted that the maximum loads during the loading condition, while at berth, are double the maximum loads during the port condition. It is considered that the sizing of the equipment installed should cover the maximum loads occurring while at berth. In this case the equipment installed should be dimensioned to handle a power rate of 2500 MVA. This value covers the ship maximum power need, and there is a commercially available size for a power transformer.

For the refitting of the Ropax in the given case study, it will be necessary to find space onboard for the following components:

- Shore Connection Switchboard: A Shore Connection Switchboard is responsible for managing the connection to the shore and providing a safe and reliable interface for the shore power cables. In this case, the cables from the shore will be directed towards an open space onboard, so no hull openings will be constructed. Figure 63 shows marked with red box a possible installation area. To ensure the compatibility and interoperability between the vessel and the visited ports, the connection equipment (receiving point) should be designed as follows:
  - ✓ Both the shore plug and ship socket-outlet shall be designed up to the maximum power demand of 6,5 MVA.
  - ✓ One cable shall be used, according to the Annex B of the applicable IEC/IEEE 80005-1, both at the shore side and at the ship side, up to the voltage transformer.
  - ✓ General arrangement of shore plug and ship socket-outlet shall be in accordance with IEC 62613-2:2016, Annex J - 12 kV 500 A three-phase accessories with seven pilot contacts.

  In case there is not enough space to install the SCS, a power pedestal should be used, in conjunction with a panel containing the Circuit Breaker.

- Cable Connection: An appropriate cable connection between the circuit breaker in the MSB and the Shore Connection Switchboard needs to be prepared. This will involve selecting and installing suitable cables to establish the electrical connection between these two panels.

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- Additional Circuit Breaker cubicle in the MSB rated for 380 VAC. This circuit breaker will act as a dedicated protection device for the shore power connection, and it should be equipped with dedicated synchronization means.

Based on the information provided, **a power transformer** is necessary to connect the ship's 380 Vac network with the port's infrastructure. It is important for the shipowner to carefully consider the requirements and specifications of the ports they plan to visit to select the appropriate LV/HV transformer for the refitting of the Ropax vessel, since some ports may provide 6.6 kV and others 11 kV according to the vessel's they aim to service.

Installing an HV/LV transformer allows for the conversion of the shore's HV network to the ship's 380 VAC network. The higher shore voltage is more suitable for long-distance transmission and offers benefits such as reduced power losses during distribution. By using an LV/HV transformer, the ship can tap into the port's power grid, ensuring compatibility and facilitating the power exchange between the ship and the shore.

When considering a RoPax ferry for shore connection, however, the challenges related to clearances and equipment size can arise. Here's a description focusing on those aspects:

- Mooring Equipment and Clearance: RoPax ferries, like cruise ships, have mooring equipment such as bollards, cleats, and fairleads. This equipment is necessary for securing the vessel during docking and can potentially obstruct the installation of shore connection equipment. Sufficient clearance should be ensured to accommodate both the mooring equipment and the shore connection infrastructure.
- Bow and Stern Configuration: RoPax ferries often have a specific bow and stern configuration designed for efficient loading and unloading of vehicles and passengers. The shape of the vessel's bow and stern can impact the placement and routing of shore connection equipment. Consideration should be given to ensure that the equipment does not interfere with the vessel's operational requirements.
- Ramp or Door Clearance: RoPax ferries typically have ramps or doors for vehicle and passenger access. These ramps or doors may require clearance for the installation of shore connection equipment. It is important to ensure that the equipment does not hinder the proper functioning of the ramps or doors during loading and unloading operations.
- Gangway Placement: RoPax ferries often use gangways for passenger access between the vessel and the shore. The placement and positioning of the shore connection equipment should be carefully planned to avoid obstructing the gangway or impeding the movement of passengers during embarkation and disembarkation.
- Deck Space Limitations: RoPax ferries have limited deck space, especially when accommodating vehicles and cargo. The available deck space needs to be carefully considered for the installation of shore connection equipment. Optimizing the equipment's footprint and positioning is crucial to make the most efficient use of the available space.
- Structural Considerations: The vessel's structural design and strength should be taken into account when installing shore connection equipment. The equipment's weight and any modifications required to the vessel's structure should be carefully evaluated to ensure they do not compromise the vessel's integrity or stability.

Ensuring proper clearances and addressing space limitations on RoPax ferries require close collaboration between vessel designers, port authorities, and engineering teams. Detailed analysis, including 3D modelling and simulations, can aid in determining the optimal placement and routing of the shore connection equipment to minimize conflicts with existing infrastructure and operational requirements of the vessel.

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In the following paragraphs, both the new arrangement and structural modification, as well as the vessel's drawing will be presented.

3.3.3 Vessels' Drawings update

As discussed in the previous chapter, it will be necessary to find space onboard for the following components:

1. Shore Connection Switchboard
2. HV cables up to transformer
3. Power Transformer, located in the ER, as close as possible to the ECR
4. LV cables up to Additional Circuit Breaker cubicle
5. Additional Circuit Breaker cubicle in the MSB room

Regarding the electrical drawings update, the single-line diagram in Figure 64 and Figure 65 illustrates the electrical connections and components within the ship's system. The SSE equipment is depicted as an additional connection point on the diagram, indicating its integration into the existing electrical infrastructure (highlighted in blue in Figure 64).

This allows the ship to draw electrical power from the shore instead of relying solely on its onboard generators, reducing emissions and operating costs during periods of stationary operation.

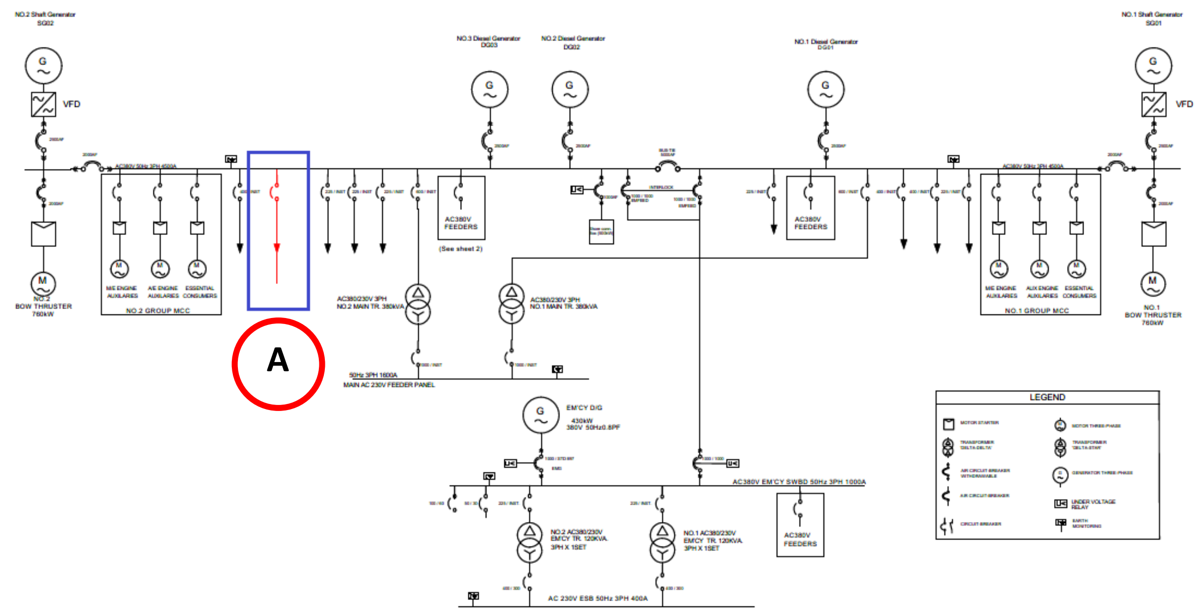

Figure 64: One line diagram of power of the Ropax case study vessel after SSE installation (highlighted in blue)

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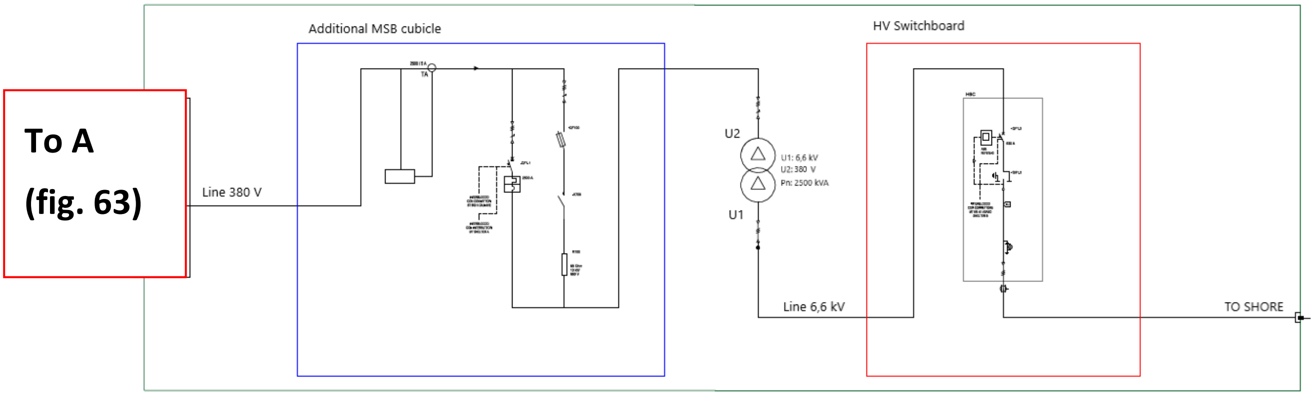

Figure 65 – LV to HV connection scheme for SSE equipment using 2,5 MVA transformer with 6,6 kV output

In Table 21 and in Table 22 are resumed the new equipment main data presenting the Shore Connection Switchboard main data and the data related to the new cubicle to be installed in the MSB room.

Table 21: SSE main data for a ropax focusing on SC cubicle equipment

SSE equipment data - SC cubicle equipment		
Power rating	6500	kVA
Rated Voltage	6600	V
Rated Current	220	A
SC cubicle dimension (H x W x D)	2200 x 1600 x 1720	mm
SC cubicle weight	2700	kg

Table 22: SSE main data for a ropax focusing on MSB equipment

SSE equipment data - MSB equipment		
Power rating	2500	kVA
Rated Voltage	380	V
Rated Current	3800	A
SC cubicle dimension (H x W x D)	Width: 800 Height and Depth depend on the existing MSB layout	mm
SC cubicle weight	1500	kg

For a Ropax vessel, a 2500 kVA transformer has been chosen due to the availability as a COTS component by the majority of transformers supplier. Indeed, the next transformer power rating would be 3150 kVA which seems to be not reasonable for the application.

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However, detailed analysis is required to validate the accuracy of the 2500 kVA power transformer size.

Table 23: Ropax additional transformer data

Transformer data		
Power rating	2500	kVA
Weight	4790	kg
Length	2110	mm
Width	1300	mm
Height	2325	mm

Finally, Table 24 contains the following main data for the selected cables in both the LV and HV sections:

- Power Rating: This refers to the power capacity or rating of the cables. It indicates the maximum amount of power that the cables can safely transmit without exceeding their designed limits.
- Voltage (LV and HV): This specifies the voltage level on each side of the cables. It represents the voltage at which the cables are designed to operate.
- Current (LV and HV): This indicates the current capacity or rating of the cables in parallel on each side. It represents the maximum current that the cables can carry without exceeding their designed limits.
- Cable Selection (LV and HV): This describes the specific type or model of cable selected for the LV side. It provides information about the number of single core cables to be routed onboard. The number of cables selected is a multiple of 3, indicating that they are configured in a three-phase arrangement to accommodate the electrical power distribution requirements.
- Cable Weight (LV and HV): This denotes the total weight in kg/km of the cables used for each side. It is an important factor to consider for installation purposes and overall weight distribution on the vessel.

These data points provide crucial information for understanding the capabilities and characteristics of the selected cables on both the LV and HV sides, enabling proper selection, installation, and performance evaluation for the refitting of the ropax vessel.

Table 24: Ropax additional cables data

Cable data			
Power rating	**2500**		**kVA**
Item	**HV side (before the Transformer)**	**LV side (after the Transformer)**	**Unit**
Voltage	6600	380	V
Current	220	3800	A
Cable selection	3* (1 x 95)	24 *(1 x 240)	mm2
Cables weight	5775	92400	kg/km

3.3.4 Technical Recommendations for Ropax Ferries

Ropax ships, like cruise ships, typically have onboard systems and infrastructure that require hot water production for various utilities while they are in port. These utilities may include heating for passenger

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accommodations, kitchens, and other areas, as well as hot water supply for showers, sinks, and other facilities. While specific data regarding the thermal load requirements of ropax ships is not provided, it can be inferred that they would have similar needs to cruise ships in terms of heating and hot water production.

In the context of implementing alternative energy sources or technologies on board ropax ships, one of the significant challenges is finding suitable space particularly on the aft side of the vessel, for new equipment, such as SC cubicles and transformers. The aft side of a ship is often already occupied by various essential systems and infrastructure. Due to the limited available space on the aft side, finding suitable locations to install additional equipment can be challenging to identify areas that provide sufficient room, accessibility for maintenance, and proper ventilation for heat dissipation.

The installation of new equipment, especially if it requires significant modifications or the allocation of a substantial physical footprint, can disrupt the existing layout and functionality of the aft section. It may be necessary to reconfigure or rearrange other systems or components to accommodate the new equipment, which can be a complex and time-consuming process. Ships, including ropax vessels, have limited space available for additional equipment due to their design and operational requirements and detailed configuration should be carried out in a case-by-case consideration.

In the context of the Ropax ship case study, the LV power cables that connect the MSB to the power transformer play a crucial role in the electrical power distribution system. The distance between the MSB and the power transformer is a critical factor that can have a significant impact on the performance and efficiency of the electrical system. Ideally, the power transformer should be installed as close as possible to the MSB, thus minimizing the length of the LV power cables. There are a few key reasons for this:

- Voltage Drop: LV power cables have a certain amount of resistance, and when current flows through them, a voltage drop occurs. The longer the cable length, the higher the resistance and subsequently the greater the voltage drop. By keeping the distance between the MSB and the power transformer minimal, the voltage drop in the cables is reduced. This is important because excessive voltage drop can lead to a decrease in voltage levels, potentially affecting the performance and reliability of connected equipment.
- Power Loss: Voltage drop in the cables also results in power loss. By positioning the power transformer closer to the MSB, the power loss in the LV cables is minimized, improving the overall efficiency of the electrical system.
- Acquisition and installation costs: Minimizing the length of expensive larger power cables from the Transformer to the MSB results in lower costs.

By installing the power transformer as close as possible to the MSB, the impact of voltage drop, power loss, and voltage regulation issues in the LV power cables can be minimized. This setup helps optimize the electrical system's performance, improves energy efficiency, and ensures reliable power distribution throughout the ropax ship.

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3.4 Case study C – Containership

In this section the engineering and interoperability with the port assessment of the installation of a SSE supply system onboard a 10,000 TEU Containership is performed.

3.4.1 Initial Assessment

The existing principal data of the Containership vessel that is used as a case study are shown in Table 25 below. In the same table the total number and electrical characteristics of diesel generators installed onboard and the power requirements of the vessel, as states in the ELA, are described. This vessel has five (5) generators installed with a total installed electrical capacity of 11.28 MW, or 14.1 MVA, when using a power factor equal to 0.8. The vessel has also installed onboard an Exhaust Gas Cleaning System (EGCS).

According to the ELA, two vessel conditions are considered applicable to the port stay. Those are the Port Condition and the Cargo Handling Condition. However, since the cargo operation for containerships are typically performed by cargo cranes installed in the port, there is no significant difference in the required electrical loads of those two (2) conditions.

The type of cargo the containership carries plays, however, a major role. As shown below, the maximum load needed is five (5) times higher when the vessel carries reefer containers onboard compared than when it doesn't. Refrigerated containers, also called reefer containers, are used for goods that need to be temperature controlled during shipping. Reefer containers are equipped with a refrigeration unit that is connected to the power supply on board the ship.

The maximum number of reefers that a containership can carry onboard is predetermined, based on its design. The ELA considers the case than the maximum number of reefers is carried by the vessel and the electrical calculation is performed based on an average power value (KW) required per reefer. The reason for that is to size the electrical equipment correctly, being able to handle the maximum power loads. In an actual operating scenario, a containership may not carry the maximum number of reefer containers onboard. The number of reefers onboard a containership, as seen, is a parameter that has significant impact to its power demand.

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Table 25: Main data of Case study C – Containership

Ship Data		
Length overall	349.65	m
Length BP	334	m
Breadth	45.6	m
Depth	27.2	m
Draft (summer)	15	m
Deadweight	118700	tons
Gross Tonnage	113515	m3
Container carrying capacity	10000	TEU
Installed equipment onboard		
Cargo cranes	N/A	
Ballast water treatment system (BWTS)	No	
Exhaust Gas Cleaning System (EGCS)	Yes	
Installed electrical power		
Main Diesel Generators	3 sets x 2460 KW 2 sets x 1950 KW	
Frequency (Hz)	60	
Nominal Voltage (V)	6600	
Maximum Electrical power used when at port – Electric Load Analysis data		
Generator used	Main Diesel Generators	
Condition	In Port Condition	Cargo Handling Condition
WITHOUT REEFERS - D/Gs running	1 set x 1950 KW	1 set x 1950 KW
WITHOUT REEFERS - Total load (kW)	1224.9	1227.3
WITH REEFERS - D/Gs running	1 set x 1950 KW 2 sets x 2460 KW	1 set x 1950 KW 2 sets x 2460 KW
WITH REEFERS - Total load (kW)	6168.3	6171.3

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The vessel is operating at a high nominal voltage of 6.6kV AC at a 60Hz frequency. In the Figure 66 is shown the single line diagram of the vessel. This vessel was constructed as SSE ready, having installed dedicated SSE equipment onboard. The SSE connection to the vessel's MSB is provided to level, the same bus bars, as the vessel's generators, as shown in the one-line diagram.

