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D4.1: Performance Assessment Framework and KPIs

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Acronyms and Abbreviations

Acronym/Abbreviation	Meaning
AoA	Analysis of Alternatives
AiP	Approval in Principle
CAPEX	Capital Expenditure Costs
CH_4	Methane
CI	Carbon Intensity
CII	Carbon Intensity Indicator
CINEA	Climate, Infrastructure and Environment Executive Agency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CONOPS	Concept of Operations
DoD	(Battery) Depth of Discharge
EC	European Commission
EMEA	Europe, Middle East, and Africa
EMEP	European Monitoring and Evaluation Programme
EROI	Energy Return on Investment
EU	European Union
EU-ETS	European Union Emission Trading System
EO	Expected Outcome
GA	Grant Agreement
GHG	Greenhouse Gases
GT	Gross Tonnage
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicator
kW	kilowatt
kWh	kilowatt hour
LCA	Life Cycle Assessment
LCoE	Levelised Cost of Electricity
LCoS	Levelised Cost of Storage
LCP-families	LCA-Comparison Product families
LFP	Lithium iron phosphate battery
LMA	Long Market Analysis
LNG	Liquified Natural Gas
M&S	Modeling and Simulation
MCDA	Multi-Criteria Decision Assessment
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
mt	metric ton

MW	Megawatt
MWh	Megawatt hour
N_2	Nitrogen
NO_x	Nitrogen Oxides
NPV	Net Present Value
NTQ	New Technology Qualification
NTQP	New Technology Qualification Plan
NTUA	National Technical University of Athens
OPEX	Operational Expenditure Costs
OPS	Offshore Power System
PM	Particulate Matter
PSM	Power Supply Module
RAINS	Regional Air Pollution INformation and Simulation
ROI	Return of Investment
SFOC	Specific Fuel Oil Consumption
SO_x	Sulfur Oxides
SSS	Short Sea Shipping
tCO_{2eq}	total CO_2 equivalent emissions
TtW	Tank to Wake
WP	Work Package
WtW	Well to Wake
VAT	Value Added Tax
VNMOC	Volatile Non-Methane Organic Compounds
VPF	Fundación Valenciaport
VRFB	Vanadium Redox Flow Battery

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1 - Executive Summary

BlueBARGE offers a sustainable, fossil-free alternative towards decarbonisation and is dedicated to delivering a modular, scalable, adaptable and flexible design approach. The proposed approach/rationale sets the environmental aspects derived from all project activities as the focal point of the decision-making process. It considers the continuing rise in international trade, which has significantly increased ship transportation, a trend expected to continue in the foreseeable future and aims to develop a power barge primarily designed to supply offshore power to anchorage vessels. In addition, the barge can be used for several other use cases identified in the context of D2.1, such as offshore power supply services in ports where the grid is power-limited. Additionally, BlueBARGE could be used to ensure the resilience of the local grid in the event of a disruptive event or high demand. To achieve its objective, the BlueBARGE project will follow the process presented in Figure 1.

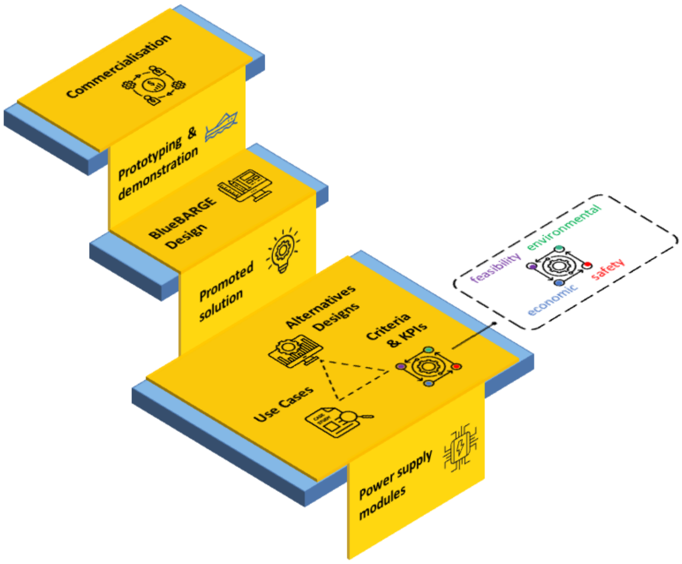

Figure 1 - BlueBARGE Methodology

Specifically, the methodology which is established in Part B of the GA includes:

i) the design and technical development of the Power Supply Modules (PSMs);
ii) the detailed definition of use cases, assessment criteria (including environmental and financial KPIs), and alternative designs for the power-barge concept;
iii) the selection of a promoted solution based on a three-fold approach of use cases, criteria and alternative designs;
iv) the basic and detailed design of the promoted solution;
v) the development of the prototype and its demonstration;
vi) the road towards commercialisation.

Along with the PSMs, integrating the energy systems and the technical development of port-barge, barge-vessel, and barge-grid interfaces are essential aspects of the design, development and testing of the power-barge solution. The establishment of a holistic approach requires assessment criteria that include environmental, economic, safety, and technical feasibility aspects. To ensure the validity of the developed results, BlueBARGE builds upon solid use cases, assuring the results are in line with respective requirements, highlighting the need to comply with the idiosyncrasy of different European ports with non-identical infrastructures, regulatory framework, support schemes, geopolitical characteristics and technological advancements.

The assessment framework aims to identify the most environmentally advantageous barge design among available alternatives (presented in D5.1) and the leading reasonably-priced and competitive technology for electricity supply, considering the significant external costs involved. This deliverable outlines the framework for evaluating the effectiveness of different power barge designs and enhancing the recommended solution. It also includes the establishment of Key Performance Indicators (KPIs) and provides arguments that stimulate decision-making discussions in assessing T4.2- BlueBARGE alternatives and optimum design.

The established methodology facilitates further engagement from different perspectives, considering the stakeholders' roles, opinions, and interests. The involvement of key stakeholders, including policymakers and regulatory bodies, in the assessment procedure, enables the project's impact on policy development and implementation.

The assessment considers monetised environmental considerations and various cost factors influencing expenses. These factors include fuel prices, taxes, electricity rates (billing and metering), the ecological ship index, port fees, depreciation, the existing infrastructure for charging the barge, and the interconnected grid and energy mix in each European Union (EU) country. Other factors that pertain to the assessment are the reliability of the supply of alternative fuels and safety, which focuses on preventing accidents.

However, the current geopolitical situations impose uncertainties that cannot be reflected in a sensitivity analysis or historical data and can exhibit significant volatility. Consequently, it is essential to note that the data utilised during the evaluation phase will rely on forecasts derived from official information that will be accessible during the relevant tasks. These calculations will undergo review by stakeholders, including vessel and terminal operators, as well as port service providers. Furthermore, the costs will reflect technical assumptions pertinent to specific applications. Since electricity and fuel prices are subject to fluctuations and depend on consumption figures, this deliverable will not discuss these aspects in detail.

1.1 Purpose of the Document

This document depicts the framework for assessing BlueBARGE's alternative designs in T4.2 and later the promoted design in T4.4. Additionally, it articulates the overall value proposition of the technology innovations and validates the sustainable integration of these technologies within the BlueBARGE project. It aims to equip evaluators with a foundational understanding to facilitate deeper discussions within the project. The decision to adopt battery PSMs for electricity power operations instead of alternative fuels extends beyond mere financial assessments within a closed port services ecosystem; it considers emerging technologies, new operational risks, infrastructure availability, and governmental policies.

The document aims to provide a thorough assessment and design optimisation framework regarding advancements in external power supply and its crucial role in the shipping industry's decarbonisation efforts. It is founded on the interrelationship among the developed framework, the project's objectives and baseline capabilities needed to minimise the design's environmental and financial impact while maximising its performance, as described in the Grant Agreement (GA). In line with the project's methodology, it seeks to engage the stakeholders in the assessment, keeping them informed about the current landscape and emerging technology trends and exploiting their expertise and valuable inputs.

1.2 Intended readership

BlueBARGE's Performance Assessment Framework and KPIs are publicly accessible online deliverables that consolidate all research and findings generated in prior project work and deliverables. This report is intended for consortium members and interested readers.

1.3 Relation to other deliverables

Several tasks will provide input to assess the BlueBARGE design alternatives and optimise the promoted solution. The GA's KPIs and additional technical criteria combined with the following will be used for this purpose:

- Use cases and energy demands described in the deliverable D2.1- "BlueBARGE use cases, technical specifications and requirements".
- PSMs that are recognised as zero-emission technologies regarding Greenhouse Gases (GHG) emissions in D3.1- "Power supply modules and microgrid specifications". The technical requirements elaborated in D5.1- "BlueBARGE design alternatives".
- The results of the safety assessment process that will take place in D2.2- "Technical and operational safety assessment report".

D4.1 will provide adequate measures, criteria, and metrics to support the high-level assessment of the BlueBARGE alternatives in D4.2- "Design alternatives evaluation report". The established framework, developed in the context of T4.1 following a Multi-Criteria Decision Assessment (MCDA), will form the basis for developing an advanced assessment and optimisation tool, as depicted in the description of D4.3- "Advanced assessment and optimisation tool." It will further support the overall performance assessment of the promoted solution in D4.4- "BlueBARGE overall performance assessment."

1.4 Document Structure

The deliverable is structured into four sections, with the current section as the introduction. Section 2 outlines the definition and methodology for designing an Assessment of Alternatives and Optimisation Framework. Consequently, Section 3 illustrates the development of BlueBARGE's unique Framework, elaborating on the selected assessment criteria to quantify the impact of the proposed alternative designs and optimise the promoted solution. Section 4, titled "Conclusions and Recommendations", provides the preliminary results of the framework's development. Annex 1 and Annex 2 outline the process, measures, criteria, and metrics for the high-level and detailed assessments. Annex 3 provides supporting and complementary criteria and measures that enhance the Technical Requirements related to Deliverables 3.1 and 5.1. Finally, Annex 4 specifies the documentation and evidence required for the issuance of a New Technology Qualification (NTQ) Statement of Maturity.

2 Assessment of Alternatives and Optimisation Framework

BlueBARGE's Assessment and Optimisation framework aims to assist decision-makers in understanding the attributes of the alternative designs to meet operational requirements while providing an analytical foundation for evaluating the performance attributes, as documented in subsequent materialisation phases of the project. It facilitates decision-quality analysis and results that inform decision-makers and other stakeholders at the next milestone or decision point. In essence, it highlights the capabilities and commercial value of the alternatives. The assessment results will empower stakeholders to discuss the appropriate trade-offs among cost, schedule, performance, and risk and evaluate the operational capabilities and affordability of the alternative designs developed in the project. Ultimately, these results will guide decision-makers in shaping and scoping courses of action for new material solutions to address operational capability needs and developing the roadmap for the development phase of the promoted design.

This approach is the analytical foundation for the performance parameters outlined in the relevant project requirements documents. It is worth mentioning that effectively utilising an assessment of an alternative design framework also offers recommendations for modifications to validated capability requirements that may seem unachievable or undesirable from the perspectives of cost, schedule, performance, or risk.