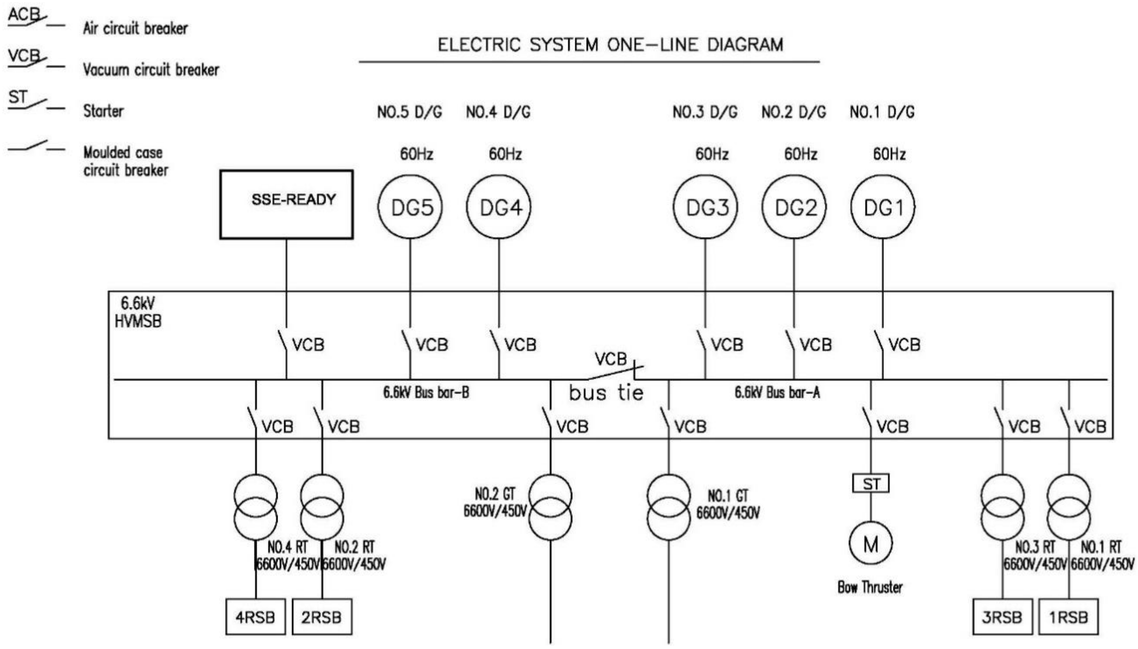

Figure 66: One line diagram of power of the Containership case study vessel

The SSE installed equipment and wiring onboard the vessel is shown in the figure below. A 6.6 kV Shore Connection panel is installed in the A Deck, as shown in Figure 70. Two (2) 350A/1250A Vacuum Circuit Breakers are installed in the Shore Connection panel. The Shore Connection panel is then connected to a dedicated SSE switchboard, that is located in the vessel's MSB. The SSE switchboard is shown in Figure 70 and Figure 74.

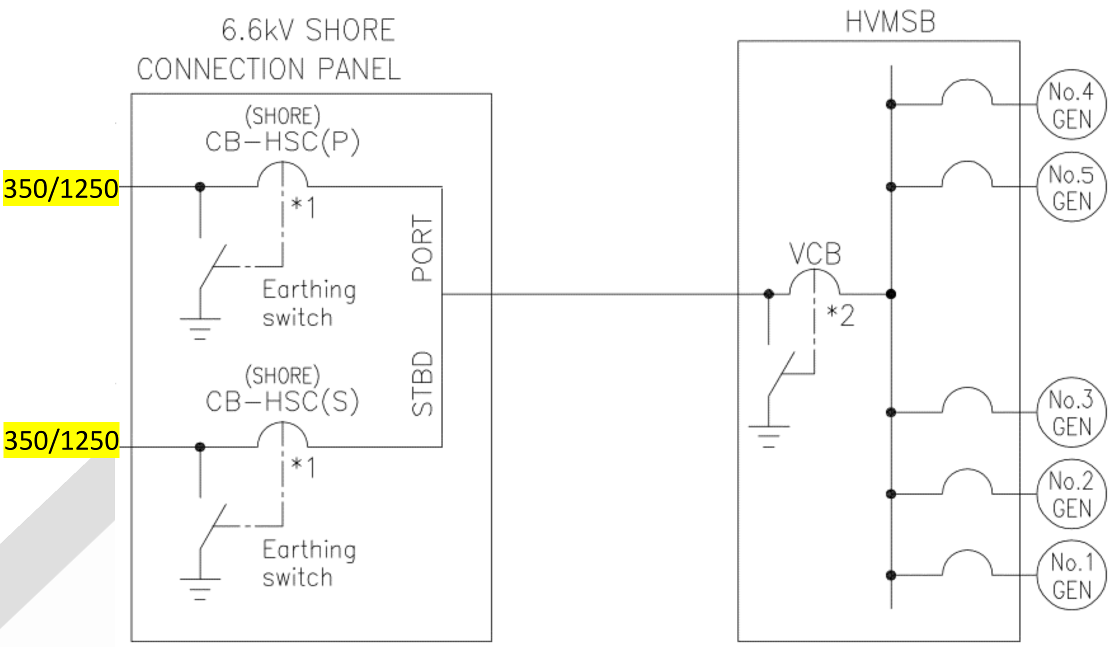

Figure 67: Single Line Diagram for SSE connection of the case study Containership vessel

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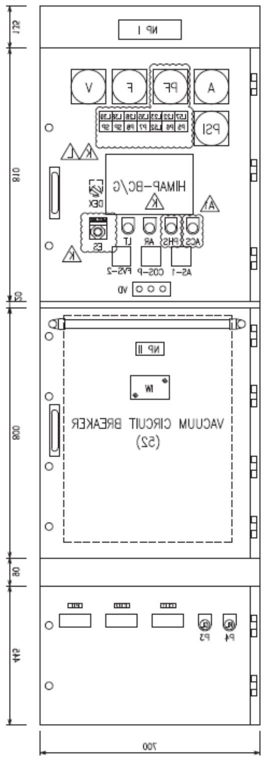

Figure 68: Existing SSE switchboard, part of vessel's MSB, located in the ECR

SYMBOL		DESCRIPTION (PNL No. R)
NAME PLATE	NP I	AMP INCOMING PANEL
	NP II	AMP
METER	A	0~900A R:620A
	F	55~65HZ R:60HZ
	V	0~9000V R:6600V
	PF	-0.5~1~0.5
SWITCH	AS-1	A-METER SEL. S/W(OFF-R-S-T-OFF)
	COS-P	CONTROL MODE MANU(M.MSB)-AUTO(AMS)
	FVS-6	FREQ/VOLTMETER
	LT	LAMP TEST
	AR	ALARM RESET
	EMS	EM'CY STOP
	PHS	PANEL HEATER
	ACS	AMP CNTR. PORT/STBD

SYMBOL		DESCRIPTION
LAMP	L28	CABLE REEL AUTO MODE(GL)
	L22	VCB CLOSED(GL)
	L23	VCB OPEN(RL)
	L35	VCB TRIP(RL)
	L38	AMP CNTR. ALARM(OL)
	L57	AMP CNTR. VCB CLOSED(GL)
	P3	INCOMING PNL ES ON(GL)
	P4	INCOMING PNL ES OFF(RL)
	P5	AMP CNTR. ES ON(GL)
	P6	AMP CNTR. ES OFF(RL)
	L52	SHORE ON (WL)
	P7	AMP MANUAL CHANGE OVER PANEL POSITION(PORT) (GL)
	P8	AMP MANUAL CHANGE OVER PANEL POSITION(STBD) (GL)
	L39	AMP CNTR. TRIP ALARM(RL)
	SP	SPARE
OTHERS	CTT1~2	CT LINE TEST TERMINAL
	PTT	PT LINE TEST TERMINAL
	VD	VOLTAGE DETECTOR
	IW	INSPECTION WINDOW FOR VCB

Figure 69: Equipment installed in the SSE Switchboard

The e A Deck arrangement of the vessel is shown below. The vessel has an installed Shore connection panel already, as shown in Figure 70. The Shore connection panel is called AMP (Alternative Maritime Power) Receiving panel in the vessel's drawings. Until today the term AMP is commonly used onboard the ships to indicate the shore supply of electricity. The terms OPS (Onshore Power Supply) and SSE are not as commonly used in vessel drawings.

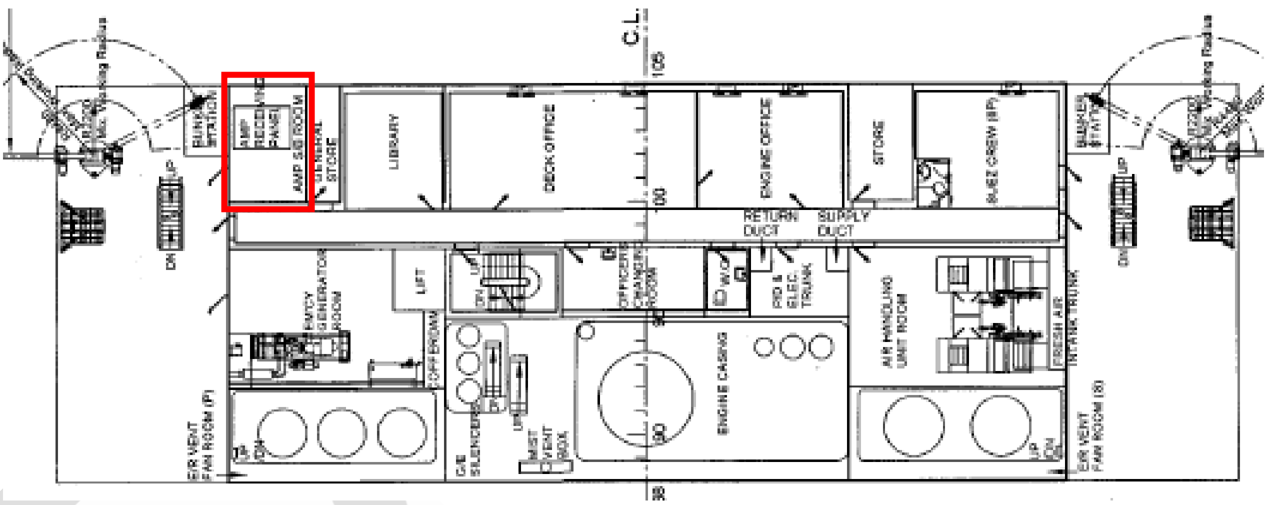

Figure 70: Plan view of the A deck of the Containership case study vessel showing the SSE reserved space (marked with red)

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3.4.2 Preliminary Analysis

For the Containership Case study, IEC/IEEE 80005-1 is applicable, as well as additional requirements as described in the first section of this chapter. Table 26 is presenting the requirements that the standard states for the HVSC for containerships compared to the case study ship's electrical energy needs.

Table 26: Summary of HVSC requirements for Containerships and corresponding Containership Case Study condition

Shore Side - HVSC		**Ship Side - HV**		
Max Power provided	up to 7.5 MVA	**Max Power required (KVA)**	**At Cargo Handling - no reefers**	1534.1
			At Cargo Handling - with reefers	7714.1
			At Port - no reefers	1531.1
			At Port - with reefers	7710.4
Voltage provided	6600 VAC	**Voltage required**		6600 VAC

It is immediately evident that during the Cargo handling with reefers condition, the vessel requires higher power that the max provided.

In general, the required equipment that is installed onboard a vessel for the supply of SSE is:

1. The CMS, only in the case of containerships
2. The receiving point
3. The receiving Circuit Breaker
4. The Power Cables up to the MSB

The equipment needed should be the same as per the cruise ship with the addition of the CMS that will be installed on board. In the case of container vessels, where the CMS is installed on board additional space must be reserved onboard.

As per the cruise ship case study, it will be necessary to find space onboard for the following components:

- Cable Management System: The containerships are the only type of ships, that needs to have the CMS onboard. To ensure the compatibility and interoperability between the vessel and the visited ports, the connection socket should be designed as follows:
  - ✓ Both the shore plug and ship socket-outlet shall be designed up to the maximum power demand of 7,5 MVA.
  - ✓ Two parallel cables with three pilot conductors each shall be used, according to the Annex D of the applicable IEC/IEEE 80005-1, both at the shore side and at the ship side.
  - ✓ General arrangement of ship plug, and shore socket-outlet shall be in accordance with IEC 62613-2:2016, Annex II, as stated in the Annex D of the IEC/IEEE 80005-1
- Shore Connection Switchboard: A Shore Connection Switchboard, which includes two circuit breakers and the necessary outlets for the shore power cables, will need to be installed. This

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panel is responsible for managing the connection to the shore and providing a safe and reliable interface for the shore power cables.

- Cable Connection: An appropriate cable connection between the circuit breaker in the main switchboard room and the Shore Connection Switchboard needs to be prepared. This will involve selecting and installing suitable cables to establish the electrical connection between these two panels
- Additional Circuit Breaker cubicle in Main Switchboard Room: To accommodate the shore connection equipment, an additional circuit breaker will need to be installed in the main switchboard room. This circuit breaker will act as a dedicated protection device for the shore power connection.

However, since the vessel was constructed SSE ready, a Shore Connection Switchboard, an Additional Circuit Breaker cubicle and the cable connection between them are already installed onboard. Furthermore, no transformer is needed in this case since the vessel already operates at 6.6kV, making the retrofit installation of the SSE equipment much simpler onboard this vessel.

3.4.3 Vessels' Drawings update

A new condition for the Electric Load Analysis is proposed to be included for the SSE where some of the maximum loads for the condition with the reefers are to be removed, so the power requirements are always lower than 6000KW (7500KVA) when receiving SSE.

Two (2) CMS are installed at both sides of the vessel, on the A or B Deck and they are connected to the Shore Connection Panel. The approximate footprint for the installation of each Cable Management System, in the port and starboard side respectively, is 4 x 4.5 m. This includes the access clearance that will be needed. The Shore Connection Panel is already installed in this vessel, as shown in Figure 71, in the dedicated space marked in a green box. Arrangement-wise, the Shore Connection Panel is usually installed in the accommodation or engine casing area. From the Shore Connection Panel, a cable connection is installed between it and a dedicated panel in the HV MSB, as shown in Figure 72, marked with red.

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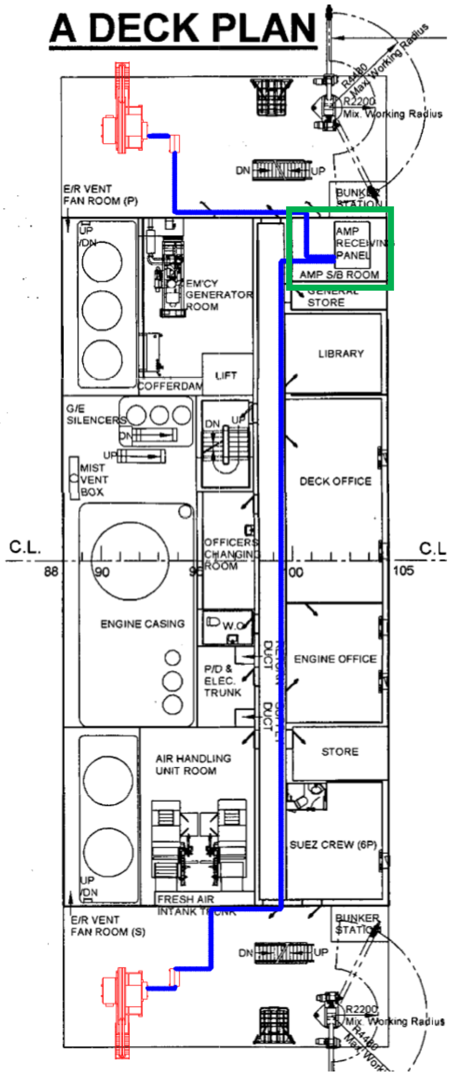

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Figure 71: Plan view of the A deck of the Containership case study vessel showing the SSE reserved space and the CMSs

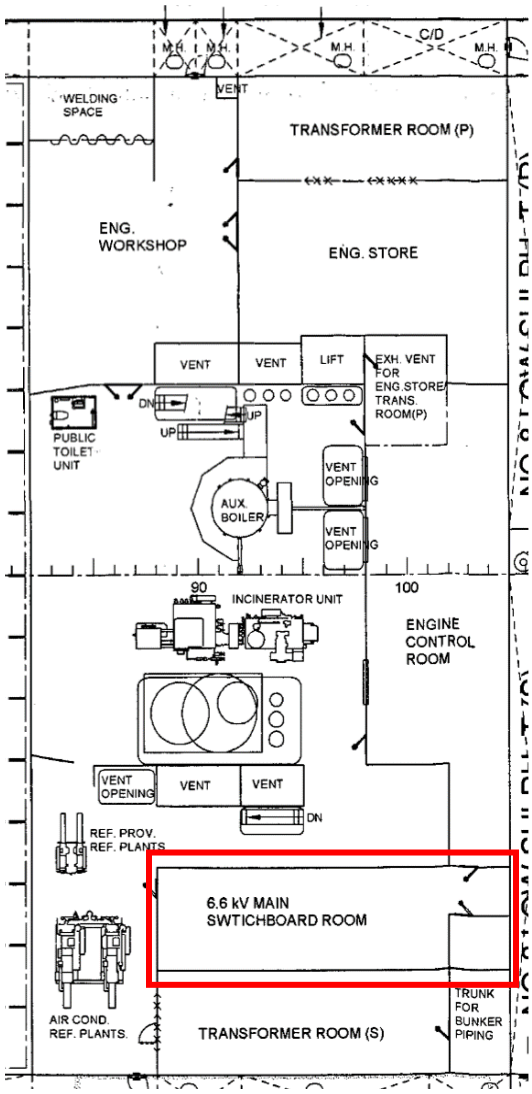

Figure 72: Plan view of the 2nd ER deck of the Containership case study vessel

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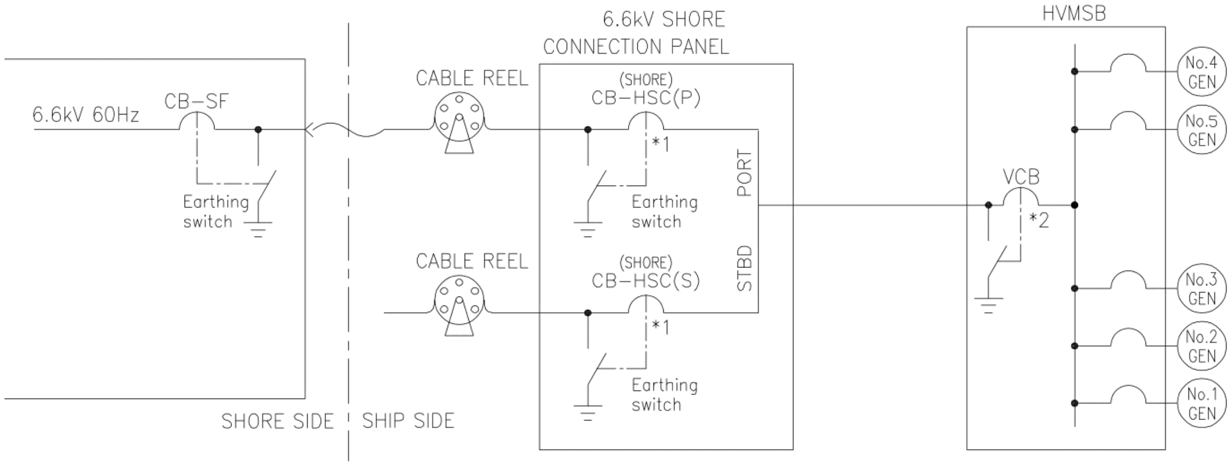

Figure 73: Single Line Diagram for SSE connection of the case study Containership vessel

Figure 73 shows the complete electrical supply line diagram from the shore side to the vessel up to the HV MSB, once the CMSs are installed onboard.

Finally, there is a need of 6 single core cables in order to connect the two cubicles with a cross section of 185 mm2 with an insulation rated capable to withstand the required 6.6 kV, as detailed in Table 27.

- Power Rating: This refers to the power capacity or rating of the cables. It indicates the maximum amount of power that the cables can safely transmit without exceeding their designed limits.
- Voltage: This specifies the rated voltage level of the cables. It represents the voltage at which the cables are designed to operate.
- Current: This indicates the current capacity or rating of the cables in parallel. It represents the maximum current that the cables can carry without exceeding their designed limits.
- Cable Selection: This describes the specific type or model of cable selected. It provides information about the number of single core cables to be routed onboard. The number of cables selected is a multiple of 3, indicating that they are configured in a three-phase arrangement to accommodate the electrical power distribution requirements.
- Cable Weight: This denotes the total weight in kg/km of the cables. It is an important factor to consider for installation purposes and overall weight distribution on the vessel.

Table 27: Container ship additional cables data

Cable data		
Power rating	7500	kVA
Voltage	6600	V
Current	660	A
Cable selection	6 // 1 x 185	mm2
Total cables weight	18810	kg/km

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3.4.4 Alternative Installation of Containerized SSE equipment

In general, in this type of vessel, a containerised SSE solution could be used, due to the nature of the cargo the vessel carries. The vessel's functionality of transporting containers may be exploited by installing containerised SSE systems onboard to improve the flexibility of the design. This can be achieved by installing the required equipment in a container. Some possible spatial arrangements are shown in Figure 74 and Figure 75. Two containers will be permanently installed on the aft side of the vessel, next to the side shell. They need to be installed above the upper deck, to not obstruct the passage in the upper deck and on the first tier since they will be permanently installed after their transportation inboard.

This design facilitates the removal of the whole container and shipping it to the manufacturer in case of equipment malfunction. It removes however two (2) billable container spaces from the cargo capacity of the ship.

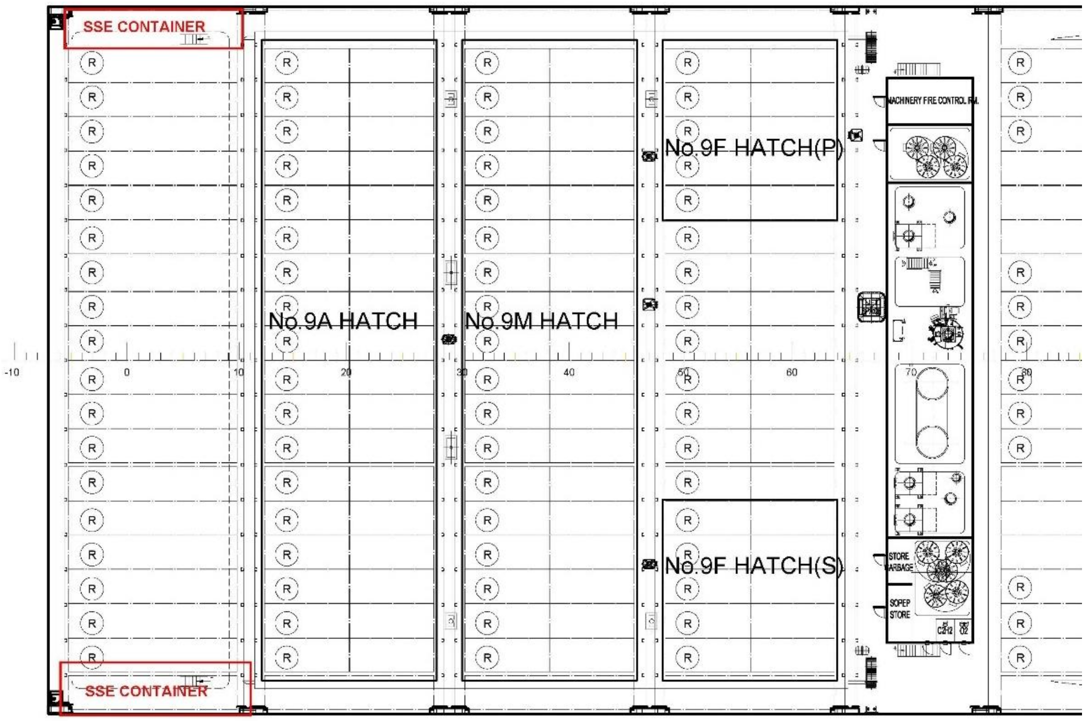

Figure 74: Plan view of the aft side of a containership, showing a possible position for the containerised SSE

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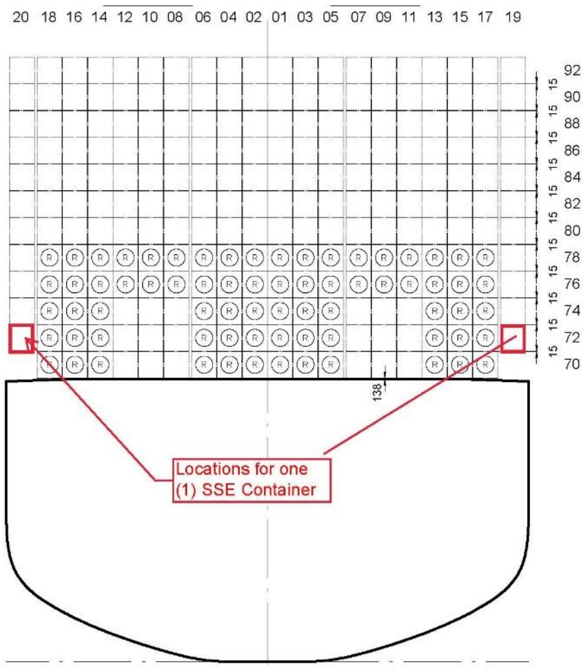

Figure 75: Section view of the aft side of a containership, showing a possible position for the containerised SSE

In this design, the SSE required equipment may be included in the container, minimizing in this way the installation space in the accommodation or engine casing area. Some different wiring scenarios are shown below. These are differentiated based on the positioning of different SSE equipment.

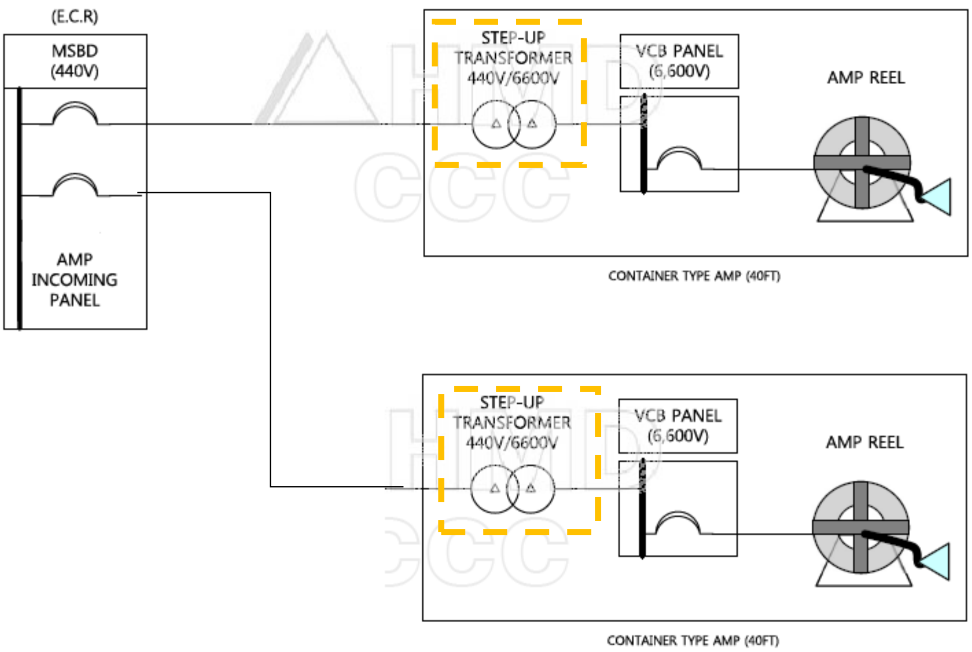

Figure 76: Wiring diagram of the containerized SSE solution - scenario 1

In Figure 76, the wiring diagram presented is showing that all the required SSE equipment is installed inside the container. The Transformer is marked with orange box, to signify that in case that the vessel operates at 6.6kV already, its installation is not needed. In this arrangement there are two (2) Shore

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Connection Switchboards and two (2) Transformers, making it not an effective arrangement, both in space and in weight utilization onboard.

In Figure 77 and in Figure 78, a second wiring diagram with the corresponding arrangement onboard is shown. In this arrangement, the SSE (or AMP alternatively called) socket box is located at one vessel side, and both the Cable Reels (AMP reel, CMS alternatively called) are connected to it. The panel containing the Vacuum Circuit Breakers (VCB) and the Voltage Transformer, if required, are installed in an enclosed space, like the Engine Casing or the Accommodation area. They are then connected to the SSE Panel, located in the MSB.

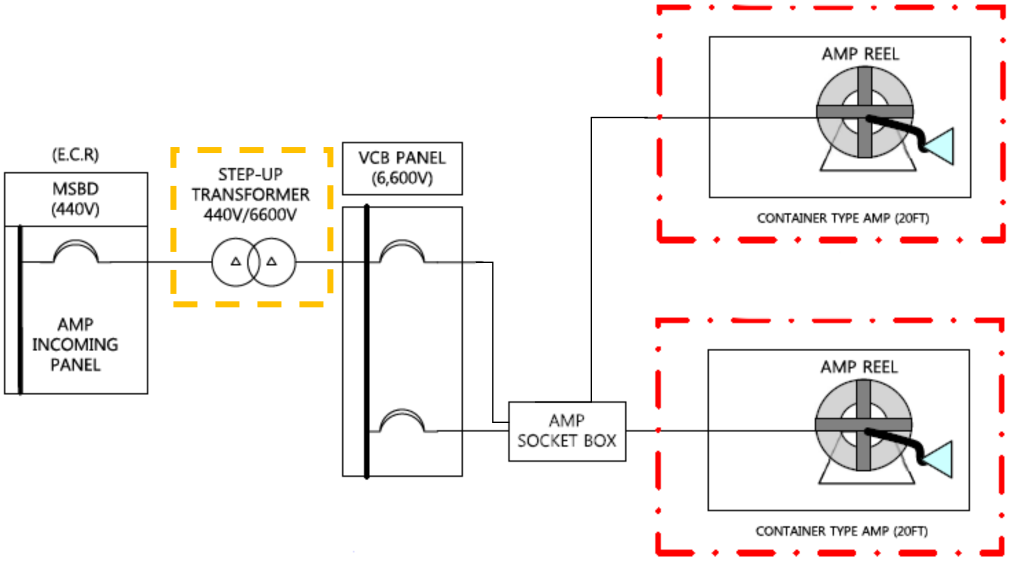

Figure 77: Wiring diagram of the containerized SSE solution - scenario 2

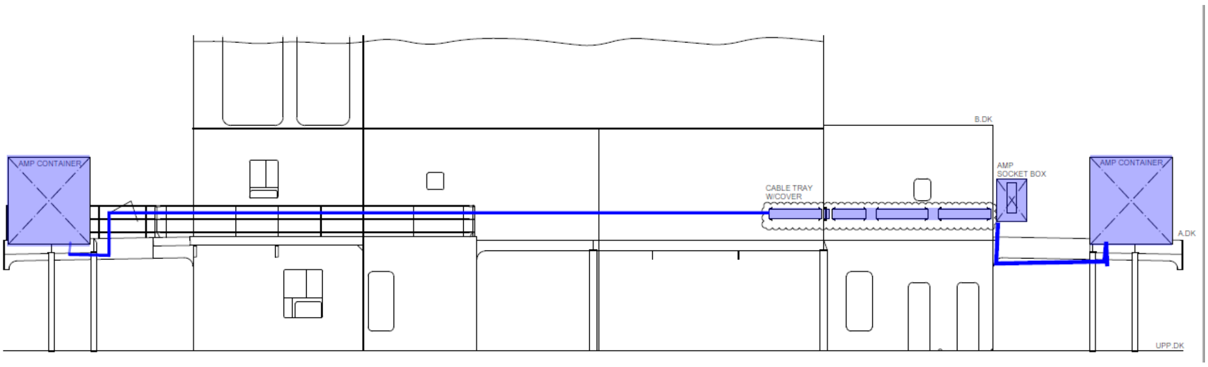

Figure 78: Conceptual arrangement of the containerized SSE solution - scenario 2

In Figure 79 and in Figure 80, the third wiring diagram with the corresponding arrangement onboard is shown. In this arrangement, the SSE socket box is located at both vessel sides and each CMS is connected to the respective one at that side. The rest of the equipment arrangement remains similar to scenario 2.

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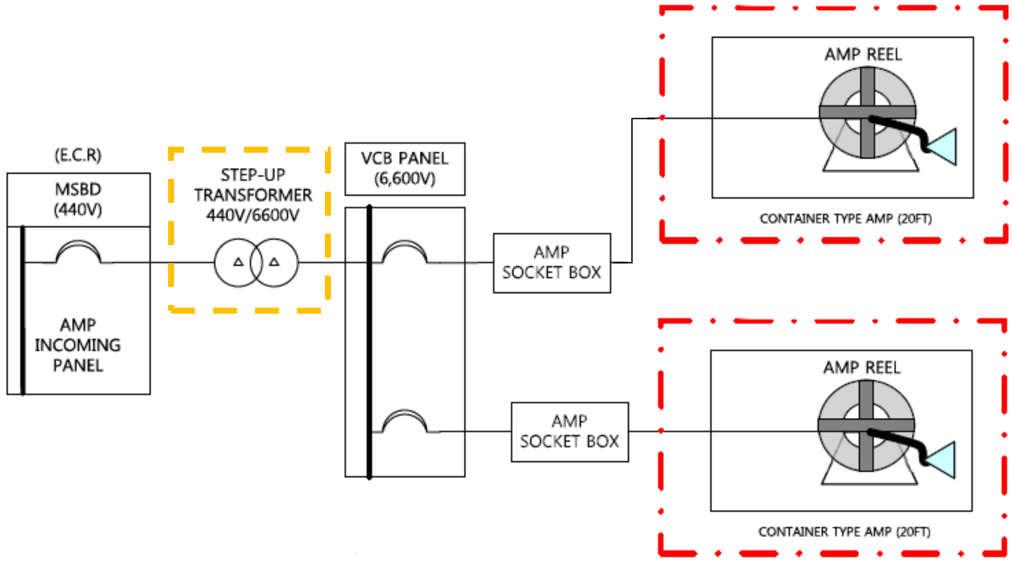

Figure 79: Wiring diagram of the containerized SSE solution - scenario 3

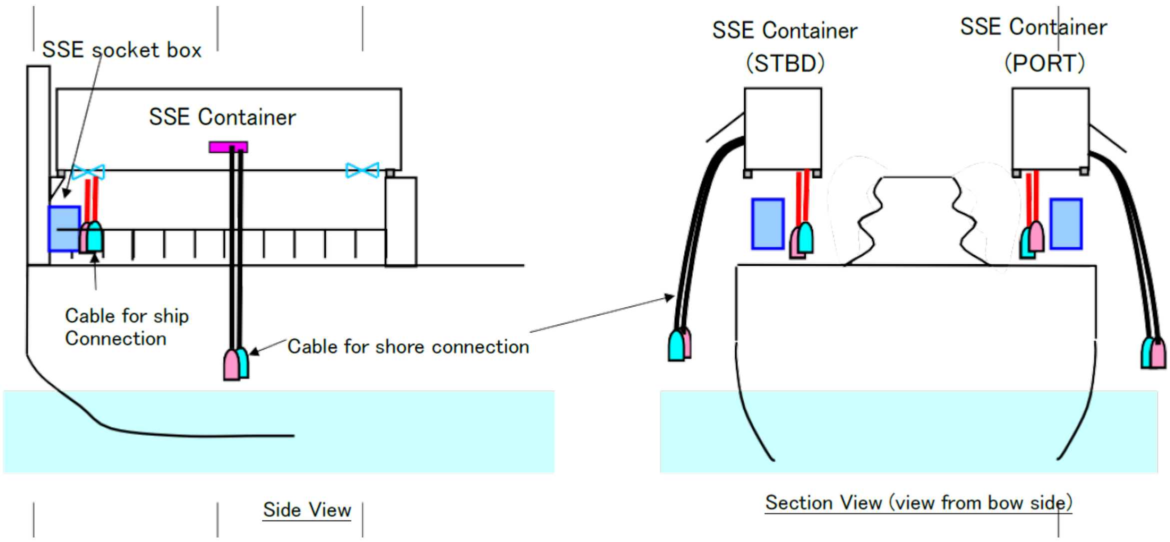

Figure 80: Conceptual arrangement of the containerized SSE solution - scenario 3

3.4.5 Technical Recommendations for Containerships

Containerships are one of the maritime industry's sectors that have the most experience with the usage of SSE onboard. As shown by the case study vessel, the containership was constructed before the IEC/IEEE 80005-1 standard came into effect, showing the heightened market's interest in this technology. However, it is crucial to ensure that the containership's electrical systems meet the latest safety standards and design requirements to ensure reliable and safe operation. The IEC/IEEE 80005 standard specifies requirements for electrical installations on ships, covering safety aspects, design considerations, and performance criteria. This recommendation emphasizes the importance of assessing the ship's electrical installations to determine compliance with the most recent regulations, such as IEC/IEEE 80005-1.