The development of such a framework is typically influenced by several key factors such as the purpose of the study, the initial guidance provided in the project statement, the baseline characteristics of the system, human factors, the assessment of system risks, and the Concept of Operations (CONOPS). The variables that determine the proposed designs and serve as an input to the framework mainly are:

- The high-level operational tasks and supporting sub-tasks.
- The expected conditions and operating environments under which the tasks must be performed according to the project's ultimate objectives are outlined.
- A comprehensive operational concept and context for the necessary capability and employment/use cases.
- The comprehensive description of the initial baseline capability, which is based on the proposal and includes the identification of all critical systems contributing to the various alternative designs.
- The specific capability gaps of the baseline identified by the analysis.
- A collection of potential equipment and equipment approaches to fill the gaps/shortfalls defined during the design sequence.
- The determination of the associated novel technologies.
- The associated operational risks that require evaluating potential material and resource solutions to mitigate those risks.
- The quantitative and qualitative measures, initial thresholds, and objective criteria related to the functions of the designs, that will be used to calculate the framework outputs.
- Finally, the decision-makers' views and recommendations on the proposed framework before finalising it and executing the assessment.

2.1 Overview of Evaluation Process

As mentioned, every project or plan should have a clear purpose (what is intended to be accomplished) and a justification for the project's team scope or need (the rationale behind the project). Alternatives are crafted to fulfil the purpose and address the identified needs. An objective analysis process for evaluating these alternatives is essential to compare them impartially, allowing for a reduction to a final set or a single preferred alternative. However, professional judgment and subjectivity may be required in the decision-making process, as it can be complex. Figure 2 illustrates the overall evaluation process (Arnold et al., 2024).

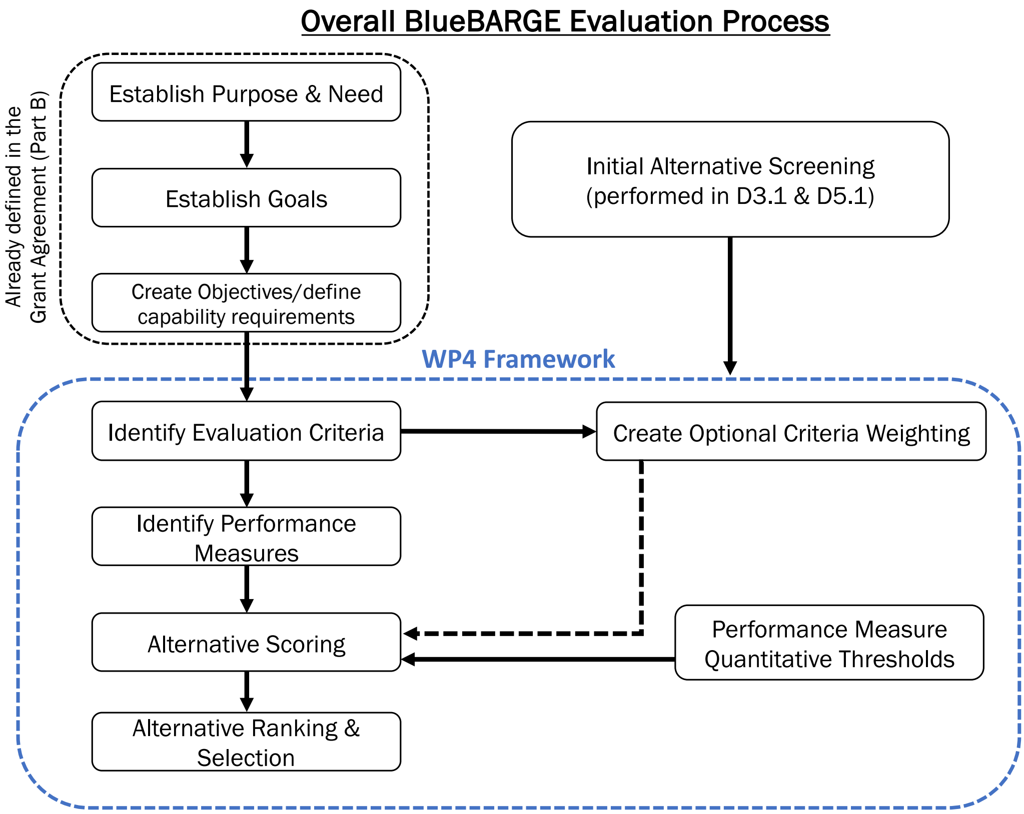

Figure 2 - Overall Alternative Evaluation Process

The purpose, scope or need are articulated into specific goals and objectives and quantified using evaluation criteria and corresponding performance measures. They may also establish policies that align with these goals and objectives. The results of the alternatives analysis, determined through performance measures, are converted into scores that are then totalled and ranked, leading to the selection of the top alternative(s). This screening process may be repeated multiple times, each iteration providing greater detail and specificity regarding the evaluation criteria and performance measures (Analysis of Alternatives (AoA) Handbook A Practical Guide to the Analysis of Alternatives, 2017).

Goals are overarching principles categorised based on safety, mobility, multimodal transportation, environmental impacts, ease of implementation, socio-economic effects, accessibility, and economic development. Typically, safety, mobility, and multimodal goals are mandated by current policies, while additional goals may be introduced through discussions with project teams and stakeholders. Some planning projects may emphasise policies alongside goals. Each goal is supported by multiple objectives that provide clear direction for achieving the goal. These objectives focus on specific topics to allow for quantification. It is important to note that goals can sometimes conflict; pursuing one goal may significantly impact another. Thus, the overall alternative analysis process involves a careful balance of compromise, cooperation, and collaboration among all team members and stakeholders.

Screening is the first stage of the overall assessment process. Some screening procedures are necessary due to the numerous projects and activities that may require further assessment. At an early stage, this alternative design screening, as an initial assessment, should be performed, sometimes before the assessment framework is developed, and shall be continued until the development of robust alternative designs, as knowledge increases. The screening aims to identify the proposals that satisfy project needs, and exclude those that do not. It is based on desktop criteria intended to ensure that the form or level of any further assessment is commensurate with the importance of the issues raised by a proposal. The designs that will successfully surpass the initial screening process will be finally assessed via the corresponding framework. To that extent, the initial assessment of some alternatives considered early may be possible because they are non-viable (e.g., cannot execute the required mission or have very low maturity levels). At the same time, as the analysis progresses, additional alternatives may be screened out, for various reasons, including poor performance, high risk, or higher costs than comparably performing alternatives. Figure 3 illustrates an indicative alternative screening as an ongoing process.

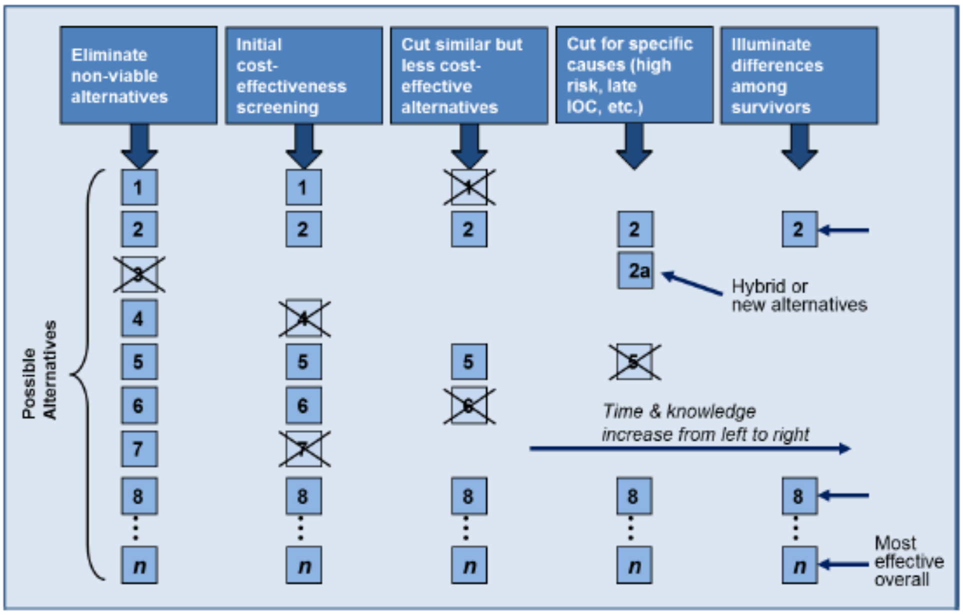

Figure 3 - Screening of alternatives Process

The qualified designs through the alternative design screening are assessed through a framework based on evaluation criteria established from the objectives to guide the analysis of alternatives. In the case of weighting these criteria, it is crucial to determine the weights before conducting any alternative analysis, to prevent the introduction of bias. Various methods exist for assigning weights, typically resulting in quantitative index values that can be consolidated into a singular value for each alternative. Weights are generally assigned based on the relative significance of each goal, often through consensus or a vote among the project team(s). If weighting is employed, it must be clearly articulated to clarify why specific criteria are prioritised over others. Thorough documentation of the weighting process is essential to mitigate the appearance of subjectivity. Weighting can also assist in balancing trade-offs between differing objectives, such as the need for increased mobility versus minimising environmental impacts. However, transforming this process into a purely mathematical exercise is not always feasible, especially when multiple sensitive issues are involved, as doing so improperly may lead to further complications.

According to the screening stage, the evaluation criteria must be adequately defined, quantifiable, and data-based (Erikson, 2014). Usually, they differ based on the level of detail regarding the phase of alternatives' evaluation processes. For example, these processes may include screening based on purpose and need (fatal flaw), screening based on goals and objectives, operational-based screening (comprehensive, detailed analysis, micro-simulation, etc.) and final assessment of alternatives. Furthermore, these criteria should be monitored by establishing performance measures to measure various aspects of interest as part of the analysis. These measures are essential to the assessment and underpin the conclusions drawn. When well-developed and articulated, measures will:

- Specify what to measure
- Determine the type of data to collect
- Identify how the data is collected
- Identify resources required to perform data collection
- Identify how the data can be analysed and interpreted

The measures development process is depicted in Figure 4.

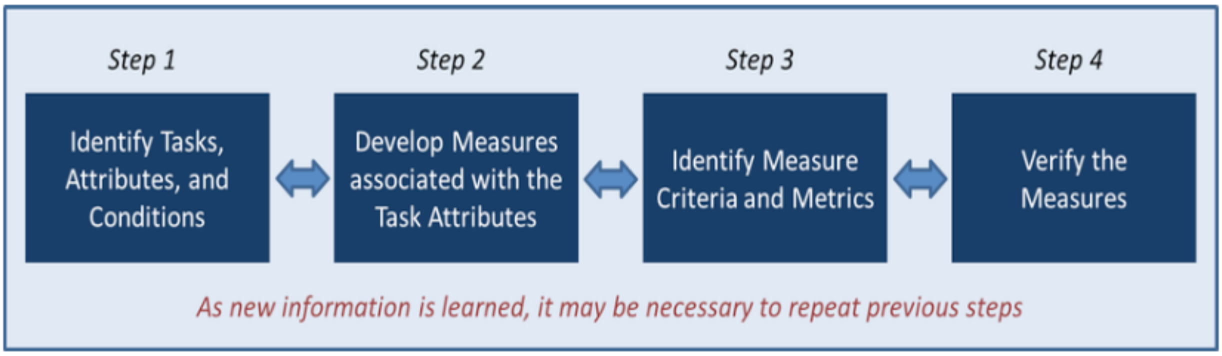

Figure 4 - Measure Development Process Steps

Specifically, the steps to be followed are the following:

- Step 1: The first step is identifying tasks, attributes, and conditions. Tasks are linked to the project's mission and outline the required actions and their purpose. Analyzing these tasks helps clarify execution requirements and the context, specifying when and where they should be performed. This analysis enables framework developers to understand how task performance contributes to the project's success.
- Step 2: Developers can formulate measures after identifying tasks, attributes, and conditions. A measure offers insights into an attribute's dimensions or quantity. Analysts should refer to project documentation for guidance in developing measures for screening analysis and AoA. Literature reviews, expert input, and brainstorming sessions can help obtain the information needed for effective measures.
- Step 3: To identify measurement criteria, developers should first examine any user-established criteria found in the capability's requirements document, such as official project documentation. If such documentation is lacking, they must establish new criteria, known as

identified criteria, from sources like CONOPS, project deliverables, prior AoAs, and relevant studies. Engaging with subject matter experts can also help refine these criteria.

- Step 4: Finally, it is important to verify that each measure is properly stated and relevant to the task and attribute.

Developers may establish a framework for further measures to outline the attributes and metrics associated with each task and the data collection and analysis methods employed in the study. The framework informs the study team, stakeholders, and oversight groups about the essential elements of each measure and analysis process. Sometimes, they may need to apply different data collection and analysis methods for specific measures. This approach is necessary when the systems, concepts, or alternatives being evaluated exhibit varying levels of maturity and definition. Such data collection and analysis-related methods are:

- Literature Review
- Expert Elicitation
- Survey Research (questionnaire)
- Brainstorming
- Modeling and Simulation (M&S)
- Parametric Analysis
- Comparative Analysis
- Concept Characterization
- Sensitivity Analysis
- Cost-Capability Analysis

Each performance measure may include additional metrics to categorise the results into, such as:

- Met Threshold
- Met Objective
- Did Not Meet Threshold- Not a Significant Shortfall
- Did Not Meet Threshold- Significant Shortfall
- Inconclusive or Not Assessed.

Additionally, applying weighted evaluation criteria would further refine the scores for each alternative, ultimately leading to a single, comprehensive score for each option.

Sometimes, creating and utilising an evaluation matrix for all options is helpful for effectively evaluating alternatives. Alternatives that meet the fundamental criteria should be considered. Those who successfully pass this initial screening should undergo a thorough assessment, which includes operational performance analysis, project refinement, and relevant preliminary cost estimates. In a collaborative environment, the alternative evaluation process must involve the project team, stakeholders, decision-makers, and other pertinent participants.

2.2 Factors of Influence

Subsequent paragraphs of this section outline, in alphabetical order, key factors that shape the environment for developing an assessment framework and offer insights to aid planning and execution (Analysis of Alternatives (AoA) Handbook A Practical Guide to the Analysis of Alternatives, 2017).

2.2.1 Assessment Methodology

The framework should at least capture what data collection, analysis and assessment methods are being considered and focus on guidance for the assessment team to follow when developing the assessment methodologies in the framework plan. Regardless of the level of understanding at this point, the following fundamental aspects of the effectiveness, cost, and risk analyses should be considered during the development framework:

- Mission tasks.
- Specific tools or techniques that the framework plans to use or is considering (e.g., official reports, parametric analysis, expert elicitation).
- Cost capability analysis and other sensitivity analyses will be conducted.
- Objectives, scenarios, CONOPS and use cases that will be used or are being considered.
- A cost analysis approach that describes the development of life cycle cost estimates and what they include (e.g., research, development, test and evaluation, procurement, operations and support, and disposal costs), then-year and base-year estimates.
- Risk assessment methodology under consideration.
- Plan to present framework methodology for review and approval of decision-makers and other stakeholders.
- The framework should fully address operational and non-operational risks in operational, schedule, cost, and technology/manufacturing readiness assessments.
- Measures, metrics and criteria for the evaluation.

2.2.2 Baseline Capabilities

A frequently overlooked aspect of study scoping is a thorough understanding of baseline capability. The framework developers must clearly understand the baseline capabilities used to identify the capability gaps which the alternative designs assessment aims to address. These baseline capabilities are usually detailed in the proposal section of the contract and include legacy systems, their approved modifications, and any existing or planned systems. The alternative options developed during the project execution should be realistic and firmly rooted in industry standards overarching the baseline capabilities. It is essential to avoid fabricating idealised alternatives that lack an industry basis. Additionally, the overall baseline capabilities within the operational effects chain, typically consist of many more components than just a single system or piece of equipment under consideration. For example, an assessment centred on alternative PSMs for a power barge should also consider the full spectrum of capabilities and limitations of the baseline platform (the barge), rather than solely focusing on the legacy power modules.

2.2.3 Common Pitfalls to Avoid in Assessments

There are several pitfalls' analysts should avoid when studying and assessing measures. One such pitfall is the use of measure weighting schemes. Measure weighting schemes can oversimplify results and potentially obscure important information since the weighting depends on the group determining the weighting, and may not be representative of what stakeholders, senior leaders, or decision-makers would consider noteworthy.

When a measure weighting scheme is used, such as in the context of a MCDA, the analyst should ensure the weighting values are developed by a group of experts with the appropriate experience and expertise. A group of at least six experts is recommended to ensure that diverse opinions are considered. Although using one or a few experts may require less effort on the assessment analyst's behalf, using a group of experts will lend much more credibility to the weighting values. Ideally, the group should provide a range of possible weighting values for each measure or item (e.g., a task) to enable the analyst to conduct a sensitivity analysis later in the study. The weighting values may be reviewed and approved by the contract sponsor, study oversight group (Advisory Board (AB)), stakeholders, or decision-makers involved in the study. Finally, the analyst may need to conduct a sensitivity analysis to demonstrate the stability of the results to changes in weighting values within the specified ranges associated with the measures or items.

Another pitfall to avoid is the inappropriate analysis of ordinal data. Ordinal data is a type of data usually collected through questionnaires or interview questions; for example, in cases of collecting data for a measure through a questionnaire, which exhibits the properties of ordinal data (i.e., data are assigned numbers such that the order of the numbers reflects an order relation based on the attribute).

2.2.4 Ground Rules, Constraints and Assumptions

Establishing clear ground rules, constraints, and assumptions during the project initiation phase is crucial for effectively scoping the assessment and minimising bias. Despite their significance, these concepts often need to be understood, leading teams to incorrectly label many elements, as assumptions, when this designation is inappropriate. These terms can be defined as follows:

- Ground rule: A broadly stated procedure that governs the assessment's overall process, conduct, and scope. For example, decision-makers will review and approve the description of the baseline capability before the study team proceeds with the development of the framework.
- Constraint: A constraint is an imposed limitation that may be physical, programmatic, or policy-related. Physical constraints include human physical or cognitive limitations and a specific operating frequency range. A programmatic constraint can be illustrated by establishing the latest acceptable date for adopting a new initial operational capability. Meanwhile, a regulatory framework serves as an example of a policy constraint.
- Assumption: A supposition that something is true, which can address various aspects related to the scope and support of the analysis. Examples may include specific workforce levels, including an alternative fuel type projected to proliferate in the future (thereby necessitating consideration of a particular system), or the expectation that another project will provide specific infrastructure or architecture.

The framework should identify key ground rules, constraints, and assumptions likely to influence the results and address essential components such as use cases, scenarios, and CONOPS used in the assessment. Ground rules, constraints, and assumptions unlikely to impact the results are less important and need not be included in the framework.

2.2.5 How many metrics are needed?

The choice of the amount and depth of metrics is a planning function that seeks a balance between risk and cost. It depends on many considerations, including system complexity, organisational complexity, reporting frequency, the number of the assessment team members, consortium size, past performance and effectiveness of similar frameworks, policy and visibility, and project type.

2.2.6 Innate Restrictions

Consequently, the framework should delineate any limitations regarding the analysis's depth and impact on the overall assessment. This involves identifying which study questions still need to be answered, which elements will not be evaluated, and which analyses will be excluded. As elaborated in the former paragraph, constraints related to time and resources and restricted access to specific data may limit the study's scope or undermine the validity of its findings. While risk mitigation strategies may be available, the framework should guide the merits of the survey even without feasible mitigation options. Additionally, given that the study's scope can significantly influence the results, the study lead should engage regularly with key stakeholders and senior leaders during this planning phase. Multiple revisions may be necessary before an appropriate framework is achieved.

2.2.7 Level of Analysis

Obtaining or estimating cost and performance data for an alternative modification to an existing system is typically straightforward for the assessment team. Conversely, gathering data for a new technology can present significant challenges. Consequently, evaluating a future system's performance may not be as thorough as evaluating a current system's performance. It is essential to inform decision-makers of all study-related risks and their implications throughout the process. When risks are identified, discussions should be focused on potential courses of action that involve tradeoffs to mitigate those risks, such as allocating additional resources, narrowing the project's scope to adhere to a tight schedule, or screening alternatives early to allocate resources effectively. This approach ensures that the level of effort and associated risks are deemed as acceptable by all stakeholders involved in the project.

2.2.8 Level of Effort

Another step is to realise the effort necessary to develop and configure the appropriate MCDA tool and plan and carry out the assessment. Understanding the required level of effort is crucial for the development of the framework, as it can influence various components of the evaluation, including the size and composition of the assessment team (specifically, the expertise and experience needed and the diversity of subject matter experts), its overall duration and the complexity of the assessment tool. The level of effort is dictated by factors such as the scope of the assessment, the assessment questions, the complexity of the problems being addressed, the analysis of the requirements (including the extent of data collection and the sophistication of analytical methods), as well as any constraints related to time and resources (such as workforce and specialised expertise). These considerations should be addressed and resolved during the regular project progress meetings.

2.2.9 Stakeholders

A key parameter for developing the assessment framework is the involvement of individuals, governmental agencies, services, or organisations with a vested interest in the study's outcome. These entities, referred to as stakeholders, may directly or indirectly engage in assessment-related activities and typically experience the effects of decisions based on these activities. In the process of identifying members of the stakeholder community, the following questions shall be considered:

- Who are the end-users of a specific capability?
- What enablers are being analysed in the assessment, such as regulatory framework, environmental factors, safety measures, autonomous systems integration, logistics, externalities, and interdependencies within the solution space?

Thus, involving stakeholders in the assessment process offers numerous advantages. The assessment team needs to incorporate representatives from the stakeholder community. Engaging stakeholders can foster buy-in and enhance understanding of the challenges, capability gaps, risks, and potential solutions while also aiding in identifying feasible alternatives.

2.2.10 Study Risks

In addition to alternative risks, the team should also consider the study risks. When determining the level of effort, it is essential to identify areas of study risk associated with any time or resource constraints in the study. Study risks and how they are mitigated can affect the assessment tool's configuration, the team's size and composition, and the study's overall conduction. Usually, these risks are associated with the planning and conduction of the assessment. They differ from the risks that will be assessed for the baseline and alternative capabilities in the risk assessment part of the project. They must be identified early and addressed to the consortium members so that the appropriate scope, time, and resources are continuously reviewed in the context of the project's provisions. Time and resource constraints are typically major root causes of study risks. For example, a study conducted with limited time and resources may reach different conclusions (or conclusions based on reduced rigour) than those undertaken with less constrained time and resources. In this example, the less constrained study could employ more suitable, yet time and resource-consuming, data collection and analysis methods compared to the more constrained study. Not only may the results be different, but the level of confidence in the results may vary given the different employed data collection and analysis methods.