Another important parameter regarding the SSE installation onboard containerships has to do with the impact of the reefer containers. The recommendation highlights the significant impact of the number of reefer containers on a containership's power demand. The more reefer containers onboard, the

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higher the power demand for the containership. Therefore, it is important to carefully consider the power capacity the ship's electrical system will require when it carries the reefer containers. The number of reefers onboard and the power required per reefer should be clearly indicated to the port in advance. Proper load calculations, electrical system design, and power management strategies should be implemented to ensure that the port can provide sufficient power to support the number of reefer containers and maintain their required temperatures throughout the vessel's stay at berth.

The installation of equipment on the aft side needs to consider the ship's weight distribution and stability. Adding significant weight or altering the balance in the aft area may have implications for the vessel's overall performance, manoeuvrability, and safety. Therefore, any modifications or additions must be carefully engineered and evaluated to ensure they do not compromise the ship's stability or exceed design limitations.

Finally, a new Electrical Load Analysis (ELA) condition dedicated to the SSE should be considered for the both the retrofit and newbuilt installations onboard Containerships. ELA involves assessing the electrical load requirements of the containership while it is connected to shore-side power during port stays. This analysis helps evaluate whether the containership's electrical load can be adequately supported by the available SSE infrastructure. Most importantly, it should limit either the number or the power provided to the reefer containers onboard. By creating this new SSE ELA condition potential mismatches or limitations between the containership's electrical load requirements and the SSE supply can be identified beforehand. This analysis enables necessary adjustments or coordination to ensure a compatible and reliable power supply, reducing reliance on onboard power generation and optimizing the use of SSE, which can have environmental and cost-saving benefits.

3.5 Case study D - Bulk Carrier

In this section the engineering and interoperability with the port assessment of the installation of a SSE supply system onboard an 87,000 DWT Bulk Carrier is performed.

3.5.1 Initial Assessment

For the Bulk carrier Case study, IEC/PAS 80005-3 is applicable since it requires less than one (1) MVA of power. In this case the vessel does not have cargo cranes installed onboard. When using the cargo cranes installed onboard the electrical demands may be even twice the sum shown above. This vessel has also not installed any Ballast water treatment system (BWTS) or Exhaust Gas Cleaning System (EGCS) onboard. During the past few years, the retrofitting of these optional systems that provide compliance with environmental regulations, has increased the energy requirements onboard considerably.

Table 28: Main data of Case study D - Bulk Carrier

Ship Data		
Length overall	229	m
Length BP	219.9	m
Breadth	36.5	m
Depth	19.9	m
Draft (summer)	14.135	m
Deadweight	87144	tons
Gross Tonnage	47051	m^3
Installed equipment onboard		
Cargo cranes	No	
Ballast water treatment system (BWTS)	No	
Exhaust Gas Cleaning System (EGCS)	No	
Installed electrical power		
Generators	3 sets x 500 KW	
Frequency (Hz)	60	
Nominal Voltage (V)	440	
Maximum Electrical power used when at port – Electric Load Analysis data		
Generator used	Main Diesel Generators	
Condition	In Port Condition	Cargo Handling Condition
D/Gs running	1 set	2 sets
Total load (kW)	252.2	683

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The single line diagram shown below provides an overview of the main electrical components and their connection on the Bulk Carrier vessel. The vessel's operating high nominal voltage is 440V and the low nominal voltage is 115V. This vessel operates at a 60Hz frequency.

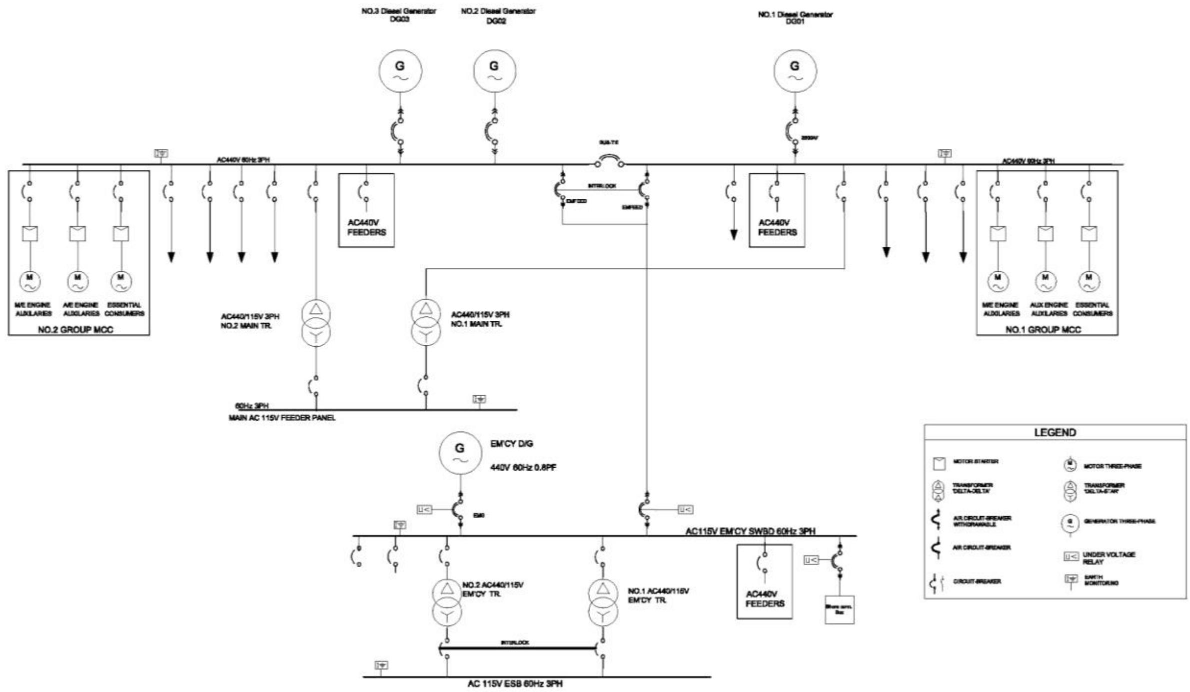

Figure 81: One line diagram of power of the Bulk Carrier case study vessel

The mid to aft side of the upper deck and the midship sections of the Bulk Carrier case study vessel are shown below in Figure 82 and Figure 83. To avoid the installation of long cabling onboard the vessel the stem area of the vessel is not considered as a possible solution, especially when considering the number and size of cables needed.

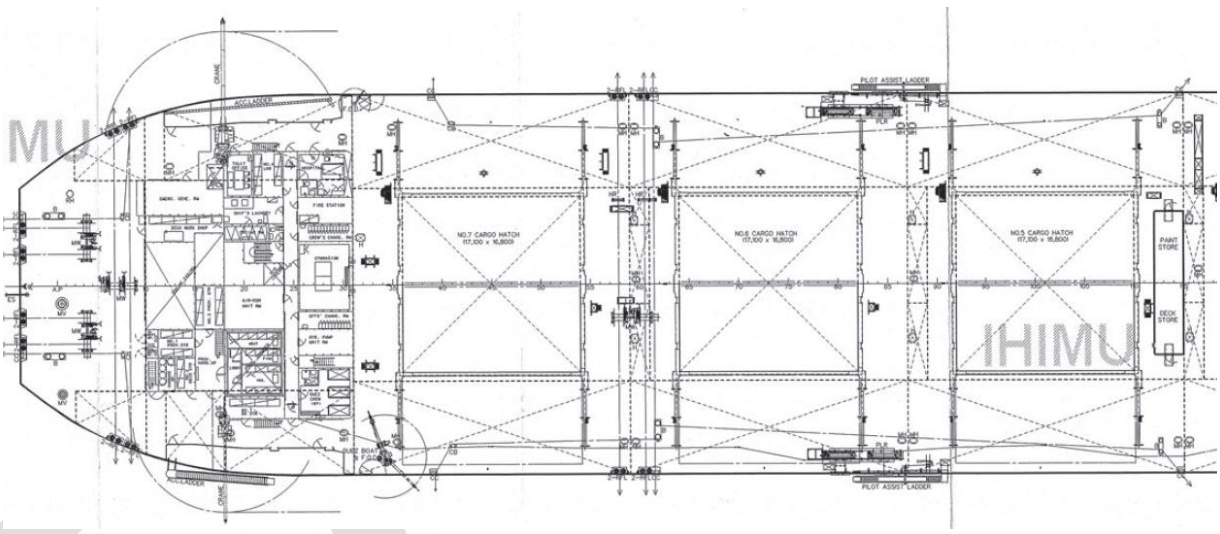

Figure 82: Plan view of the aft side of the upper deck of the Bulk Carrier case study vessel

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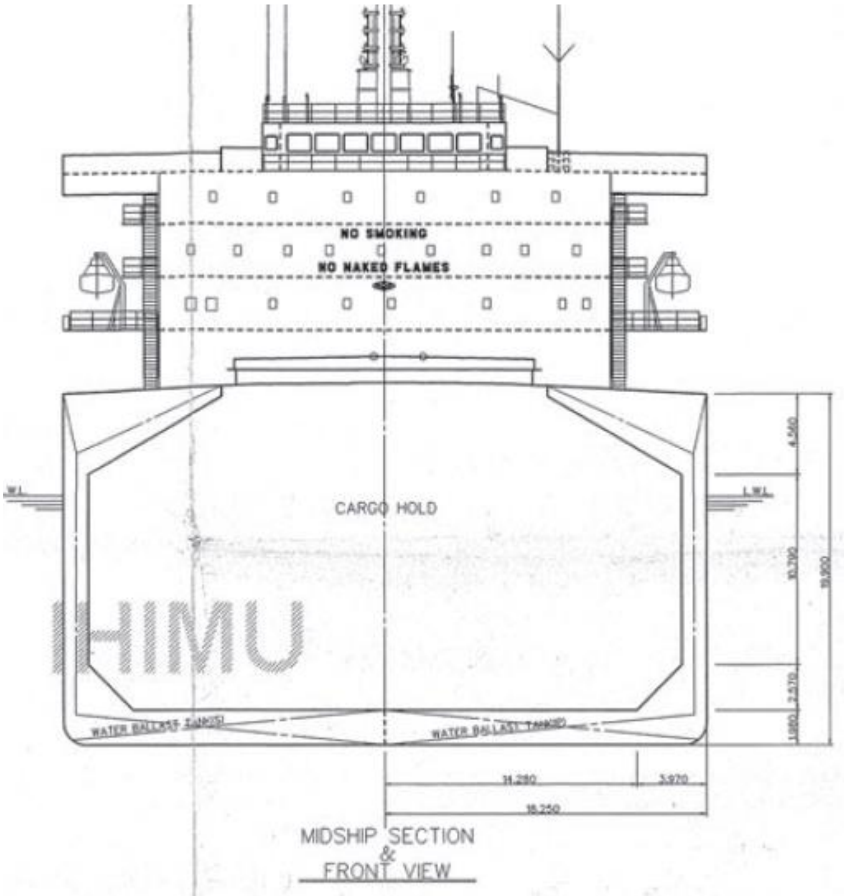

Figure 83: Midship section of the Bulk Carrier case study vessel

3.5.2 Preliminary Analysis

The table below is presenting the requirements that the standard states for the LVSC for bulk carriers, that fall under the general requirements sections of the standard, compared to the case study ship's electrical energy needs.

Table 29: Summary of LVSC requirements and corresponding Bulk Carrier Case Study condition

Shore Side - LVSC		Ship Side - LV		
MVA provided	up to 1 MVA	**Max MVA needed**	**At Cargo Handling**	853.8 KVA
			At Port	307.3 KVA
Voltage provided	690 VAC	**Voltage required**		440 VAC
	440 VAC			
	400 VAC			

It is considered that the sizing of the equipment installed should cover the maximum loads occurring while at berth. In this case the equipment installed should be dimensioned to handle a minimum of 1000 kVA.

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For the refitting of the bulk carrier in the given case study, it will be necessary to find space onboard for the following components:

- Power pedestal: Due to onboard space limitation, solely socket boxes containing the ship inlet and any required accessories that is responsible for managing the connection to the shore and providing a safe and reliable interface for the shore power cables are used. To ensure the compatibility and interoperability between the vessel and the visited ports, the connection equipment (receiving point) should be designed as follows:
  - ✓ Both the shore plug and ship socket-outlet shall be designed up to the maximum power demand of 1 MVA.
  - ✓ The cables number will depend on the voltage used for this vessel. Up to five (5) may be used.
  - ✓ General arrangement of shore plug and ship socket-outlet shall be in accordance with IEC/IEEE 80005-3
- Receiving Circuit Breakers Panel: An electrical panel where the two Receiving Circuit Breakers are located. The Breakers are connected to the socket boxes that receive electrical power from ashore. The breakers are interlocked so when the port side socket in connected to the port infrastructure the starboard side cannot be energized. The Panel is then connected through the cable connection to the newly installed cubicle in MSB Room.
- Cable Connection: An appropriate cable connection between the circuit breaker in the main switchboard room and the Receiving Circuit Breakers Panel needs to be prepared. This will involve selecting and installing suitable cables to establish the electrical connection between these two panels.
- Additional Circuit Breaker cubicle in MSB Room: To accommodate the shore connection equipment, an additional circuit breaker will need to be installed in the main switchboard room. This circuit breaker will act as a dedicated protection device for the shore power connection.

Based on the information provided, a power transformer is necessary to connect the ship's 440 Vac network with the port's infrastructure. Since the power demand is below 1 MVA, it is recommended to install an LV/LV transformer to match the different voltage available at berth. Installing an LV/LV transformer allows for the conversion of the ship's 440Vac network to a higher or lower voltage level (400/440/690 V) by utilising a tap changer. By using an LV/LV transformer, the ship can tap into the port's power grid, ensuring compatibility and facilitating the power exchange between the ship and the shore.

These components collectively can theoretically allow for the connection of the bulk carrier to the shore power supply. The circuit breaker in the shore connection panel ensures the safety and control of the connection, while the low voltage circuit breaker and transformer manage the voltage transformation from the shore power source to the vessel's electrical system. In Figure 84, a wiring diagram for the SSE installation onboard a LV bulk carrier is shown, however, showcasing that there is still the issue of voltage rating the socket boxes (receiving points) and the new SSE receiving panel that will contain the receiving circuit breakers. The fact that the shore voltage requirements are ill-defined, according to the standard, hinders the SSE adoption by these sectors.

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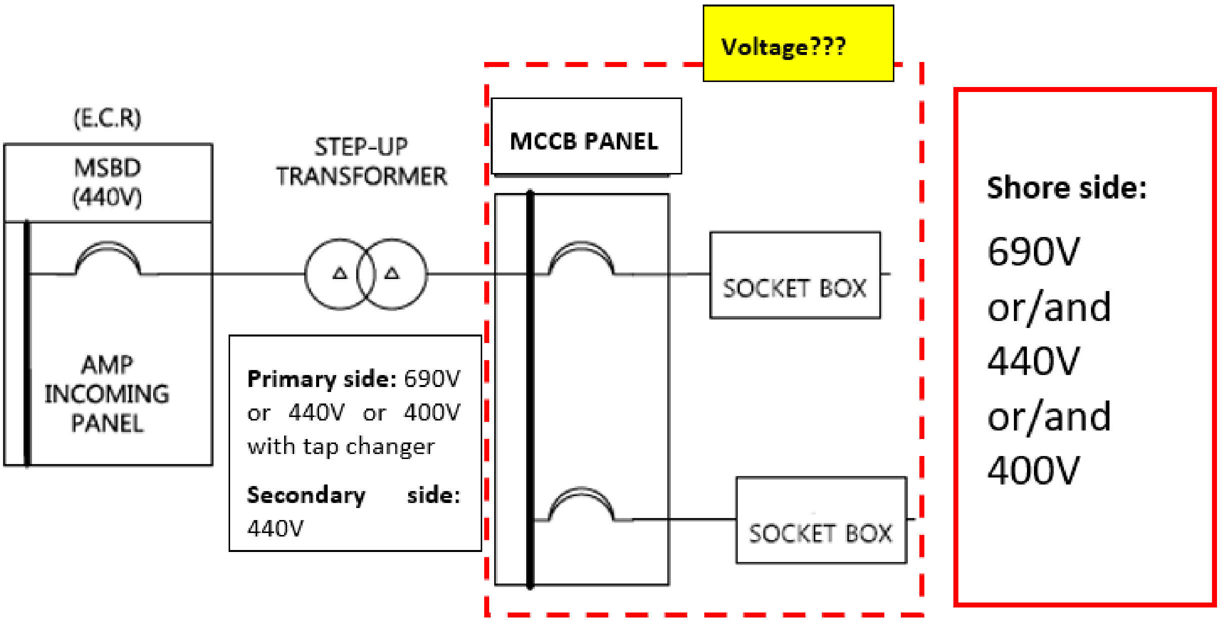

Figure 84: Wiring diagram of the SSE equipment in a LV bulk carrier based on the IEC 8005-3 standard

Figure 85 and Figure 86 present two possible solutions to the problem presented above. In the first scenario in Figure 85, only 690V are provided by the shore side, making it simple to connect to the shore. If a voltage transformer is required, then it will be installed onboard.

In the second scenario, the voltage transformer is installed in the shore side providing 690V and 440V. Since a large majority of bulk carriers have a 440V distribution network this arrangement would simplify the arrangement and facilitate their connection to the shore supply.