2.2.11 Timeframe

The framework must also consider the timeframe of interest during the assessment. This encompasses the projected timeline for delivering solutions to address or mitigate capability gaps. By establishing a precise timeframe of interest, the assessment team can define the operational context for the evaluation in a more effective way. Moreover, the framework should consider the number of alternatives to be analysed and assessed, and whether the analysis can be completed within the available time and resource constraints. In certain instances, grouping similar concepts and analysing a single representative from each group may be feasible. In all cases, alternatives should remain broad at the desktop stage.

3 BlueBARGE Framework Analysis

The following section outlines the core elements of the assessment and optimization framework as specified and stipulated in the provisions of the GA.

3.1 Purpose

The shipping industry is responsible for around 3% of global greenhouse gas emissions, which is expected to increase as international trade and shipping activity grows. As such, reducing emissions from shipping is an integral part of global efforts to tackle climate change. In recent years, policies and legislation, mainly focusing on environmental sustainability, have pushed international shipping toward the process of its decarbonisation. Regulatory bodies are pressing on the maritime world by adopting ambitious targets and by introducing several initiatives that will facilitate the transition to a sustainable future, including the International Maritime Organization's (IMO) strategy to reduce greenhouse gas emissions from shipping, which aims to halve emissions from the sector by 2050 compared to 2008 levels.

3.2 Scope

To this end, BlueBARGE will design, develop and demonstrate an optimum power-barge solution to mainly support offshore power supply to moored and anchored vessels, limiting local polluting emissions and global GHG footprint in a life cycle perspective, following a modular, scalable, adaptable and flexible design approach which will facilitate its commercialisation by 2030. The proposed power-barge solution will consider different alternatives, such as containerised PSMs in various configurations, where battery modules will serve as the basis due to their high energy efficiency and readiness level, and other modules considered include hydrogen fuel cells and hydrogen generators. The project will address electrical integration issues, interfacing challenges of the barge with ships, ports and local grid, operational safety and regulatory compliance aspects, delivering a high-readiness and complete "power bunkering" solution. Overall, the BlueBARGE project's fully integrated system aims to contribute to shifting the maritime industry towards electrification and decarbonisation at an EU and international level.

3.3 Objectives and Baseline Capabilities

The following paragraph outlines the specific project's Objectives and Baseline Capabilities. Objectives related to the assessment result from the Work Programme and Call are described in paragraph 1.1.1 of GA's Part B, and related to the assessment framework as follows:

- **Objective 1 (O1):** Design an optimised power-barge innovative solution by considering different alternatives and configurations of containerised PSMs, following a modular, scalable, adaptable and flexible design approach.
- **Objective 3 (O3):** Showcase the reduction in GHG and other polluting emissions for all BlueBARGE use cases through relevant KPIs and prove the environmental benefit of the innovative power-barge solution considering a life cycle perspective.
- **Objective 4 (O4):** Assess the power-barge solution's financial viability and commercial attractiveness, including all applicable costs, and deliver a commercialisation plan for its deployment before 2030.
- **Objective 5 (O5):** Perform a detailed safety assessment covering the power-barge solution's technical and operational aspects and assess regulatory compliance.

Following the above, GA, WP2, and WP3 detail the baseline capabilities, outlining use cases, requirements, and specifications for the power barge and PSMs. Technical requirements, including design alternatives, are further evolved and refined in Deliverable D5.1.

3.4 Identification of Measures and Criteria

The assessment will encompass several parameters and attributes identified in the project proposal and by design developers as critical or essential capabilities. They will, in turn, define measures, criteria and metrics that will vary qualitatively and quantitatively between the high-level assessment of alternative designs and the detailed assessment of the promoted design. The system performance attributes, considered **critical** for developing effective operational capability, are measured via criteria connected with given KPIs within the GA. They will serve as **"Go/No-Go" criteria, and will not be weighed.** The KPIs related to the assessment framework are presented in Table 1, along with their implementation based on the assessment level (high-level or detailed).

Table 1 - Objectives and KPIs associated with the Assessment Framework

No	Proposal Objective	No #	KPI Description	Level of Assessment
O1	Design an optimised power-barge innovative solution by considering different alternatives and configurations of containerised PSMs, following a modular, scalable, adaptable and flexible design approach.	1	**KPI 1.3** Scalable solution should be able to cover 95% of commercial fleet of container ships and passenger vessels, including cruise ships, of at least 5,000 Gross Tonnage (GT)	High - Level
		2	**KPI 1.4** Achieve at least 3-Megawatt (MW) discharge power and 35 MWh power capacity through the BlueBARGE promoted design	High - Level
O3	Showcase the reduction in GHG and other polluting emissions for all BlueBARGE use cases through relevant KPIs, and prove the environmental benefit of the innovative power-barge solution considering a life cycle perspective	3	**KPI 3.1** Showcase emission reduction through at least 10 environmental KPIs	High – Level and Detailed
		4	**KPI 3.3** Showcase the reduction of noises and vibrations up to 80% during barge service, compared with the actual onboard energy generation	High – Level and Detailed
O4	Assess the financial viability and commercial attractiveness of the power-barge solution by including all applicable costs and deliver a commercialisation plan for its deployment before 2030	5	**KPI 4.1** At least 20% net savings from investing in BlueBARGE	Detailed
			KPI 4.3 Limited – or even non – conflict with regulatory framework	Detailed
O5	Perform detailed safety assessment covering all technical and operational	6	**KPI 5.1** Issue New Technology Qualification (NTQ) Statement of Maturity for all innovations	High – Level and Detailed

	aspects of the power-barge solution and assess regulatory compliance	7	**KPI 5.2** Address all identified high-risk areas with at least 1 risk control measure	Detailed
		8	**KPI 5.3** Approval-in-principle (AiP) by classification society granted	Detailed

Additional performance attributes are considered important for achieving a balanced solution or approach to the system, but they are not critical enough to be classified as KPIs. **Instead, these attributes will be evaluated via weighted criteria based on their significance for each umbrella use case.** Attributes marked with "SHOULD" in the Technical Requirements sections of Deliverables 3.1 and 5.1 are **vital** for the system's overall integrity. The framework handles them as key system attributes. Performance attributes that do not reach the level of significance to be categorised as KPIs or key system attributes yet are still **essential** to the framework are classified as additional performance attributes, and are denoted by the notation "COULD" in the Technical Requirements sections of Deliverables 3.1 and 5.1. Other system attributes that are not explicitly mentioned but **relevant** to the framework, marked by the notation "MAY" in the Technical Requirements. For weighting, the hierarchical significance levels among these attributes are classified as SHOULD, COULD, and MAY.

According to the provisions of the GA, the above-mentioned criteria for both the high-level and detailed power-barge performance assessment are grouped into four categories/pillars:

- Environmental KPIs (e.g., tCO2eq in absolute values and/or per kWh and/or per anchorage waiting hours, respectively, for NO_X, SO_X and PM), indicating the reduction in emissions per use case for a particular representative scenario.
- Financial KPIs [e.g., Capital Expenditure Costs (CAPEX), Operational Expenditure Costs (OPEX), Net Present Value (NPV), Return of Investment (ROI)], considering an estimation of the market energy supply price in €/KWh and competitive prices for the provided service, indicating mainly an early assessment of related costs.
- Technical feasibility criteria, based on technical, operational and safety requirements (e.g., power supply thresholds, minimum and maximum discharge time, fuel availability, infrastructure availability) produced during the early phase of the project.
- Safety criteria, which are based on an early safety assessment (e.g., multiple identified hazards, high probability of occurrence, lack of risk mitigation measures).

3.5 Assessment Methodology

An initial screening assessment was conducted in T5.1 based on the various energy supply modules and their configurations identified in WP3, eliminating non-viable alternatives. A secondary screening of alternative designs will rely on the data availability from manufacturers of relevant subsystems and equipment that make up each alternative. Designs that are too general or lack essential information will be excluded due to the difficulty in assessing feasibility. Additionally, designs that are only inventory studies and do not support further development, innovation or project's objectives and outcomes, will also be disregarded in the last screening phase.

A high-level assessment, as detailed in Annex 1- High-Level Assessment of Design Alternatives, will take place following the screening phase. This comprehensive assessment of all proposed alternatives will be conducted on a "Go/No-Go" basis, to evaluate their adherence to the provisions of the GA, through their validation against some high-interest parameters and attributes referred to as KPIs in the GA. Their compliance with the threshold values, defined in KPI1.3 and KPI1.4, outlines the necessary performance and operational benchmarks each alternative must meet to move forward. In addition to technical compliance, each alternative's environmental impact will be scrutinised according to the guidelines outlined in KPI3.1 and KPI3.3. Furthermore, safety considerations will be evaluated by the provisions of KPI5.1. This assessment will include a review of each alternative's eligibility for issuing an NTQ. Assessing these three critical areas- technical, environmental, and safety- ensures that the options selected for advancement meet the project's crucial baseline requirements. Only the designs that fulfil these KPIs will be further assessed through a MCDA methodology, combining all aspects under one framework, associating umbrella use cases and various capabilities, and introducing criteria related to significant environmental impacts, costs, risks and technical feasibility requirements. MCDA will consider incorporating fuzzy set theory represented by linguistic values or numbering for the overall assessment. This approach will assess and compare the different solutions based on multiple criteria to identify the most sustainable, viable, and practical design choice.

The assessment will be interactive, allowing different stakeholders' (industry partners, Advisory Board members, stakeholder network- as defined in GA and in D2.1) influence to be systematically investigated in an integrated system of team thinking, transparency and multi-decision making. Assessors will weigh criteria only related to capabilities according to their significance for each umbrella use case. Applying a weighted scoring system (W_{ij}) that differs for each j^{th} umbrella use case (j=1…3) and i^{th} category / pillar of criteria (i=1…3) ensures a balanced and thorough comparison of all alternatives, facilitating informed decision-making. The Weight factors- dictating the relative importance- will be freely judged by the reviewers/experts according to the CBA Multi-criteria assessment tool in T4.2. The process outlined will be systematically applied to each umbrella use case. Reliability of evaluation and consistency in the interpretation of conclusions will be achieved by assigning further weight factors to each evaluator, associating his knowledge background with the nature of the evaluation criteria. However, it is important to point out that the final design that will be promoted and implemented will be a single, unified design, consolidating insights and elements from all the use cases.

To evaluate the alternatives' environmental performance, each option will be scored from best to worst based on their fulfilment of KPIs, specifically KPI3.1 and KPI3.3, as outlined in Table 3. This scoring identifies which alternatives align most closely with the project's sustainability objectives. Once scores have been assigned, a Monetized Life Cycle Assessment (LCA) will follow, focusing exclusively on the impact categories associated with KPI3.1. This will involve quantifying environmental impacts in monetary terms, which facilitates a more precise comparison among the alternatives. Applying a different weight factor for each of the three umbrella use cases, designated as W_{1j}, to the results of the assessment of the environmental performance will help prioritize the importance of various impact categories within KPI3.1. This ensures that the evaluation accurately reflects the project's specific sustainable goals and values.

In assessing the alternatives' financial aspects (FA), they will be ranked from most favourable to least favourable based on the results from the calculation of the Levelized Cost of Storage (LCOS), using high-level key criteria such as operational costs (OPEX), capital expenditures (CAPEX) of the PSMs, and the time required to bring each option to market. A weight factor denoted as W_{2j}, will be applied to these criteria for each umbrella use case to enhance evaluation accuracy. This will ensure that the comprehensive analysis of the financial viability of each alternative highlights its overall impact on the assessment process.

The Technical Feasibility criteria assessment comprehensively evaluates the various alternatives based on how effectively they meet the technical requirements outlined in KPI1.3, KPI1.4, and the deliverables D2.1 and D5.1. Each alternative will be scored from best to worst, considering baseline capabilities, efficiency, autonomy, modularity, and scalability factors described in Annex 3-Complementary Technical Feasibility Criteria. A weight factor, W_{3j}, will be assigned to the pillar, with a different value for each umbrella use case, reflecting its relative importance in the overall assessment.

In assessing the safety criterion, the alternative options will be evaluated and ranked objectively from best to worst based on the effort and time required to comply with KPI5.1, as detailed in Annex 4-Plans for NTQs, and the results of a high-level safety assessment as outlined in Task 2.3. Assessment results will be assigned a weight factor that varies for each umbrella use case, designated as W_{4j}, to reflect its importance in the overall evaluation process.

The assessment will yield a score for each alternative, enabling a ranking that, in turn, highlights a promoted design. The ranking will follow TOPSIS theory according to the inherited set-up of the multi-criteria tool in T4.2. If needed, the ranking procedure will be supplemented by the following equation that represent each design:

$$S_{i=1}^{5} = \sum_{j=1}^{3} W_{1j} \cdot EA_{ij} + W_{2j} \cdot FA_{ij} + W_{3j} \cdot TFC_{1j} + W_{4j} \cdot SC_{ij}$$

This equation involves various weighted contributions from the different factors, with W_{ij} representing the weights, and EA_{ij}, FA_{ij}, TFC_{ij}, and SC_{ij} denoting the respective environmental, financial, technical feasibility and safety attributes of the design.

The final full-scale design of the promoted solution will be further assessed, as described in Annex 2-Detailed Assessment and Optimisation of the Promoted Solution, through a detailed calculation of the identified environmental KPIs and additional financial KPIs [e.g., net present value (NPV), return of investment (ROI), average annual benefits, payback period)] related to the investment to promote commercialisation. Safety will be further enhanced through proposed risk mitigation measures (i.e., risk control measures and options) to be integrated into the design process, following the standards of risk-based design. Optimisation will be introduced through a revision and update of the promoted design by implementing the test results from the prototype demonstration, as described in WP7.

Figure 5 depicts the BlueBARGE Assessment and Optimisation Framework. The framework and the overall assessment process are developed using data collected through literature review, expert elicitation, survey research (questionnaires), brainstorming sessions, and concept characterization.

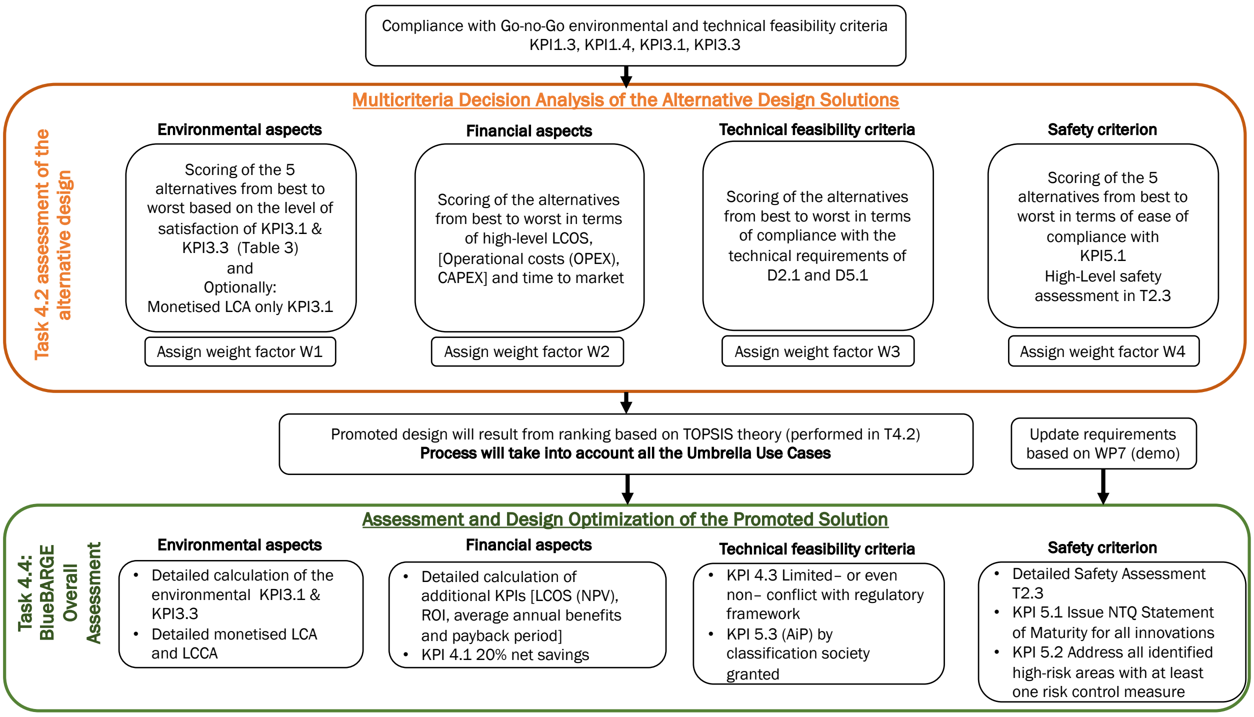

Figure 5 - BlueBARGE's Assessment and Design Optimisation Framework

3.7 Constraints and Assumptions

BlueBARGE is recognised as an effective strategy for minimising air emissions from ships while berthed; however, its implementation presents several challenges since maritime transport has difficulty adapting to continuously evolving frameworks. Each port has a distinct culture, layout, business climate and backgroung, types of ship calls, operational practices, local air quality issues, and surrounding communities. Furthermore, ship owners frequently hesitate to adopt the latest innovations and technologies due to concerns about efficiency and costs. However, except for the localised nature of the prevailing considerations regarding the adoption of the BlueBARGE concept, some globally unified ground rules, constraints and assumptions can be categorised into several key areas.

3.7.1 Ground Rules

Each alternative design will be checked against the availability of the appropriate data provided by the relevant subsystems and equipment manufacturers to make the assessment feasible and limit the number of assumptions and uncertainties regarding the development. These pertain to a design that is too general in its description, lacking essential information, making it difficult to assess its feasibility, thus excluding it from further assessment. This approach also excludes a design that is an inventory study, which does not provide a springboard for additional development, it is not innovative and does not contribute to the expected outcomes (EO) specified in the 2023-D5-01-14 topic.

Energy for berthed vessels, primarily generated from Marine Gas Oil (MGO), produces GHG emissions, local air pollution, and noise. Implementing BlueBARGE power supply systems can significantly reduce pollution and noise levels in harbours. The European Union Emission Trading System (EU-ETS) is a regulatory framework designed to manage GHG emissions, encompassing all 28 EU member states and the European Economic Area countries of Iceland, Norway, and Liechtenstein. The EU-ETS includes over 11,000 high-energy-consuming installations, such as power stations, industrial plants, and airlines, collectively accounting for about 45% of the EU's GHG emissions. **Transitioning to**

BlueBARGE power means that the ship doesn't produce emissions that fall into the EU-ETS, indicating that using this power source will not lead to additional emissions.

According to Annex III of Regulation (EU) 2023/1805 (Office of the European Union, 2023) which details the general requirements for zero-emission technologies, Lithium iron phosphate (LFP) batteries, Vanadium Redox Flow Batteries (VRFB), Fuel Cells and supercapacitors- collectively referred to as **PSM in D3.1- are recognised as zero-emission technologies regarding GHG emissions**. Beyond GHG emissions, addressing air pollution from local contaminants is crucial. Improving air quality is a significant public health concern, particularly in densely populated areas like major trading ports. Since combustion processes are the primary source of these air pollutants, adopting **a power barge running on batteries or fuel cells zeroes a vessel's environmental impact.**

Utilising an external power supply for vessels at berth is an effective option that removes the necessity for onboard power generation. This approach significantly reduces generator noise and vibrations, diminishing the engine room ventilation requirement. **As a result, the overall noise and vibrations from a ship's engine room and a barge equipped with battery or/and fuel cell PSM are also expected to be zero, thus fulfilling KPI 3.3. Showcase the reduction of noises and vibrations up to 80% during barge service, compared with the actual onboard energy generation**(Noise from Ships in Ports. Possibilities for Noise Reduction, n.d.)**.**

3.7.2 Constraints

A primary constraint is **the substantial expense of the shore-side power infrastructure required to charge the BlueBARGE.** Consequently, the costs of building shore-power-ready terminals will differ markedly, and to some degree, these expenses will be passed on to the barge owners. Thus, implementing BlueBARGE, in addition to the fixed costs, places utility rates at the forefront of factors influencing the program's cost-effectiveness. These rates can differ significantly based on various factors such as location, the transmission grid and the power source for charging the barge, seasonal demand, and overall consumption. For example, grid connection costs are heavily influenced by the availability of grid capacity, which can change due to local demand and the necessity for grid reinforcement. Ship owners often view onboard power generation for anchored vessels as more familiar and cost-effective. This perception largely stems from the fact that it mainly involves fuel expenses without the extra costs associated with land-side power transformation, transmission, barge charging, and the logistics of manoeuvring the barge alongside the ship.

To that extent, **investment costs will reflect current conditions and fluctuate over time.** Additionally, there is considerable uncertainty surrounding fuel price variations. Any increases or decreases in the prices of MGO and Liquified Natural Gas (LNG) will affect the validity of the assessment and lead to variations in the price difference between total electricity charges and MGO prices. Furthermore, the ship owners can employ several alternatives to fuel oil in the future, such as direct combustion of LNG on vessels, liquid biogas, hydrogen, methanol, and ethanol. **The availability of these alternative energy sources poses constraints regarding the time frame for amortising investments in BlueBARGE as an alternative to onboard genset-fuelled solutions.**

Other constraints **include the increased power demand from a port shore power program, the existing power infrastructure, and local supply;** additional power sources may be required to charge a fleet of barges. Furthermore, the origins of land-side power generation, such as biomass, coal, natural gas, wind, and solar, are often perceived as merely shifting emissions from marine vessels to local power plants, which could also contribute to an increased load on the regional grid.