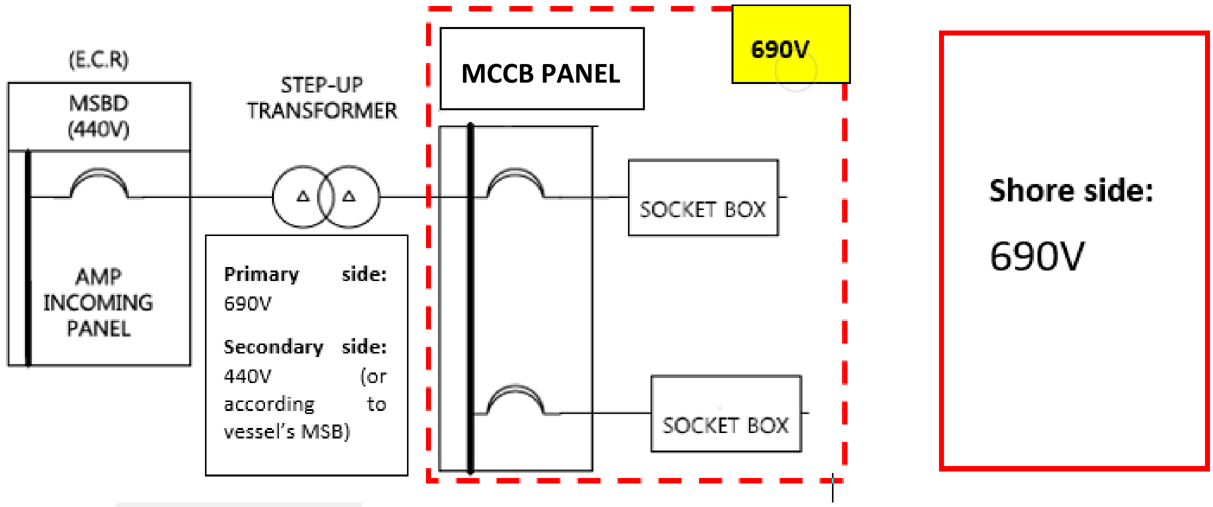

Figure 85: Possible SSE Wiring diagram between a LV bulk carrier and the shore side – scenario 1

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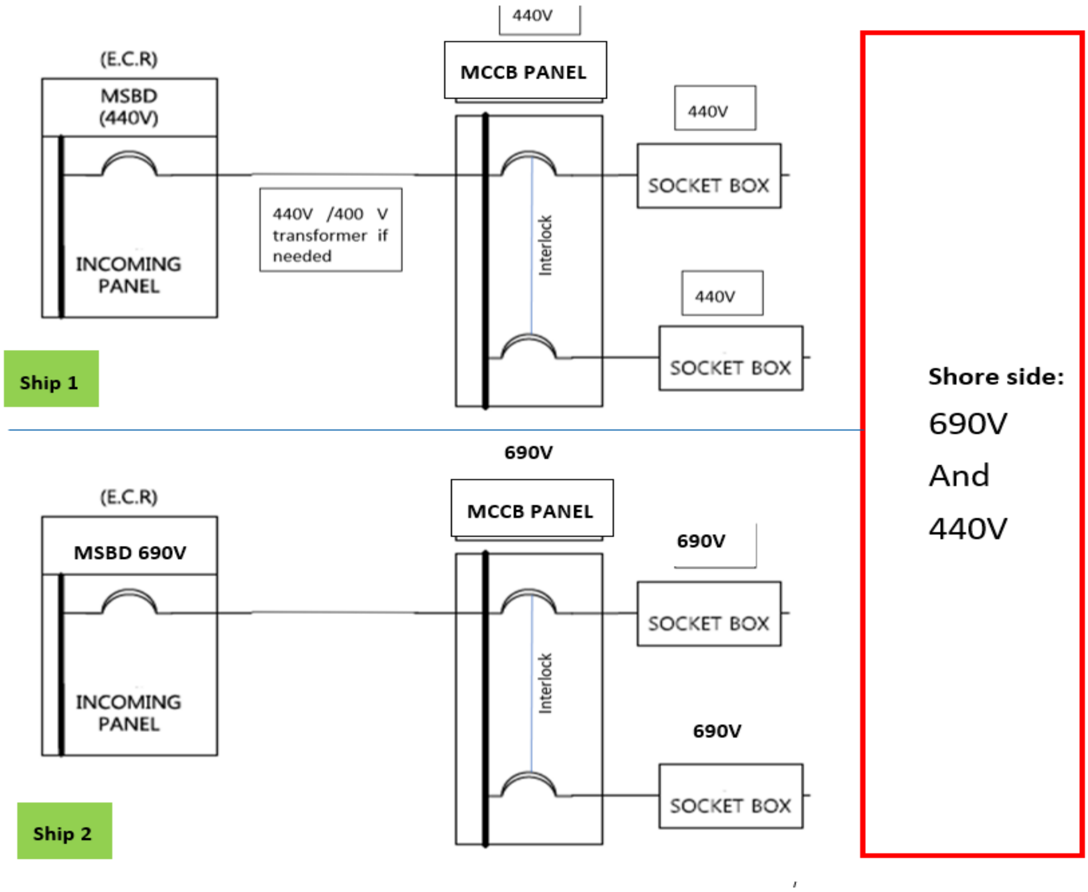

Figure 86: Possible SSE Wiring diagram between a LV bulk carrier and the shore side – scenario 2

3.5.3 Vessels' Drawings update

One possible arrangement for the case of Bulk Carrier is to install two (2) SSE socket boxes in the accommodation area (Figure 87). One will be located in the port and one in the starboard area, to service all the vessel's mooring positions. The rest of the SSE will be installed in the accommodation and Engine Room (ER) areas.

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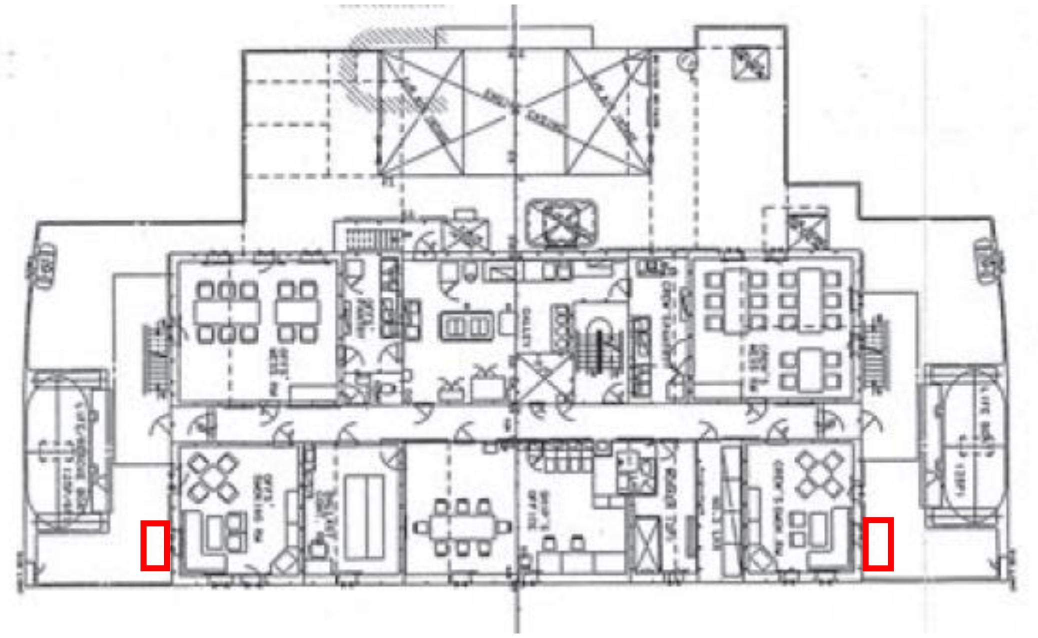

Figure 87: Indicative position of SSE sockets to be installed in the A deck

The possibility of the installation of the SSE equipment in the upper deck in a dedicated deckhouse (Figure 88) could result in interfering with the mooring equipment and lengthier cabling distance, so was not further investigated.

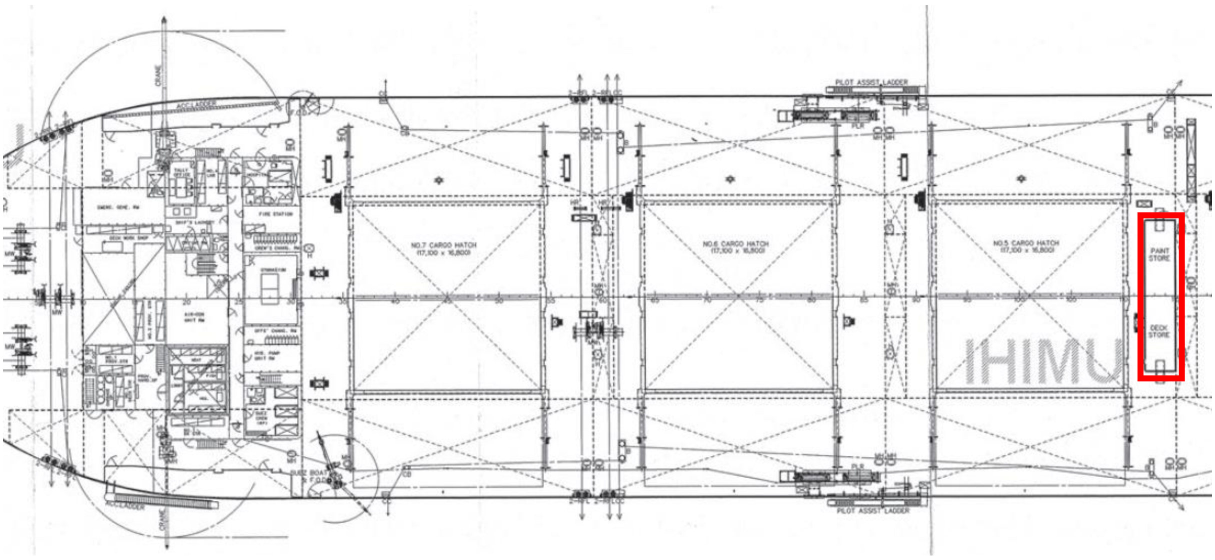

Figure 88: Indicative position of connection sockets to be installed in the upper deck

Regarding the electrical drawings update, the single-line diagram in Figure 89 and Figure 90 illustrates the electrical connections and components within the ship's system. The SSE equipment is depicted as an additional connection point on the diagram, indicating its integration into the existing electrical infrastructure (highlighted in blue in Figure 89).

This allows the ship to draw electrical power from the shore instead of relying solely on its onboard generators, reducing emissions and operating costs during periods of stationary operation.

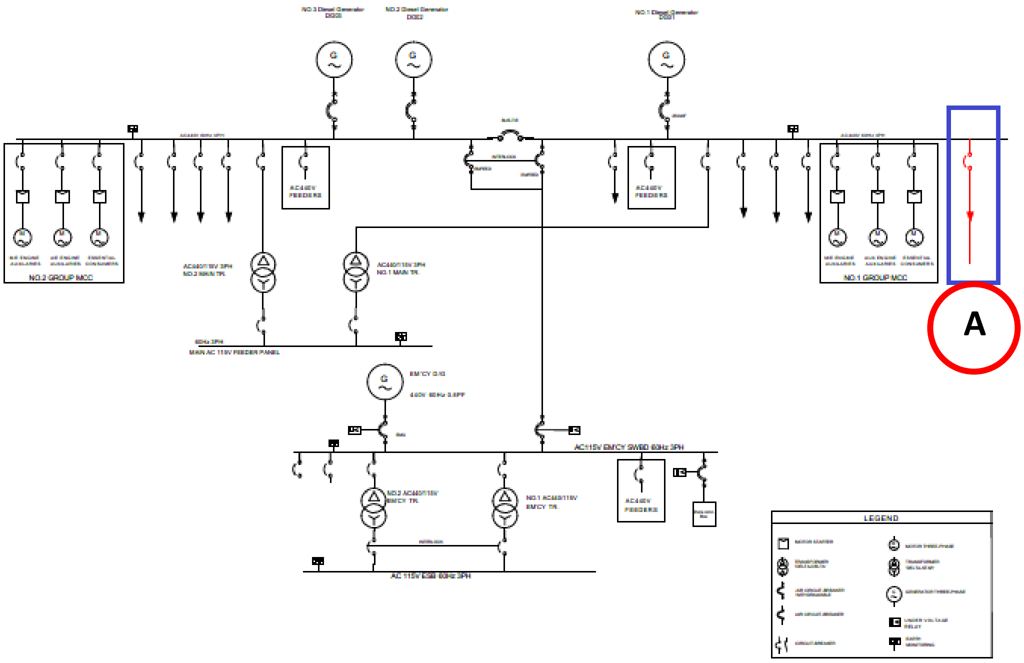

Figure 89: Single Line Diagram for Bulk carrier vessel with the embedded Shore Connection Switchboard

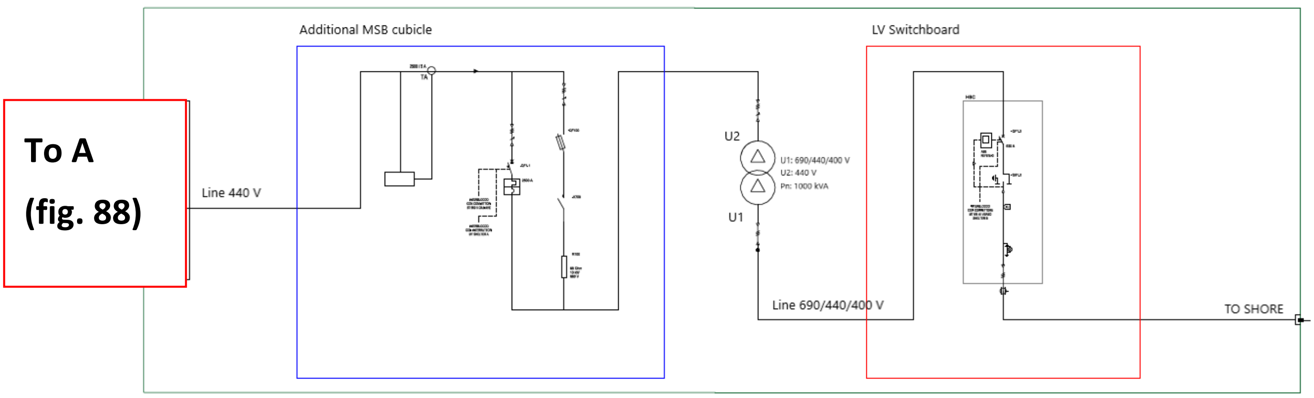

Figure 90: LV to LV connection scheme for SSE equipment using 1 MVA transformer with tap changer

In Table 30 and Table 31 are resumed the new equipment main data presenting the Shore Connection Switchboard main data and the data related to the new cubicle to be installed in the MSB room.

Table 30: SSE main data for a bulk carrier focusing on SC cubicle equipment

SSE equipment data		
Power rating	1000	kVA
Rated Voltage	690	V
Rated Current	837	A
SC cubicle dimension (H x W x D)	2200 x 1200 x 1720	mm
SC cubicle weight	1800	kg

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Table 31: SSE main data for a bulk carrier focusing on MSB equipment

SSE equipment data		
Power rating	1000	kVA
Rated Voltage	440	V
Rated Current	1315	A
SC cubicle dimension (H x W x D)	Width: 600 Height and Depth depends on the existing MSB layout	mm
SC cubicle weight	1200	kg

For bulk carrier vessel, 1000 kVA transformer has been chosen due to the availability as a COTS component by the majority of transformers supplier. The power transformer should be equipped with a tap changer on the SC side to match different voltages levels at berth.

Table 32: Bulk carrier additional transformer data

Transformer data – with tap changer		
Power rating	1000	kVA
Weight	2850	kg
Length	1620	mm
Width	1000	mm
Height	2035	mm

Finally, Table 24 contains the following main data for the selected cables in both the MSB and SC sections:

- Power Rating: This refers to the power capacity or rating of the cables. It indicates the maximum amount of power that the cables can safely transmit without exceeding their designed limits.
- Voltage (MSB and SC): This specifies the voltage level on each side of the cables. It represents the voltage at which the cables are designed to operate.
- Current (LV and HV): This indicates the current capacity or rating of the cables in parallel on each side. It represents the maximum current that the cables can carry without exceeding their designed limits.
- Cable Selection (MSB and SC): This describes the specific type or model of cable selected for the LV side. It provides information about the number of single core cables to be routed onboard. The number of cables selected is a multiple of 3, indicating that they are configured in a three-phase arrangement to accommodate the electrical power distribution requirements.

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- Cable Weight (MSB and SC): This denotes the total weight in kg/km of the cables used for each side. It is an important factor to consider for installation purposes and overall weight distribution on the vessel.

These data points provide crucial information for understanding the capabilities and characteristics of the selected cables on both the LV and LV sides, enabling proper selection, installation, and performance evaluation for the refitting of the Bulk carrier vessel.

Table 33: Bulk carrier additional cables data

Cable data		
Power rating	1000	kVA
Voltage (MSB side)	440	V
Current (MSB side)	1315	A
Cable selection (MSB side)	12 // 1 x 185	mm2
Cables weight (MSB side)	37620	kg/km
Voltage (SC side)	400	V
Current (SC side)	1445	A
Cable selection (SC side)	12 // 1 x 185	mm2
Cables weight (SC side)	37620	kg/km

3.5.4 Technical Recommendations for Bulk Carriers

In terms of voltage requirements, it is essential to ascertain the voltage provided at the berthing position. Different ports or terminals may have varying voltage requirements or standards. The bulk carrier in the case study has a 440V electrical system and it may not be able to directly connect to shore power where this voltage level is not available.

Here, a transformer plays a crucial role. A transformer can step up or step down the voltage level to match the requirements of the ship's electrical system or the available shore power source. In the case of a ship with a 440V system trying to connect to a shore power source with a different voltage, the transformer will adjust the voltage level, accordingly, enabling a safe and efficient connection.

Ships gain the flexibility to connect to different shore power sources worldwide, regardless of the voltage variations by having a tap changer transformer for shore connection onboard. In detail, a tap changer transformer, also known as a voltage regulator transformer or simply a tap changer, is a type of transformer that allows for the adjustment of its output voltage by changing the tapping points on the transformer winding. Indeed, the primary purpose of a tap changer transformer is to maintain a consistent voltage level despite changes in the berth voltage, rendering the vessel flexible for SSE connection, while visiting different ports.

However, in this case this may not be enough, since the uncertainty regarding the voltage level provided by the shore will also affect the rest of SSE interface equipment onboard, as shown. By

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limiting the options of the voltage providing to one (690V) or by proving the voltage transformation ashore the adoption of SSE onboard vessel's that require less than 1 MVA of power will be facilitated.

Assuming this issue is not resolved and considering the voltage compatibility between the ship and the port in advance, ship operators can use the information, if it is provided beforehand, and request shore power by ports that can provide the appropriate voltage, thus minimizing the vessel's emissions. In this case an information system that provides this kind of information would be of benefit since ship operators can select ports that can provide the appropriate voltage for shore power.