BlueBARGE heavily relies on shore power, which is generally more expensive than using marine fuel oil, to operate onboard generators. As shore power has become a mandatory requirement for EU ports, it could diminish their competitiveness unless they possess a unique geographic advantage. Consequently, cargo and goods may be redirected to other ports with fewer air quality concerns. **This shift could lead to increased land-based transportation (whether by rail or truck) to deliver goods to their intended destinations, ultimately straining the existing transportation infrastructure and merely reallocating the impacts of air emissions.**

3.7.3 Assumptions

The designed barge offers notable flexibility, enabling it to adjust power output, voltage, and frequency according to customer requirements. It will adhere to international Offshore Power System (OPS) standards, facilitating connections for ships. This relatively new technology and publicly available pricing primarily arise from pilot projects, making it difficult to estimate the cost of a new power barge solution accurately. However, insights from consortium partners and subject matter experts will inform the pricing used in this assessment.

The anticipated number of port calls, average laytime, and power demand for the calculation period will be obtained from port log data and information supplied by the relevant port authorities. **They will be assumed stable in order to ensure consistency throughout the assessment period.** Minor fluctuations in traffic are not expected to affect the utilisation of the BlueBARGE, thus it could be assumed that they will not impact the overall results.

Based on the information collected for T2.1 (and presented in D2.1), it can be concluded that the most cost-effective candidates for using BlueBARGE electric power are vessels with high hoteling power demands, frequent port visits, and significant time spent at berth during each call. These characteristics contribute to significant annual energy consumption (MWh), resulting in greater potential for emissions reductions and higher penalties associated with EU-ETS compliance. **However, for the assessment described in the context of this deliverable, it can be assumed that container and passenger ships are open to electrification through BlueBARGE.**

Regarding the OPEX, BlueBarge is a floating power station supplying electricity stored in the PSM, as outlined in D3.1. This power barge is particularly suitable for operation in harbours and remote locations, offering an environmentally friendly alternative to MGO. In the current project, it is assumed that a third party owns and operates the BlueBARGE. The owner can purchase electricity from the port's grid and sell it to vessels. It's important to note that the proposed PSMs are not a stand-alone solution; therefore, the owner will incur costs related to grid connection or grid tariffs. The cable handling costs for the power barge are anticipated to be comparable to those of a shore-to-ship solution. **The operation and maintenance expenses associated with the power barge are affected by the type and number of PSMs and auxiliaries installed on it. An appropriate efficiency factor will be used to calculate the energy costs for each alternative solution.**

Reported electricity costs vary significantly based on annual consumption and maximum power requirements. While Statnett's Long Market Analysis (LMA) cites around €43 per MWh before taxes for 2030, as shown in Figure 6 (Gunnerød et al., n.d.), industrial electricity price data suggests higher prices. Simultaneously, in Europe, tax rates range from zero to €0.03/kWh. Additionally, there is a standing charge, a fixed amount paid to the electricity supplier as a connection fee based on the maximum power consumption.

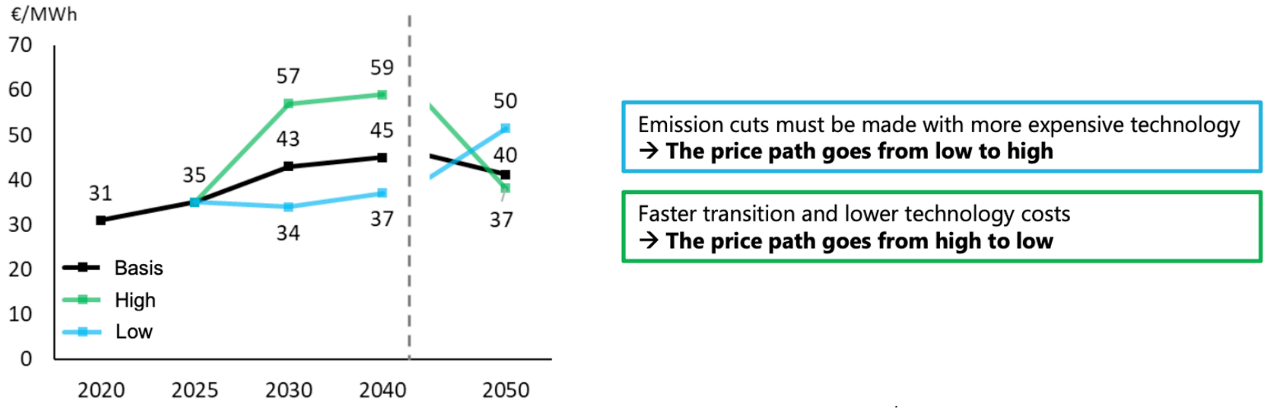

Figure 6 - Power price scenario from Statnett's LMA 20

Total electricity charges are determined by the ports' purchasing price of electricity and encompass three key components: the electricity price, grid tariffs, and national taxes and levies. It's important to note that total electricity charges can also differ within each country, influenced by local variations in grid tariffs and multiple price areas. **The assessment will consider the total electricity charges in the different ports for 2030, given the EUROSTAT forecasted industrial electricity prices in the EU for huge consumers, including taxes (excluding Value Added Tax (VAT) and other recoverable taxes and levies) and grid tariffs; it is assumed that the electricity price will evolve by the available price forecasts.**

Ship owners may be inclined to accept a higher price for electricity sales than initially projected in their business cases. This willingness may stem from a desire to showcase environmental responsibility, or enhance passenger comfort by reducing noise and pollution while anchored or docked. Furthermore, the variations in overall electricity charges at different ports will likely affect ship owners' readiness to pay for electricity. Cruise vessels are expected to be less willing to pay in ports with higher total electricity costs than those with lower overall electricity expenses. **Therefore, it is assumed that ship owners will require a reduction or a flexible tariff scheme in the electricity sales price to consider adopting shore power at a level determined by subject matter experts during the assessment.**

Several EU member states require ship owners operating their vessels in EU ports or near the coast to switch from bunker oil to distillate oil (0.1% sulfur). This makes BlueBARGE a cost-effective option for boats that frequently visit these ports. The average price of distillate oil is significantly higher than that of bunker oil, and potential fuel cost benefits depend heavily on legislation. Savings from using shore-generated power rather than auxiliary diesel engines rely primarily on current fuel prices. The switch to 0.1% sulfur fuel in the EU in 2010 has notably improved the cost-effectiveness of Short Sea Shipping (SSS), as it involves the use of MGO, which in the middle of October 2024, was approximately US $225 per tonne more expensive than IFO380, at a Europe, Middle East, and Africa (EMEA) average bunker price (World Bunker Prices, 2024), excluding supply charges to the ship. **A forecasted average price for EMEA up to 2030 will be used for the assessment, with supply charges determined by expert judgment.** Another critical issue is the need for auxiliary engine maintenance. **Ships must keep their auxiliary engines for port visits without SSS and use at sea, and reduced engine usage saves, on average, €2 per running hour per engine in operation and maintenance costs, excluding fuel** (Homer Pro, n.d.). **As the price of MGO is quoted in dollars, the European Central Bank's reference rates will be used to convert dollars to euros during the assessment** (EURO - US Dollar Reference Rate, 2024).

Given this price difference and the imposed EU-ETS tariffs, ship owners may be concerned about the potential financial advantages port authorities might gain at their expense, which could ultimately decrease over time. From an economic perspective, the European carbon price has averaged €85.3 per ton in 2023, reaching a new record high since its establishment in 2005 (YAN QIN, 2024). In May 2020, the average price of Carbon Dioxide (CO_2) in the EU-ETS exceeded 50 € per ton, doubling since early November 2020. The EU's new target has primarily driven this surge to reduce emissions by 55% by 2030, along with growing confidence in the emissions trading system and greater certainty that the EU's objectives will be upheld and potentially strengthened. Factors such as the annual emission settlement period and the withdrawal of allowances through the Market Stabilization Reserve have also contributed to this price increase. The market has also seen a rise in the number of financial players. While an increase in CO_2 prices was anticipated, it occurred earlier in the 2020s than many analysts had forecasted. Consequently, as shown in Figure 7 (Gunnerød et al., n.d.), **most external analysts have significantly revised their projections, now expecting the price of CO_2 to reach around 70 €/ton by 2030, a price to be considered during the calculation of OPEX due to EU-ETS charges** (Gunnerød et al., 2021.), **for assessment purposes.**

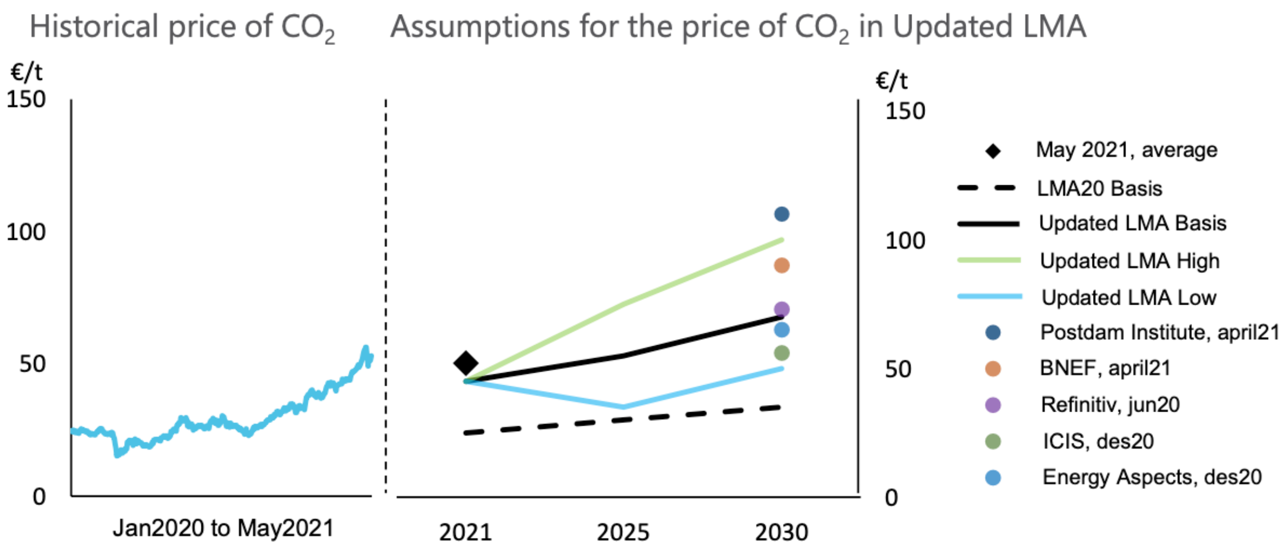

Figure 7 - Price of CO_2 trends

At the international level, initial regulations in the sector primarily adopt a Tank Wake (TtW) approach, as evidenced by frameworks such as the EU's Monitoring- Reporting- Verification, the International Maritime Organisation (IMO) Data Collection System, and the Carbon Intensity Indicator (CII). These frameworks do not take upstream factors into account. Adopting a Well to Wake (WtW) approach for assessment is essential, as multiple variables can influence BlueBARGE's sustainability ranking. **The lack of formal information regarding the Carbon Intensity (CI) of MGO production hinders the calculation of GenSets emissions from a WtW perspective, so current information from Classification Societies will be utilised.**

While berthed, the emissions released by ships result from fuel combustion in their marine ICE; thus, they are mainly related to engine technology. Local pollutant emissions can be managed by controlling combustion technology and exhaust gas treatment and managing fuel quality; both approaches address emissions. The regulations outlined in Marpol Annex VI focus on the desired outcomes rather than prescribing specific methods for compliance. Technologies for reducing emissions include enhanced engine design, fuel injection systems, and electronic timing to maximise efficiency, thereby reducing CO_2, PM, and VNMOC emissions. Other methods include Exhaust Gas Recirculation to alter the physical properties of Internal Combustion Engines charge air, Selective Catalytic Reduction to convert NO_x to Nitrogen (N_2) and water (H_2O), Selective Non-Catalytic Reduction to reduce NO_x using a reducing agent, and seawater scrubbing to remove SO_2 and reduce PM. However, according to European Monitoring and Evaluation Programme (EMEP) guidelines, they have yet to be systematically adopted from the maritime sector. Therefore, **abatement emission technologies and methods cannot be explicitly and systematically considered for the computation of emissions during the BlueBARGE project.**

4 Conclusions and Recommendations

In light of the initial results from the assessment framework, implementing the BlueBARGE initiative can notably reduce external costs, compared to the overall system costs. This suggests that BlueBARGE has the potential to position ports and shipowners as local environmental leaders and responsible stewards, with socio-economic activities designed to benefit the surrounding communities. Such an approach can help to counter the perception of ports and ships as "pollutants" and lay the groundwork for strengthening their environmental initiatives and collaboration with residents. By prioritising ecological concerns and a socio-economic approach like BlueBARGE, a port enhances its vital role within the community, thus creating a "win-win" scenario for all stakeholders involved.