Another thing that needs to be considered is the installation of equipment in relation to the ship's weight distribution and stability. Adding significant weight in the aft area will have implications for the vessel's lightweight. Therefore, any modifications or additions must be carefully engineered and evaluated in compliance with the rules and regulations.

3.6 Case study E - Tanker

In this section the engineering and interoperability with the port assessment of the installation of a SSE supply system onboard a 50,000 DWT Tanker is performed.

3.6.1 Initial Assessment

The existing main data of the Tanker vessel that is used as a case study are shown below. This vessel has three (3) generators installed. According to the ELA, two vessel conditions are considered applicable to the port stay. Those are the Port Condition and the Cargo Handling Condition. As shown below, the maximum load needed is almost four (4) times higher when the vessel is unloading its cargo. During the cargo unloading the vessel is using its own cargo pumps and generators by extension, when the pumps are electrically driven, while during cargo loading the terminal pumps are used.

One interesting fact is that, although during the Cargo Handling Condition the power load stated in the ELA exceeds the 1MVA limit, during the Port Condition the power requirement is less than it. The main data of the Tanker are shown in the table below.

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Table 34: Main data of Case study – Tanker

Ship Data		
Length overall	183.06	m
Length BP	175.15	m
Breadth	32.2	m
Depth	19.1	m
Draft (summer)	13.3	m
Deadweight	50000	tons
Gross Tonnage	29723	m3
Installed equipment onboard		
Cargo cranes	N/A	
Ballast water treatment system (BWTS)	No	
Exhaust Gas Cleaning System (EGCS)	Yes	
Installed electrical power		
Main Diesel Generators	3 sets x 1100 KW	
Frequency (Hz)	60	
Nominal Voltage (V)	440	
Maximum Electrical power used when at port – Electric Load Analysis data		
Generator used	Main Diesel Generators	
Condition	In Port Condition	Cargo Handling Condition
D/Gs running	1 set	2 sets
Total load (kW)	564.5	1812.8

The single line diagram shown below provides an overview of the main electrical components and their connection on the Tanker. The vessel's operating high nominal voltage is 440V and the low nominal voltage is 220V. This vessel operates at a 60Hz frequency.

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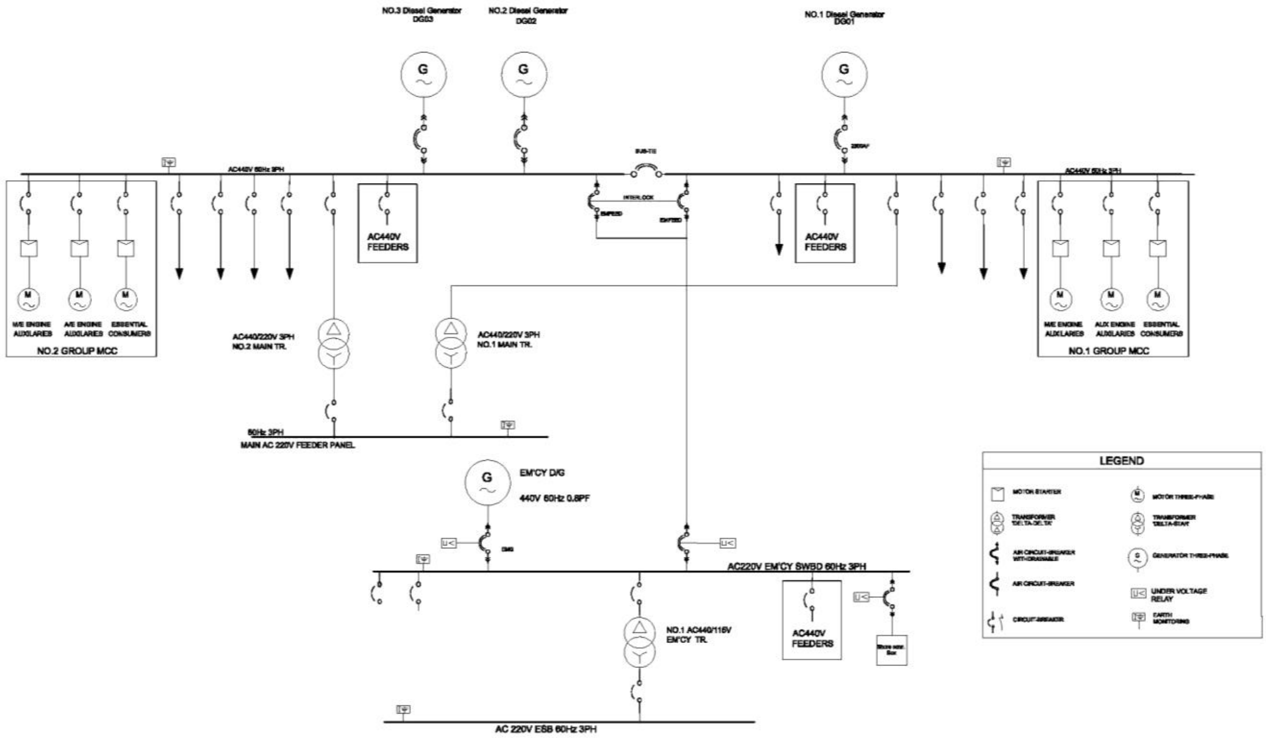

Figure 91: One line diagram of power of the Tanker case study vessel

The accommodation area and the plan view of the Tanker case study vessel are shown below in Figure 92 and Figure 93. Like in the case of the bulk carrier, the installation of long cabling onboard the vessel the stem area of the vessel is not considered as a possible solution.

For this type of vessels, the existence of the hazardous areas (Figure 94), due to the nature of its cargo, impose additional constrains in the installation of a SSE system onboard the vessel.

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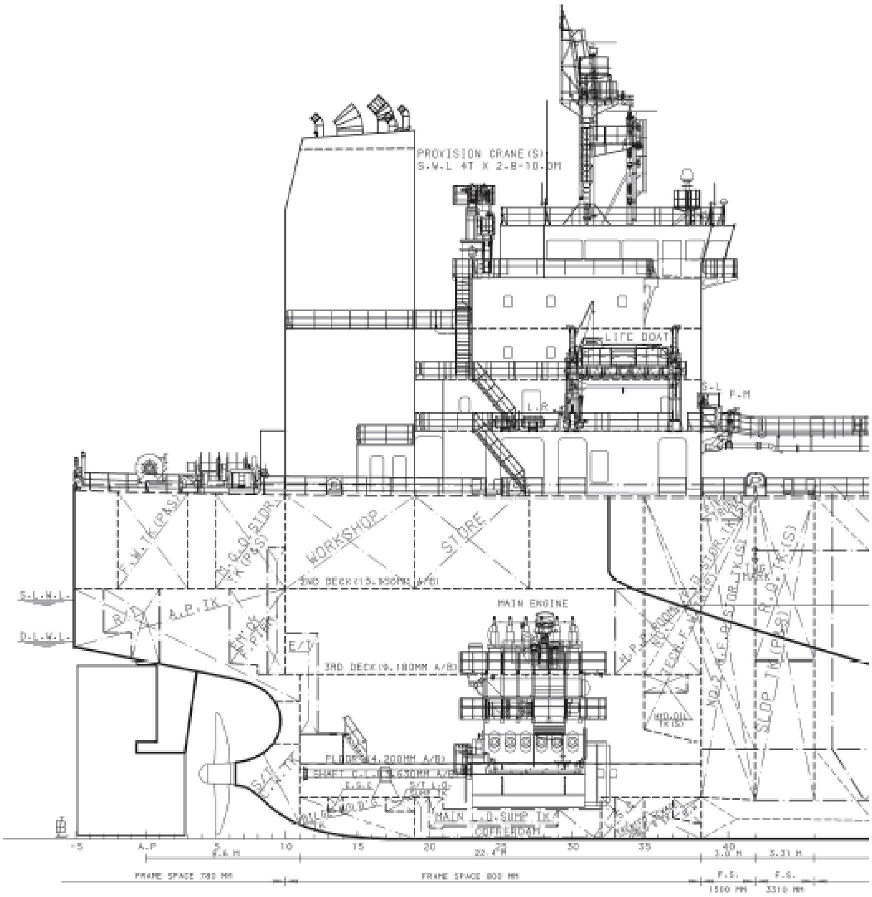

Figure 92: Profile view of the aft side of the Tanker case study vessel, showing the accommodation areas and the ER

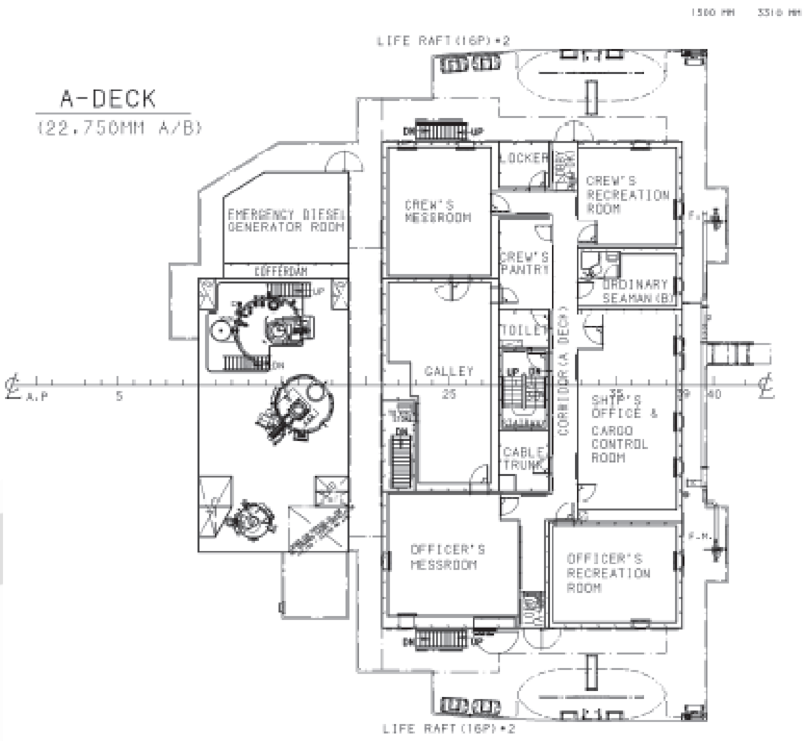

Figure 93: Plan view of the A deck in the accommodation area

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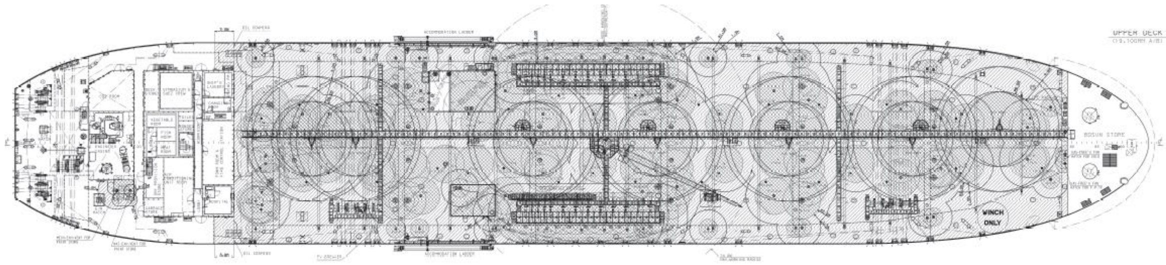

Figure 94: Plan view of the upper deck, showing the dangerous areas marked with grey color

3.6.2 Preliminary Analysis

The table below is presenting the requirements for the HVSC of tankers compared to the case study ship's electrical energy needs. For the Tanker Case study, IEC/IEEE 80005-1 is applicable, since at the Cargo Handling Condition it requires more than 1 MVA of power to be provided. Additional requirements for tankers are also applicable as per Annex F of the same standard. It is noted, however, that for the Port Condition less than 1 MVA is required.

Table 35: Summary of HVSC requirements for Tankers and corresponding Tanker Case Study condition

Shore Side - HVSC		Ship Side - LV		
MVA provided	equal to 10.8 MVA	**Max KVA needed**	**At Cargo Handling**	2266 MVA
			At Port	705.6 MVA
Voltage provided	6600 VAC	**Voltage needed**		440 VAC

The following implementation of HV shore connection installations are shown below:

1. HV shore connection equipment and components placed in a dedicated non-hazardous connection space on a hazardous area, like the upper deck (Figure 95).
2. Installation of the HV shore connection equipment in a safe area, typically in the aft area of the vessel. Interface equipment is installed in a connection compartment containing ship inlet and accessories (Figure 96).

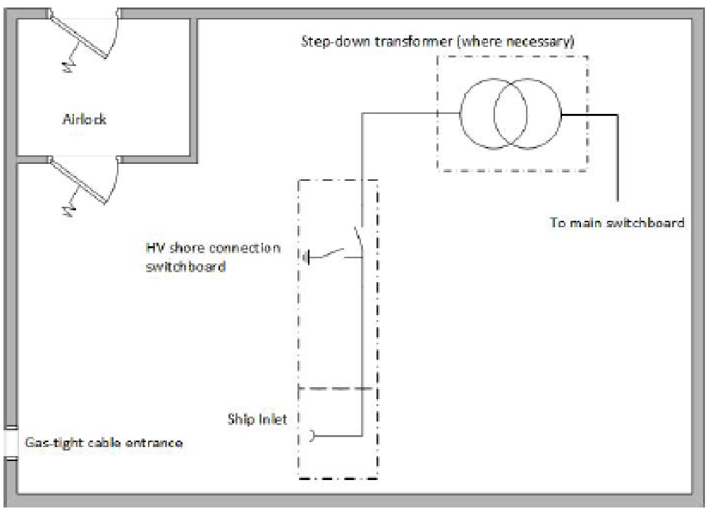

Figure 95: Arrangement for non-ex proof equipment installation in dedicated safe area

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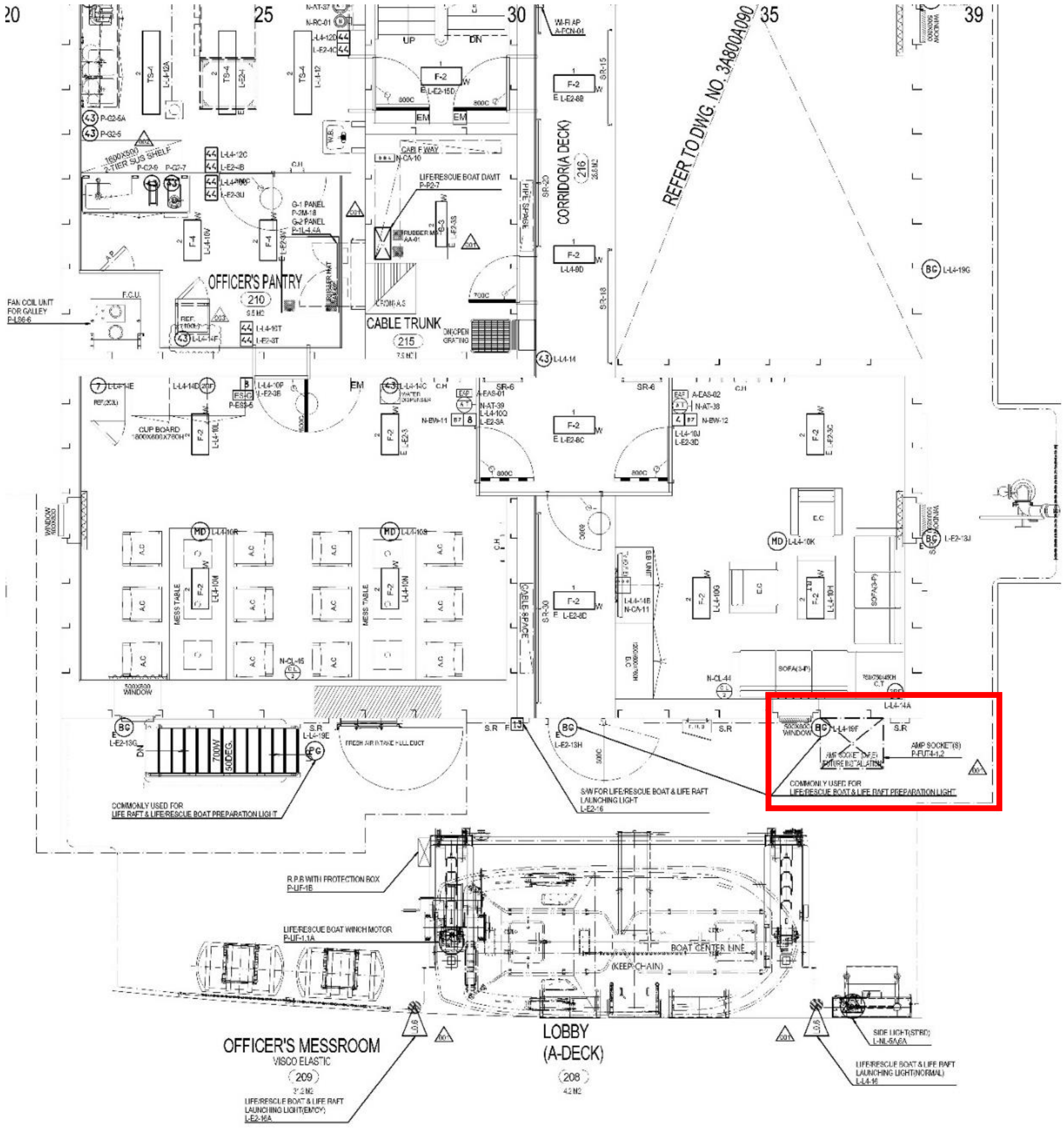

Figure 96: Socket box containing ship inlet and accessories marked in red

For the arrangement shown in Figure 96, it will be necessary to find space onboard for the following components:

- Power pedestal: Due to onboard space limitation, solely socket boxes containing the ship inlet and any required accessories that is responsible for managing the connection to the shore and providing a safe and reliable interface for the shore power cables are used. To ensure the compatibility and interoperability between the vessel and the visited ports, the connection equipment (receiving point) should be designed as follows:
  - ✓ Both the shore plug and ship socket-outlet shall be designed up to the maximum power demand of 10,8 MVA.
  - ✓ One cable shall be used, according to the Annex F of the applicable IEC/IEEE 80005-1, both at the shore side and at the ship side, up to the voltage transformer.