The assessment framework must utilise established criteria and set proficiency standards, as these elements are crucial for success. One key conclusion derived from the analysis is that pursuing a more ambitious framework than what has already been outlined in the GA is not considered feasible. This is mainly because such a pursuit would significantly complicate the assessment. Moreover, the current global geopolitical landscape, combined with the technical and commercial reliability of the necessary information, further limits the feasibility of the evaluation.

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6 Annex 1- High-Level Assessment of Design Alternatives

Annex 1 portrays the evaluation process and several measures, criteria and metrics for the power-barge high-level performance assessment. Initially, all alternative designs must meet the standards set by the ground rules of the GA and the KPIs 1.3, 1.4, 3.1, and 3.3, which will serve as "Go/No-Go" criteria. The assessment will be conducted by considering a set of KPIs to be utilised in the framework, focusing on environmental aspects (e.g., tCO2eq, tNOX, tSOX, and tPM) as well as financial elements (e.g., CAPEX, OPEX). These indicators will be based on various technical parameters (e.g., capacity, power output, charging time). Technical feasibility will be evaluated based on the fulfilment of specific technical requirements described in the GA. Furthermore, safety will be incorporated as a criterion, informed by the risk levels assessed through the safety evaluation process in T2.3, in alignment with the risk-based design approach.

6.1 Environmental Assessment

GHG emissions typically represent the most important KPI for most companies and businesses, and the EU expects them to address their climate change impacts. Thus, the environmental KPIs outlined and weighted in Table 2, on a scale from 1 to 5 (Environmental Key Performance Indicators Reporting Guidelines for UK Business, n.d.) are aligned with Task 4.1, which identifies a set of KPIs to be used in the framework regarding environmental aspects, thus fulfilling the demands of Objective 3 (O3).

Table 2 - Weighted Environmental KPIs

KPI	Pollutant	Significant Direct KPI
3.1	Greenhouse Gases (CO_2, CH_4, N_2O in tCO2eq)	1
	Acid Rain, Eutrophication and Smog (SO_2, NOx, NH_3, CO)	2
	Particulate Matter (PM) 2.5 & 10	3
	Volatile Non-Methane Organic Compounds (VNMOC)	3
3.3	Noises and vibrations	3

Environmental KPIs such as total CO_2 equivalent emissions (tCO_{2eq}) in absolute values and per kWh, as well as waiting hours for Nitrogen Oxides (NO_X), SO_X, and PM, indicate the reduction in emissions for specific usage scenarios. The term CO_{2eq} emissions refers to the amount of CO_2 emissions that would have the same overall impact on the Earth's radiative balance over a specific period as the emitted quantity of a GHG or a combination of GHGs. To calculate the CO_{2eq} emission, the emission of a GHG is multiplied by its 100-year Global Warming Potential for the given time horizon. In the case of a mixture of GHGs, the CO_{2eq} emission is determined by adding together the CO_{2eq} emissions of each gas. While CO_{2eq} emissions provide a standard scale for comparing emissions of different GHGs, it does not imply that the corresponding climate change responses are equivalent (Climate Change 2014: Synthesis Report: Longer Report, 2015).

In the proposed framework, the environmental high-level assessment model evaluates emissions reduction per unit of energy consumed by containerships and passenger ships while at berth, anchored, or moored compared to the use of the BlueBARGE. **Using ENTEC's Shore-Side Electricity assessment methodology** (European Commission Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-Based Instruments Task 2a-Shore-Side Electricity Final Report Entec UK Limited, 2005), **which compares only the relevant Emission Factors without further extended calculations, BlueBARGE will show its superior environmental performance against on, indicating that no further extensional evaluation is necessary.**

6.1.1 Emission Factors and SFOC for Ships Using Marine Diesel/Gas Oil

GHG emissions (CO_2, CH_4, N_2O) can be calculated as tCO_{2eq} from the fuel oil consumption of the ICE generators onboard the ship, using Marine Diesel Oil (MDO) or MGO according to the TtW methodology of Regulation (EU) 2023/1805 1 (Office of the European Union, 2023), and Emission Factors of Table 3.

Table 3 - GHG Emission Factors for Ships using Marine Diesel Oil/Marine Gas Oil

Pollutant	Value	Unit
CO_2	3.206	$gCO_2/gFuel$
CH_4	0.00005	$gCH_4/gFuel$
N_2O	0.00018	$gNO_2/gFuel$
CO_{2eq} WtT	51.84	gCO_{2eq}/kWh
CO_{2eq} WtW	645	gCO_{2eq}/kWh

As Table 3 shows, when addressing GHG emissions in a WtW approach, a typical value of MGO's emissions is 645 gCO_{2eq}/kWh (Alternative Fuels Outlook for Shipping an Overview of Alternative Fuels from a Well-To-Wake Perspective Methanol Lpg Biofuel Lng Ammonia Hydrogen, 2022; By et al., n.d.). Table 4 shows the emission factors for computing local air pollutants responsible for acid rain, eutrophication, smog, PM 10, and VNMOC.

Table 4 - Local Pollutants Emission Factors and SFOC for Ships during Hotelling

Diesel Engine Type	Fuel Type	CO g/kWh	NOx Tier 0 g/kWh	NMVOC g/kWh	PM10/2.5 g/kWh	SO2 Kg/tfuel	SFOC gf/kWh
High-speed	BFO	1.1	8.53	0.649	1.03	19.2	235
	MDO/MGO	1.1	8.53	0.649	0.649	1.82	224
	LNG	2.92	0.566	0.38	1.80E-04	1.82	196
Medium-speed	BFO	0.974	10.8	0.397	0.93	19.2	203
	MDO/MGO	0.974	10.8	0.397	0.215	1.82	194
	LNG	2.92	0.566	0.38	1.80E-04	1.82	169

6.1.2 BlueBARGE's Emissions

BlueBARGE's emissions occurred during the PSMs' operation and the grid's charging. According to Annex III of Regulation (EU) 2023/1805 (Office of the European Union, 2023), which details the general requirements for zero-emission technologies, LFP batteries, VRFBs, Fuel Cells and supercapacitors- collectively referred to as PSM in D3.1- are recognised as zero-emission technologies regarding GHG emissions. Beyond GHG emissions, addressing air pollution from local contaminants is crucial. Improving air quality is a significant public health concern, particularly in densely populated areas like major trading ports. Since combustion processes are the primary source of these air pollutants, adopting batteries or fuel cells can substantially reduce a vessel's environmental impact.

To calculate the emissions induced due to the charging of BlueBARGE's PSMs in a WtW approach, the information presented in Table 5 will be used, which pertains to the CI values associated with the countries of origin for the ports detailed in D2.1. This data will be essential for calculating the emissions resulting from electricity consumption during the charging procedure. The assessment will utilise real-time values sourced from Electricity Maps (Electricity Maps, n.d.), which will serve as informational references within the scope of the deliverable. The initiative organises worldwide electricity data to support shifting towards a decarbonised electricity system. It provides data from electricity consumption for over 200 zones worldwide, employing state-of-the-art approaches to collect data from official sources and using various techniques to estimate missing data. A flow-tracing pipeline is then utilised to determine the flow of electricity and its CI between countries, providing comprehensive information on CI for production and consumption in each country.

Table 5 - CI of Consumed Electricity

Country	CI [grCO2eq/kWh]	% RES
Belgium	178	34
Canary Islands	763	19
Cyprus	711	20
Denmark	132	81
Egypt	554	12
Estonia	291	52
France	53	28
Germany	372	59
Gibraltar	640	0
Greece	365	48
Italy	279-554	54-33
Lithuania	188	67
Malta	460	10
Netherlands	297	46
Poland	750	29
Portugal	154	72
Romania	312	47
Slovenia	248	46
Spain	154	53
Sweden	17-40	100-61
Turkey	437	39
United Kingdom	200	47

The CI factors displayed on the map are emission factors computed based on the lifecycle of utilised fuels and generation technologies. These factors are primarily sourced from the Intergovernmental Panel on Climate Change (IPCC) (Climate Change 2014: Synthesis Report: Longer Report, 2015), which consolidates emissions estimated by numerous peer-reviewed studies and is considered the global standard for measuring the Global Warming Potential of different electricity sources. The calculation of CO_{2eq} emissions from electricity consumption for a specific zone considers the electricity production within that zone or country, the electricity exchanged between countries, and how it was produced in neighbouring countries. This process, referred to as flow tracing, involves tracing back the origin of the electricity.

Table 6 presents the average emission factors for local pollutants during electricity generation, utilising EU emissions data from the Regional Air Pollution Information and Simulation (RAINS) model and electricity production statistics from the European Commission report on Energy and Transport Trends to 2030.

Table 6 - Average Local Emission Factors for EU Electricity Production

Pollutant	Value (g/kWh)
NOx	0.35
SO2	0.46
NMVOC	0.02
PM 10/2.5	0.03

6.1.3 Life-Cycle Assessment

A "cradle-to-grave" assessment of alternative designs is required to fulfil KR3.1 for the Environmental Assessment of design alternatives (WP4, T4.2) and KR3.2 for BlueBARGE environmental performance (WP4, T4.4). The analysis will compare different configurations of the energy supply system, including its related life cycle stages, such as manufacturing, operation, and end-of-life. Adopting a life cycle approach to emission reduction is essential for understanding the complete environmental impact of each design and preventing potential burden shifting (Istrate et al., 2022).

The evaluation will encompass the systems from CORVUS, ELKON, ENEROX, MMS, and REGBES, respectively. The Bill of Materials will define the system boundaries without chemical composition, and the Impact Assessment will be conducted accordingly. Alternative designs constitute a group of products sharing traits suitable for comparing their Life Cycle Assessment (LCA) results. They meet the criteria of Scalability and Pragmatism, which are inherent in the BlueBARGE project, thus forming a Life Cycle Comparison family (LCP family) (Collado-Ruiz & Ostad-Ahmad-Ghorabi, 2010). To that extent, the assessment will exclude standard systems or subsystems among the alternatives, qualitatively and quantitatively, including the same type and quantity of equipment/machinery.