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- ✓ General arrangement of shore plug and ship socket-outlet shall be in accordance with IEC 62613-2:2016, Annex IIV accessories with three pilot contacts as included in IEC/IEEE 80005-1.

- Receiving Circuit Breakers Panel: An electrical panel where the two Receiving Circuit Breakers are located. The Breakers are connected to the socket boxes that receive electrical power from ashore. The breakers are interlocked so when the port side socket in connected to the port infrastructure the starboard side cannot be energized. The Panel is then connected through the cable connection to the newly installed cubicle in MSB Room.
- Cable Connection: An appropriate cable connection between the circuit breaker in the main switchboard room and the Receiving Circuit Breakers Panel needs to be prepared. This will involve selecting and installing suitable cables to establish the electrical connection between these two panels.
- Additional Circuit Breaker cubicle in MSB Room: To accommodate the shore connection equipment, an additional circuit breaker will need to be installed in the main switchboard room. This circuit breaker will act as a dedicated protection device for the shore power connection.

Based on the information provided, a power transformer is necessary to connect the ship's 440 Vac network with the port's infrastructure. Since the power demand exceeds 1 MVA, a LV/HV transformer is required. Installing an LV/HV transformer allows for the conversion of the ship's 440 Vac network to a higher voltage level, in the range of 6,6 kV. This higher voltage is more suitable for long-distance transmission and offers benefits such as reduced power losses during distribution. By using an LV/HV transformer, the ship can connect to the port's electrical infrastructure more efficiently. It enables the ship to tap into the port's power grid, ensuring compatibility and facilitating the power exchange between the ship and the shore.

To avoid any interference with the mooring equipment, the arrangement shown in Figure 96 will be considered below.

3.6.3 Vessels' Drawings update

As discussed in the previous chapters, it will be necessary to find space onboard for the following components:

1. Socket box – located in a safe area of the accommodation area
2. Power Transformer, located in the ER, as close as possible to the ECR
3. Cable Connections
4. Additional Circuit Breaker cubicle in the MSB room

Regarding the electrical drawings update, the single-line diagram in Figure 97 and Figure 98 illustrates the electrical connections and components within the ship's system. The SSE equipment is depicted as an additional connection point on the diagram, indicating its integration into the existing electrical infrastructure (highlighted in blue in Figure 97).

This allows the ship to draw electrical power from the shore instead of relying solely on its onboard generators, reducing emissions and operating costs during periods of stationary operation.

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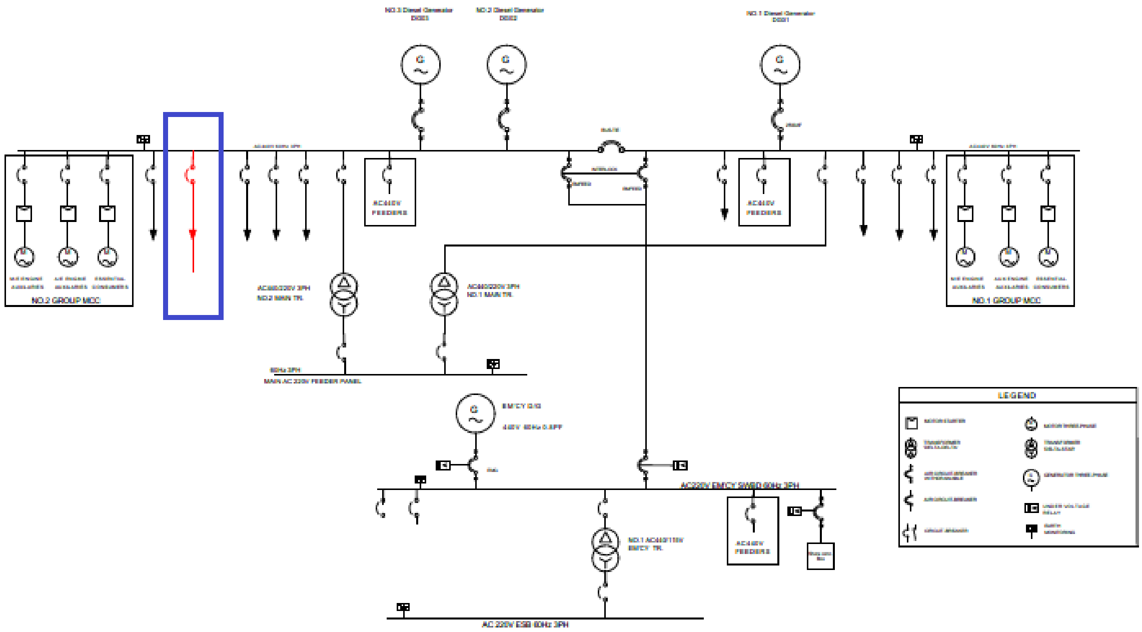

Figure 97: One line diagram of power of the Tanker case study vessel after SSE installation (highlighted in blue)

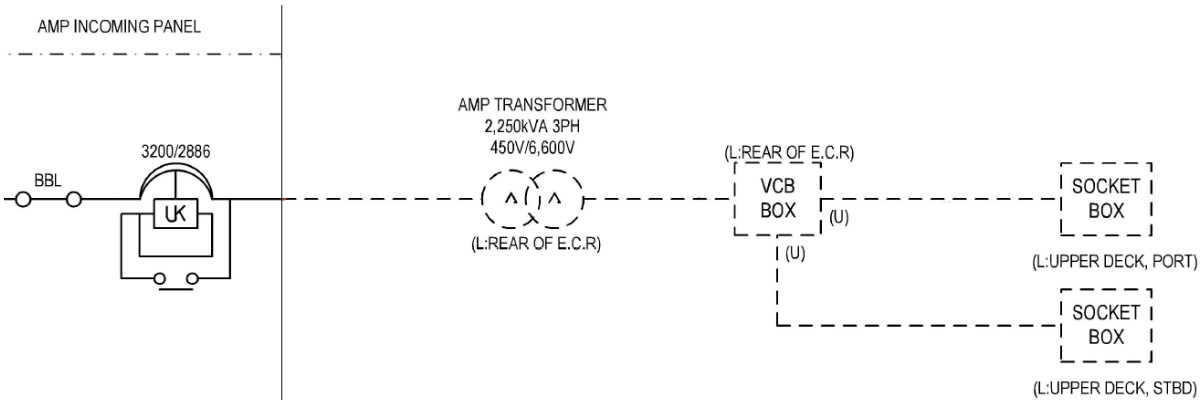

Figure 98: LV to HV connection scheme for SSE equipment using socket boxes

In Table 36 the new equipment main data related to the new cubicle to be installed in the MSB room are shown.

Table 36: SSE main data for a tanker focusing on MSB equipment

SSE equipment data		
Power rating	2500	kVA
Rated Voltage	440	V
Rated Current	3290	A
SC cubicle dimension (H x W x D)	Width: 600 Height and Depth depends on the existing MSB layout	mm
SC cubicle weight	1500	kg

For Tanker vessel, 2500 kVA transformer has been chosen due to the availability as a COTS component by the majority of transformers supplier. Indeed, the next transformer power rating would be 3150 kVA and it seems to be no reasonable for the application. However, detailed analysis is required to validate the accuracy of the 2500 kVA power transformer size.

Table 37: Tanker additional transformer data

Transformer data		
Power rating	2500	kVA
Weight	4790	kg
Lenght	2110	mm
Width	1300	mm
Height	2325	mm

Finally, Table 38 contains the following main data for the selected cables in both the LV and HV sections:

- Power Rating: This refers to the power capacity or rating of the cables. It indicates the maximum amount of power that the cables can safely transmit without exceeding their designed limits.
- Voltage (LV and HV): This specifies the voltage level on each side of the cables. It represents the voltage at which the cables are designed to operate.
- Current (LV and HV): This indicates the current capacity or rating of the cables in parallel on each side. It represents the maximum current that the cables can carry without exceeding their designed limits.
- Cable Selection (LV and HV): This describes the specific type or model of cable selected for the LV side. It provides information about the number of single core cables to be routed onboard. The number of cables selected is a multiple of 3, indicating that they are configured in a three-phase arrangement to accommodate the electrical power distribution requirements.
- Cable Weight (LV and HV): This denotes the total weight in kg/km of the cables used for each side. It is an important factor to consider for installation purposes and overall weight distribution on the vessel.

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These data points provide crucial information for understanding the capabilities and characteristics of the selected cables on both the LV and HV sides, enabling proper selection, installation, and performance evaluation for the refitting of the tanker vessel.

Table 38: Tanker additional cables data

Cable data		
Power rating	2500	kVA
Voltage (LV side)	440	V
Current (LV side)	3280	A
Cable selection (LV side)	21 // 1 x 240	mm^2
Cables weight (LV side)	80850	kg/km
Voltage (HV side)	6600	V
Current (HV side)	220	A
Cable selection (HV side)	3 // 1 x 95	mm^2
Cables weight (HV side)	5775	kg/km

3.6.4 Technical Recommendations for Tankers

During the course of the project, it was identified that no SSE interface equipment with ex-proof certification was available from equipment makers. HV shore connection equipment may be accepted in hazardous areas provided the installation complies with the applicable regulations, however the positioning of equipment in the upper deck area needs further evaluation to not cause interference with the mooring equipment.

The distance between the MSB and the power transformer is a critical factor. Ideally, the power transformer should be installed as close as possible to the MSB, minimizing the length of the LV power cables. By installing the power transformer as close as possible to the MSB, the impact of voltage drop, power loss, and voltage regulation issues in the LV power cables can be minimized. This setup helps optimize the electrical system's performance, improves energy efficiency, and ensures reliable power distribution throughout the tanker ship.

Finally, there is a gap in the IEC 80005-1 requirements, where a separate control CMS is shown for the case of the tankers, but no further information is given. This needs to be evaluated.

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4. PRELIMINARY IMPLEMENTATION PLAN

The successful implementation of any project requires careful planning and strategizing. In the context of refitting a cruise ship, for instance, for the installation of SSE equipment, it is essential to develop a comprehensive implementation plan. This chapter will delve into the preliminary aspects of the implementation plan, focusing on the work sequence, timeline estimation, and cost estimations.

The steps described below refer to the shipyard implementation process. This is the final step of the installation process of the SSE system onboard. In summary, the previous steps will be a technoeconomic feasibility and a detailed engineering study of the selected SSE system to be installed onboard performed by engineering consultants, a classification society approval process to ensure and verify compliance with the applicable rules and regulations, selection of the shipyard to carry out the installation by the shipping company, and procurement of required materials and equipment, performed by the shipping company and the shipyard.

4.1 Preliminary Work sequence

The work sequence outlines the logical order in which the activities for the installation of shore side electricity equipment will be carried out. This includes tasks such as the disassembly of designated areas, adaptation of new spaces, procurement of necessary equipment, embarkation, and installation of equipment, as well as functional and full commissioning processes. By defining a clear work sequence, the project team can ensure a smooth flow of activities and minimize disruptions during the refitting process.

Here's a description of the activities related to refitting a cruise ship, used as reference, for the installation of shore side electricity equipment:

- Disassembly of the designated area for the installation of the shore connection cubicle: This involves removing any existing equipment or structures in the designated area to make space for the shore connection cubicle.

- Adaptation of the new area to meet the vessel's category requirements according to classification societies: The newly cleared area needs to be modified and prepared to meet the specific standards and regulations of the naval registries. This includes ensuring it is suitable for accommodating electrical panels and equipment.

- Procurement of necessary equipment: The required equipment (section 3.2.2), such as the shore connection cubicle and an additional cubicle to be installed in the main electrical switchboard room, needs to be sourced and procured. This involves identifying suitable suppliers, evaluating options, acquiring the equipment, and arranging delivery times.

- Embarkation and installation of the new equipment on board: Once the equipment is procured, it is loaded onto the cruise ship and installed in the designated areas. This may involve coordination with the ship's crew, technicians, and contractors to ensure proper installation according to specifications.

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- Functional test commissioning: After the installation, a series of functional tests are conducted to ensure that the shoreside electricity equipment is operating correctly. This involves checking the connections, verifying power supply, and ensuring proper communication between the shore connection cubicle and the ship's electrical systems.

- Full commissioning at the first port with appropriate infrastructure: Once the functional tests are successfully completed, the full commissioning of the shore side electricity system takes place. This typically happens at the first port that has the necessary infrastructure to supply shore power. During the commissioning process, the system is thoroughly tested and validated to ensure it functions properly and meets all safety requirements.

These activities are essential for the successful installation and implementation of shore side electricity on a cruise ship, allowing it to connect to the onshore power grid while in port, reducing emissions and environmental impact.

4.2 Preliminary Timeline and Cost Estimation

Time is a crucial factor in any project, and estimating the timeline for each activity is essential for effective project management. This section will discuss the preliminary timeline estimation for the refitting project. It takes into account factors such as the complexity of each task, availability of resources, coordination with suppliers and contractors, and any potential dependencies or constraints. A well-defined timeline estimation will assist in scheduling activities and setting realistic project milestones.

Moreover, cost estimation plays a vital role in project planning and budgeting. In this section, we will explore the preliminary cost estimations associated with the installation of SSE equipment. This includes the costs of disassembly, adaptation, equipment procurement, installation, functional testing, and full commissioning. By providing a comprehensive overview of the anticipated costs, project stakeholders can make informed decisions regarding budget allocation, resource allocation, and potential cost-saving strategies.

In this regard, the following Figure 99 depicts the GANTT Chart for the activities illustrated in the previous chapter with a preliminary estimation of the weeks required to complete each activity.

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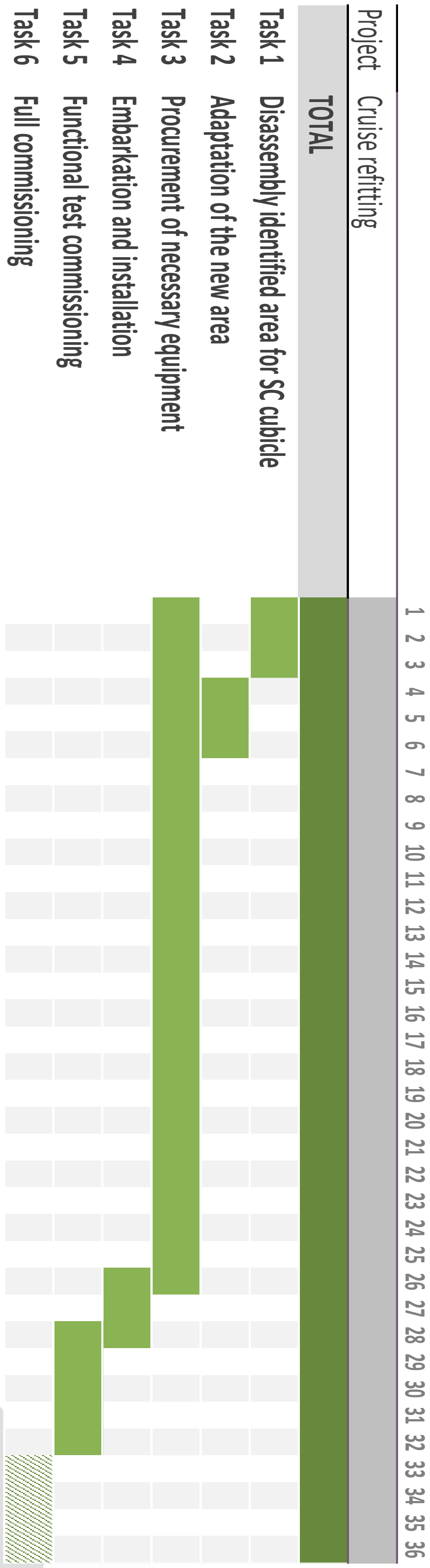

Figure 99 GANTT for the Cruise Ship refitting

Additionally, it is worth noting that the procurement phase has a significant impact on the overall completion of the activities. Sourcing and acquiring the necessary equipment, such as the shore connection cubicle and additional cubicles, can sometimes present challenges in terms of lead times, availability, and coordination with suppliers. Effective management of the procurement process is crucial to ensure timely delivery of the required equipment, minimizing delays in the refitting project.

Furthermore, the activities can be estimated in two different ways, depending on the circumstances. Firstly, they can be scheduled during a designated dry dock phase, typically lasting around two weeks. This allows for focused carpentry work to be carried out in a controlled environment, where the ship is out of the water and in a stationary position.

Alternatively, if the necessary permits for hot work are obtained, carpentry activities can be performed during the ship's navigation, typically lasting around four weeks. However, it is important to note that performing carpentry work during navigation requires strict adherence to safety protocols and regulations to mitigate any risks associated with working in a dynamic environment.

Finally, it is important to note that the final cost for the specific refitting project is estimated to be around 1.2 million euros as a lamp sum approach. However, it is crucial to consider that this estimate can significantly vary depending on the specific technical requirements of the work and the equipment to be purchased, driven mainly by the vessel size and type. Factors such as the size and type of the ship, the complexity of the installation process, the quality and specifications of the shore connection equipment, and any additional customization or modifications needed can influence the overall cost.

The estimate of 1.2 million euros serves as a preliminary guideline, providing a general idea of the expected investment with respect. However, it is necessary to conduct a detailed analysis of the project's scope, engage with suppliers and contractors, and obtain accurate cost quotations based on the specific technical specifications and requirements.

By addressing the preliminary implementation plan, work sequence, timeline estimation, and cost estimations, this chapter aims to lay a solid foundation for the successful execution of the refitting project. It emphasizes the importance of meticulous planning, efficient resource management, and effective coordination to ensure a seamless transition towards implementing shore side electricity on the cruise ship.

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5. TECHNICAL AND REGULATORY RECOMMENDATIONS

The analysis of the relevant regulations and the results of this deliverable aim to lead to technical and regulatory recommendations that could facilitate the SSE adoption by the maritime industry.

5.1 Regulatory Recommendations

Based on the analysis of specific aspects related to the onboard electrical infrastructure, vessel's arrangement, power requirements, voltage requirements and connector types in the context of maritime electrification some specific regulatory recommendations will be presented in this section.

There is a visible risk that the deadlines in some of the directives and regulations will not be met due to a lack of clarity and harmonisation in the regulations. To avoid adjustments concerning the deadlines defined in the upcoming environmental regulations in the context of Fit for 55 legislative package a set of recommendations have been developed. The purpose of these recommendations is to highlight key considerations and requirements that shipping companies, vessel operators, and port authorities should address when implementing SSE infrastructure or while planning its operation.

The aspects outlined in the list below focus on ensuring the effective implementation and smooth operation of SSE systems:

- **On the ship side, a designated person-in-charge should be assigned at the shipping company level as well as onboard the vessel**. This person-in-charge is responsible for overseeing the SSE installation and ensuring its proper operation. They act as a point of contact between the shipping company, the vessel, and the port authorities regarding SSE-related matters. Both those individuals should have a thorough understanding of SSE systems, relevant regulations, and safety procedures. This should be clearly established in the regulations.
- A main concern that has been highlighted, not only in this document but also in the previous deliverable D2.1 ("Report on the analysis of the standards relevant to shipside installation for shore side electricity supply"), and throughout the different studies performed in EALING Project Activity 2, is the **personnel safety**, both at shore and on board. This issue is explicitly mentioned in different regulations and standards, but it seems it is not sufficiently developed regarding SSE supply on the ship side. Proper training programs and qualification certificates are required, but they should be harmonized. Manuals for the crew are also requested, along with the inclusion of SSE procedures and safety measures in the Standards of Training, Certification and Watchkeeping. Training programs should cover various aspects, including SSE connection procedures, general electrical safety practices, emergency response protocols, troubleshooting techniques, and general awareness of SSE regulations and standards. This training helps personnel understand the operational requirements of SSE systems, promotes safe handling of electrical equipment, and ensures that potential risks are mitigated effectively. Operators must be certified for handling the SSE, as appropriate, and in the emergency procedures. Operators must be kept informed of any changes in safety procedures and facility operations. Regular training updates and refresher courses should be provided to keep personnel up to date with the latest practices and technologies related to SSE. The development of specific **Emergency Response Plans** is also critical. Personnel handling SSE or designing equipment for SSE systems must become familiar with the physical, electrical, and specific hazards related to it. Training should include detailed safety programs that recognize human capabilities and limitations. The goal of the safety program is to eliminate accidents and to minimize the severity of accidents that occur.
- **An SSE operational manual** should be established detailing all the needed information. The operational manual serves as a comprehensive guide for the crew and personnel involved in

the operation of SSE systems onboard the ship. It provides detailed instructions on the proper use, maintenance, troubleshooting, and safety protocols related to SSE. The manual covers topics such as SSE connection procedures, electrical system configurations, emergency response plans, and any specific requirements or guidelines set by regulatory bodies or port authorities.

- **A SSE Hazard Communication Program** should be developed, implemented, and maintained at the workplace a written hazard communication. **Annual Review shall be implemented** for all operations being performed at the installation to ensure that the safety training program is working effectively and to identify and enter into the program all potentially hazardous situations, as identified since the last review. Employee safety committees, employee representatives, and other interested groups should be provided an opportunity to assist in the identification process.
- **Designer Training.** Personnel involved in equipment design and operations planning must be trained to carefully adhere to accepted standards and guidelines and comply with the regulatory codes.
- **A Certificate of Compliance with the latest applicable IEC/IEEE standards** should be provided to the vessels. This certificate verifies that the SSE installation on the ship complies with the latest version of relevant international standards and regulations, specifically those established by the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE). It ensures that the SSE system meets the necessary safety, electrical, and operational requirements, thereby promoting the safe and reliable connection of the ship to the shore side electrical network.
- **Development of an information system which collates SSE information on EU ports** and makes it available on the Internet. This information system aims to gather and provide comprehensive SSE-related information for European Union (EU) ports. It includes details such as the port name, number of berths, types of vessels accommodated at each berth, availability of SSE infrastructure, power capacity (measured in MVA) at each berth, voltage provided at each berth, and other relevant data. By establishing and effectively operating such a system, unbiased information about SSE infrastructure across EU ports is made accessible on the internet. This promotes transparency in maritime transport and allows stakeholders to make informed decisions regarding the connection of ships to the shore side electrical network.
- **The engagement of more shipping segments** towards lowering emissions at berth by 2030 could be also promoted in EU **by providing technical guidelines for SSE installation onboard** vessels, including, where possible, standard areas for socket placement per ship type could be developed to narrow infrastructure deployment onboard.

- The statistical analysis of the Thetis MRV data (see section 2.4.3) from year 2019 provides some interesting insights about the total emissions from vessels at berth in EU ports. Regarding average emissions per type of vessel, the ones with highest emissions are passenger ships, i.e. cruise ships, followed by ro-paxes and ro-ro ships. Then, cargo vessels follow in the list, starting with oil tankers. The vessels with the lowest emissions were bulk carriers. However, regarding total CO2 emissions reported per year, passenger and ro-pax ships represent only 21% of the total contribution of emissions. Their contribution to the total is lower because they are outnumbered by other types of cargo vessels, such as tankers, bulk carriers and container ships. The highest values of total emissions per ship type in year 2019 are reported by the group of oil tankers with 24% of the total emissions, followed by container ships (19%) and ro-pax ships (12%). From the total number of vessels that reported emissions that year, bulk carriers were in the first place, followed by oil tankers in the second, and container ships in the third position. As can be seen, **SSE will surely contribute to reduce the GHG intensity of vessels calling at EU ports**, especially for passenger and ro-pax ships, but also for container vessels, bulk carriers and tankers. **A concern, however, regarding SSE is about**

its real contribution to reduce emissions. To have a more accurate view of the potential savings **the term "ship at berth"**, however, as used in the EU MRV, **needs to be differentiated between ship at dock and ship at anchorage, since SSE is applied at ships at dock.**

- **Development of an information system which collates SSE information on the ship side actual power requirements**. Another problem is the power rating of the SSE berthing positions and the onboard equipment. As described in the previous chapters, it is usual practice to dimension the ELA conditions with higher loads than they be used when at port stay. This number is usually considerably lower than the one stated in the ELA. Especially for the installations onboard, additional to cost considerations, the weight of any installed equipment and the space that this equipment occupy are important limitations. So, **the dimensioning of the equipment and the cabling is proposed to be performed according to the vessel's actual needs. To achieve that the energy consumption (KWhs) while at dock and the respective hours the vessel was at dock should be reported at the EU Thetis MRV.**

- **Expansion of the Thetis MRV public database**. The Thetis MRV is a useful repository to assess emissions at the maritime sector in Europe. The data collected from ship calls is currently including a list of variables that include information very useful from the perspective of SSE supply to vessels at berth, such as the CO_2 emissions which occurred within ports under a MS jurisdiction at berth. However, to truly assess the electricity demand from the vessels, **additional information would be needed and could be collected, such as the total time spent at berth, and the total fuel consumption as well as the fuel type while at berth.** These two variables would allow a direct estimation of power and energy needs to properly size the future SSE systems at ports. Besides, as the SSE systems become ready and operative around Europe, **the total electricity demand in SSE per vessel could also be collected and included in the repository**.
- **Development of an information system which collates SSE information electrical technical characteristics of the vessels**, such as nominal voltage, frequency, nominal capacity of generator engines, and other. This information is key to characterize the vessels' SSE needs and is not always easy to obtain. Since significant investments will be made by the ports and the ship owners, alike, for the acquisition, installation, and operation of SSE systems, it is of paramount importance to have accurate information on the expected ship side voltage levels per ship type and/or ship size and the expected percentages per voltage level. For example, let's assume that 690V is used for less than 5% of the bulk carriers' distribution network. Then the ports could be instructed not to include the 690V as an option for LV bulk carriers. And similarly, the bulk carriers would not need to install a voltage transformer onboard. This could result in saving wasted money investments and disincentivizing some ship sectors from using SSE. It should be noted that no official data are available at this point to back up the assumption that 690V are not used in LV bulk carriers. The example is included to showcase a line of thinking.
- In many cases the IEC standards allow for the port to provide different voltage levels this could result in uncertainty that could be avoided. **The IEC standards need to limit or define the available voltage options from ashore.** It needs to be further clarified for example, whether in the case of 1MVA installed in the port IEC/IEEE 80005 -1 or IEC/IEEE 80005 -3 is applicable, thus the expected voltage provided by the port. This is already seen in the FEED studies of the EALING ports where 440V, 6.6kV and 11kV were all used at different positions for 1MVA, while at the same time being compliant with the IEC/IEEE 80005 standards. This will also affect the SSE equipment installation onboard. Another example is the fact that 400V, 440V and 690V are all options and assuming that LV vessel may have 400V, 440V and 690V with the same level of probability, this results in 9 different voltage combinations, and increased investment uncertainty. Incompatibilities between the shore-side installation at berth and the installation

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onboard vessels in the case of voltage conversion were observed for the low voltage connections of vessels making the regulations for the low voltage connections of vessels ill-defined.

- As concerns the commissioning test of the SSE infrastructure upon the first arrival of a vessel, as described in the IMO interim guidelines related to the test procedures for each type of vessel could be developed for further and comprehensive performance. **Specific checklists should be provided in the Annex to facilitate both ship and port operators.** Existing checklists, like the ones used by the Port of Los Angeles, that are publicly available can be used as valuable input.
- The participation of ports that have gained experience on this subject the last years and the publication of a set of guidelines based on lesson learnt from the ports and the vessels could accelerate the wide adoption of the SSE in EU.
- **Gaps have been identified in the regulatory framework related to the** standardization of the connection, cables, and voltage the SSE installations at ports and onboard **especially for LVSC**. Some **potential regulatory overlaps** have also been found regarding training of operators and PICs, and occupational hazards' prevention. A gap is observed in the IEC 80005-1 requirements, where a separate control CMS is shown for the case of the tankers, but no further information is given. Another thing that **needs to be clarified in the IEC 80005** is that when a vessel is requiring at its higher demand condition more than one (1) MVA, but in normal port stay less than one (1) MVA, there is no limitation by the regulations to still receive HV shore supply. A detailed gap analysis regarding the SSE should be performed.
- Case specific exemptions should be identified for Deep Sea transhipping, which does not operate on fixed schedule.

5.2 Technical Recommendations

Based on these previous studies, five specific vessels have been selected, to serve as **Use Cases**, or **representatives** of most of the scope of calls at ports in the EU (and more specifically at the EALING Project ports). The resulting technical recommendations are derived by these case studies:

- As discussed in the previous chapters, various types of ships face different challenges and requirements when it comes to meeting their **thermal load demands.** Ships, in general, rely on their own onboard systems to handle heating, cooling, and temperature control functions usually by exploiting the heat of other systems (Waste Heat Recovery Systems) or by using oil-fired boilers. When ships are docked, by connecting to SSE for their electrical power needs, they are switching off the generators, making the sources of Waste Heat Recovery no longer present. At the same time, in some cases, the oil-fired boilers will need to be operated so it can meet its thermal load requirements, thus contributing to the vessel's emissions. **Specialized studies should be planned to examine the impact of the SSE and its effects on thermal energy availability.**
- In the context of implementing alternative energy sources or technologies on board ships, one of the significant challenges is finding suitable space for new equipment, such as SC cubicles and transformers. Ships have limited space available for additional equipment due to their design and operational requirements **a detailed configuration should be carried out in a case-by-case consideration** since it may be difficult to identify areas that provide sufficient room, accessibility for maintenance, and proper ventilation for heat dissipation. The installation of new equipment, especially if it requires significant modifications or the allocation of a substantial physical footprint, can disrupt the existing layout and functionality of the aft section. It may be necessary to reconfigure or rearrange other systems or components to

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accommodate the new equipment, which can be a complex and time-consuming process so timely preparation is crucial.

- The retrofitting of shore side equipment requires careful planning and adherence to international standards. **Vessels equipped with SSE systems compliant with either the previous version of the IEC standard (2012) or with other best practice/standard reference will need to perform studies to verify their compliance with the latest regulations**.
- The power cables that connect the MSB to the power transformer, specifically the LV cables, play a crucial role in distributing electrical power throughout the vessel. **By installing the power transformer as close as possible to the MSB, the negative effects of voltage drop, power loss, and voltage regulation issues in the LV power cables can be minimized.** This setup helps optimize the performance of the electrical system, improves energy efficiency, and ensures reliable power distribution throughout the vessel. The principles discussed here can be applied to other types of vessels as well, as minimizing cable length and addressing voltage drop and power loss are important considerations for any electrical power distribution system.
- One of the main issues that allows a proper supply of SSE, and affects all the vessels, is the location of the connection point. **The position of the receiving point should be strategically determined** to facilitate efficient cable routing and minimize power losses, the voltage drop and the required cables length, as well as to reduce the impact in the existing ship arrangement and operations. The last two depends on the type of the vessel mostly. The positioning of equipment in the upper deck area should not cause interference with the mooring equipment.
- To provide flexibility regarding the position of the vessel while at dock **two receiving points, one for the port and one for the starboard side, are recommended** to be installed onboard the vessel.
- **Receiving points not to be installed in the dangerous areas when it can be avoided.** When selecting the locations for SSE receiving points, it is important to avoid installing them in hazardous areas. This precaution is necessary because there are no CMS currently available in the market with an ATEX rating. By avoiding dangerous areas, the risk of potential explosions or other hazardous incidents can be mitigated.
- HV shore connection equipment may be accepted in hazardous areas provided the installation complies with the applicable regulation. In the case of the equipment being installed in a safe compartment in a dangerous area onboard the vessel, **it is unclear if in the connection/disconnection process of the plug and the socket, assuming that they are intrinsically safe, further steps need to be evaluated to be considered safe.**
- **Plug/socket power rating specification to be the same in the shore side and the ship side to ensure compatibility.** To ensure seamless connection and compatibility between shore side and ship side SSE systems, it is necessary to establish a consistent power rating specification for the plugs and sockets used. This standardization facilitates the secure and efficient transfer of electrical power between the two systems.
- **Separate ELA condition for SSE to be established.** To account for the unique requirements of SSE installations, a separate ELA condition specific to SSE should be established. This condition will consider factors such as power consumption, load fluctuations, and peak demands, enabling accurate assessment and design of SSE systems.
- The synchronization or load transfer procedure, crucial for the safe and efficient operation of shore equipment installation onboard ships should be documented as a step by step checklist for the vessel operators. It guarantees a reliable and uninterrupted power supply during port stays, enabling the ship to access the required electrical power from the shore while maintaining the necessary electrical stability and synchronization. **A comparative study of using the synchronization method versus the blackout method for the load transferring**

should be detailed to facilitate the owners understand the associated implications of each design.

- In the case of container vessels, there is a direct relationship between the power demand and the number of connected reefers. Therefore, it is important to carefully consider the power capacity the ship's electrical system will require when it carries the reefer containers. In this sense, **it would highly facilitate the connection indicating to the port the number of reefers onboard and the power required per reefer in advance.**
- For bulk carriers if the vessel has cranes on board will greatly impact its electrical demand. For tankers, the cargo unloading procedure will be much more energy consuming since it will use its own pumps. **The important parameters that affect the energy consumption for each type of vessel need to be further documented**
- One issue regarding the SSE is that different voltage levels may apply. A SSE infrastructure at berth may provide only one of these values. For this reason, **a transformer onboard with a tap changer is recommended.** A transformer can step up or step down the voltage level to match the requirements of the ship's electrical system or the available shore power source. In the case of a ship with a 440V system trying to connect to a shore power source with a different voltage, the transformer will adjust the voltage level, accordingly, enabling a safe and efficient connection. This way, ships gain the flexibility to connect to different shore power sources worldwide, regardless of the voltage variations by having a tap changer transformer for shore connection onboard.
- However, in the case of LVSC this may not be enough, since the uncertainty regarding the voltage level provided by the shore will also affect the rest of SSE interface equipment onboard, as shown. **In this case, sizing the low-level voltage electrical infrastructure to the maximum voltage (690 Vac) is an option to be considered**. This voltage level has been identified as suitable for SSE operations, offering a balance between power transmission efficiency (also reducing the number of cables needed for LV operations) and electrical safety.
- **Tension bars to be included as standard safety equipment.** Tension bars are essential safety components that should be included as standard equipment in SSE installations. These bars help prevent accidents caused by the sudden release of tension in the electrical cables, ensuring the safety of personnel and equipment.
- **No access and maintenance areas to be established near the receiving points.** To maintain safety standards, it is crucial to establish designated areas near the SSE receiving points where access is prohibited for non-authorized personnel. This ensures that personnel are not exposed to potential electrical hazards during operation and maintenance procedures.
- **Impact to vessel's lightweight to be assessed:** The implementation of SSE systems may have an impact on the lightweight of vessels. It is important to evaluate and assess this especially for the installation of Transformers, if this can be avoided with proper design. Proper consideration of the additional weight introduced by SSE equipment and infrastructure is crucial in maintaining the vessel's overall performance and safety.

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6. CONCLUSIONS

The installation of SSE systems onboard different types of vessels is examined and presented in this report, along with our findings and interpretations. Our aim is to make a meaningful contribution, within the limitations of our study, to the existing knowledge base and to inspire further research in the area of shore side electricity supply to maritime vessels.

Based on the data presented the SSE is a viable solution, both in newbuilds and existing vessels, towards a greener shipping achieving the 2030 FIT-for-55 objectives. Crucially this seems to be applicable not only for the passenger and container vessels, currently targeted by the regulations, but for cargo vessels, too.

Pre-FEED (feasibility) design studies for five types of ships were presented, a cruise ship, a Ropax vessel, a containership, an oil tanker and a bulk carrier. The purpose of these five FEED studies is to present the critical limitations and parameters and to ensure a comprehensive approach into the implementation of the SSE. Safety, operability, minimizing disruption to existing vessel operations, cost-effectiveness, and the maximization of cooperation between port and vessel stakeholders are encompassed in our focus. By these essential aspects being addressed, the development of sound solutions that optimally meet the diverse needs of all parties involved is aimed to be facilitated.

These aspects are collected and summarised in section 5 of this document, separated in regulatory and technical recommendations, to facilitate adaptation and connectivity of ships to Shore Side Electricity (SSE) in the EU. These recommendations from the ship side complement the recommendations for a harmonized SSE framework from the shore side, collected and described in the document "Milestone 6 - Final recommendations for a harmonised framework on OPS in EU ports", performed as an outcome of the studies performed in Activity 1 of the EALING Project.

With these recommendations as the basis and the presented problems effectively addressed, the possibility of refocusing on other specific safety issues arising from daily operations and the formulation of further recommendations and solutions becomes feasible. Through the context gained, the relevant stakeholders can be better positioned to develop targeted and precise safety recommendations to further facilitate and promote the use of SSE in the maritime industry.

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