Various methods have been established to provide a standardised approach for assessing the environmental impacts of products. These methods employ LCA to evaluate a product's environmental impact throughout its life cycle stages from raw material extraction and manufacturing to distribution, usage, and final disposal. The main goal is to enable accurate and consistent communication of a product's environmental footprint to consumers. These methodologies categorise ecological impacts into the distinct areas of Figure 8 (What are the Environmental Impact Categories?, n.d.), acknowledging through weighting factors that not all contribute equally to the product's overall environmental impact, typically represented by a single score.

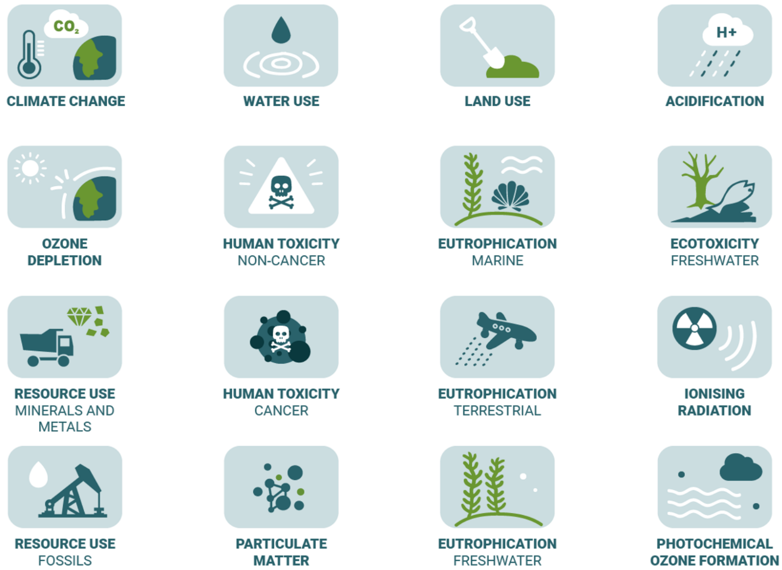

Figure 8 - Environmental Impact Categories

To that extent, the use of environmental prices to weigh impacts in LCA indicates the relative value of various emissions and is used to compare products. In LCA, the focus is on the mutual comparison of emissions, with weighting factors reflecting the socio-economic weight of environmental impacts. These factors were developed based on the ReCiPe characterisation method but can also be adapted to other methods like Centrum voor Milieuwetenschappen2 and Product Environmental Footprint (Product Environmental Footprint Category, 2018). However, challenges arise due to different pollutants considered in various techniques, complicating simple conversions. The weighting factors represent a weighted average of damage caused by contaminants in the EU28 for 2015, making them specific to this region and period. The environmental prices described in Table 7, as weighting factors, should be multiplied by the LCA outcomes at the midpoint level, using the 'weighting factor' set to achieve this (De Bruyn et al., 2018). The environmental price as an 'external cost' set is based on hierarchies and individualistic perspectives. **Alternative designs will be ranked further based on their Monetised-LCA score, with a lower score indicating a higher ranking.**

Table 7 - Environmental prices per impact category for use in LCA

	Impact category	Unit	Environmental price as external cost
1	Climate change	€/kg CO2-eq.	€ 0.057
2	Ozone layer depletion	€/kg CFC-eq.	€ 30.4
3	Human toxicity	€/kg 1,4 DB-eq.	€ 0.0991
4	Photochemical oxidant formation	€/kg NMVOC-eq.	€ 1.15
5	Particulate matter formation	€/kg PM10-eq.	€ 39.2
6	Ionizing radiation	€/kg kBq U235-eq.	€ 0.0461
7	Acidification	€/kg SO2-eq.	€ 4.97
8	Freshwater eutrophication	€/kg P-eq.	€ 1.86
9	Marine eutrophication	€/kg N	€ 3.11
10	Terrestrial ecotoxicity	€/kg 1,4 DB-eq.	€ 8.69
11	Freshwater ecotoxicity	€/kg 1,4 DB-eq	€ 0.0361
12	Marine ecotoxicity	€/kg 1,4 DB-eq.	€ 0.00739
13	Land use	€/m2a	€ 0.084521

6.1.4 Noise and Vibrations

Utilising an external power supply for vessels at berth is an effective option that removes the necessity for onboard power generation. This approach significantly reduces generator noise and vibrations, diminishing the engine room ventilation requirement. Ships that frequently call at ports with lengthy stay durations, high noise levels, or a tonal quality to their noise are ideal candidates for external power supply systems. However, establishing an external power supply represents a substantial investment, yet it offers considerable potential for zeroing noise and vibration (Noise from Ships in Ports. Possibilities for Noise Reduction, n.d.). As a result, the overall noise and vibrations emitted from a barge equipped with battery or/and fuel cell PSM are expected to be zero, thus fulfilling KPI3.3. Showcase the reduction of noises and vibrations by up to 80% during barge service, compared with the actual onboard energy generation. To that extent, they will not be measured.

6.2 Financial Assessment

The financial assessment model employs the unit cost of discharging energy stored on a barge (€/MWh). Given the absence of detailed information, the evaluation will focus solely on comparing the total relevant CAPEX and OPEX for each alternative design to identify the most feasible, lower value. The assessment of the alternative designs will include a ranking of Time to Market in terms of Critical Design Review Time and the Time Ratio for Design to Development Work. Time to Market refers to the duration from the initial concept to the point at which the power barge is operational, and it is critical to evaluate this to meet the set-to-work by the GA target of 2030, while considering the most feasible, lower value. Critical Design Review Cycle Time is required to verify that a system can progress to the subsequent phases.

6.3 Technical Feasibility Assessment

According to KPI1.3, the scalable solution must be able to service 95% of the commercial fleet, which includes containerships and passenger vessels, with a minimum gross tonnage of 5,000 GT. Furthermore, KPI1.4 stipulates that the proposed design must achieve a discharge power of at least 3 MW and a power capacity of 35 MWh, an alternative design comparison outlined in the GA. **They will be assessed first as a “Go/No Go” decision based on the KPIs, and then they will be evaluated through both relative percentages (about the 95% minimum threshold target) and absolute values (about the 3 MW and 35 MWh minimum threshold requirements).** Additional elaboration of the assessment will be conducted in the high-level analysis during T4.2 using the complementary technical criteria and metrics defined in Annex 3- Complementary Technical Feasibility Criteria of this deliverale to support experts' elicitation if needed.

New trends in naval architecture are revitalising the industry, emphasising emissions reduction and operations optimisation. These trends are significantly complementary and offer valuable lessons, insights, and guidance for shaping future design development. The rapid pace of technological advancement and its widespread adoption necessitates a more adaptable, asymmetric, and innovative approach to system integration to effectively address the fast pace of regulations' evolution. Capabilities must be accessible, discrete, integrated, modular, reusable, sustainable and scalable. Thus, designs must be flexible, maintainable, upgradeable, and versatile by embracing autonomy, modularity, scalability, and sustainability. Key benefits include enhanced adaptability, improved time efficiency, potential cost savings, increased availability, and the futureproofing of platforms and systems.

A "scalable design" approach emphasises developing products that can be easily adapted and expanded to meet customers' and businesses' changing needs. To evaluate and test scalability and adaptability in engineering design, it is crucial to establish criteria that effectively measure these attributes. The requirements may vary depending on the specific type and scope of the design. This approach simplifies the process of modifying, customising, updating, and enhancing products. **In BlueBARGE, a simplified approach will be adopted, measuring scalability by calculating the range of the min-max ratio of Energy Capacity per Design Available Area (MWh/m²) for each alternative.**

Moreover, BlueBARGE introduced modular design, a principle that involves breaking products down into multiple components (or modules) that can be combined and assembled to produce many different finished products. Modularity in the maritime industry is sourced from Naval Forces Maritime Operating Concept. It brings numerous benefits through its capability for adaptation via the timely addition or substitution of new capabilities, whether at home or while deployed (MARITIME MODULARITY CONCEPT, 2022). Figure 9 illustrates the flexibility of a Modular Adaptive approach for missions compared to the traditional robust design.

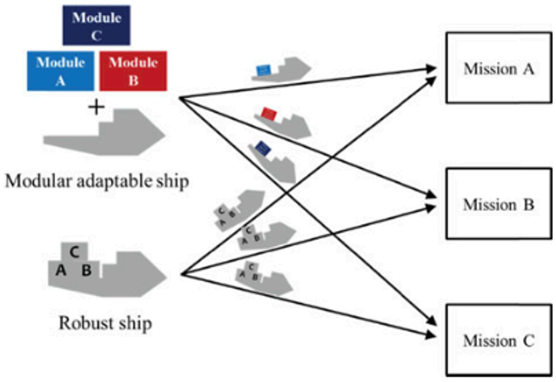

Figure 9 - Mission Flexibility of Modular Adaptability vs Robustness

One of the primary advantages of the modular ship design process, shown in Figure 10 (Choi & Erikstad, 2017), is its adaptability; units can swiftly interchange equipment or systems, allowing for flexible re-roles without the need to return to base. This adaptability is supported by common and international integration standards, ensuring seamless operations. Additionally, the approach promotes time efficiency by improving shipbuilding and manufacturing processes. This is achieved by decoupling capabilities from platforms, making modernisation more straightforward. Cost-effectiveness is another significant benefit, as modular systems across various platforms reduce overall costs and allow upgrades without extensive refits.

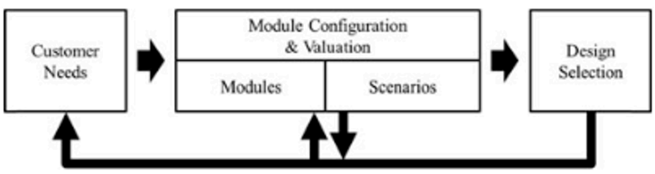

Figure 10 - Modular ship design process

One step beyond, maritime modularity enhances availability. It reduces refit requirements, thus improving access to maritime platforms and enabling systems to be replaced directly in the field. Futureproofing is also critical, as it ensures a long-term service life by isolating components that may require frequent updates. Furthermore, the increased adaptability leads to enhanced operational sustainment and logistics efficiency, ultimately improving workforce experience by establishing specialised teams. However, it is essential to note that successful implementation of these modular systems requires careful attention to integration, compatibility, training, and system development to mitigate potential risks.

There are four types of modularity, which are illustrated in Figure 11 (Choi & Erikstad, 2017), as follows:

- Component swapping modularity, where interfaces are specific to the module type, allows for different configurations and rapid refits. However, each equipment type has a predefined location where the appropriate interface slot is available.
- Combinational modularity, a variant of component-swapping modularity, also has diverse interfaces but no central body.
- Bus modularity, where the interface is standardised across several module types, allows different selections and combinations of (equipment) modules to customise the product for other purposes.
- Sectional modularity is a no “platform” module to which the other modules attach. All modules have one or a few standard interfaces (such as piping and HVAC systems in ships), which typically allow a more extensive variety in the physical layout of the product.

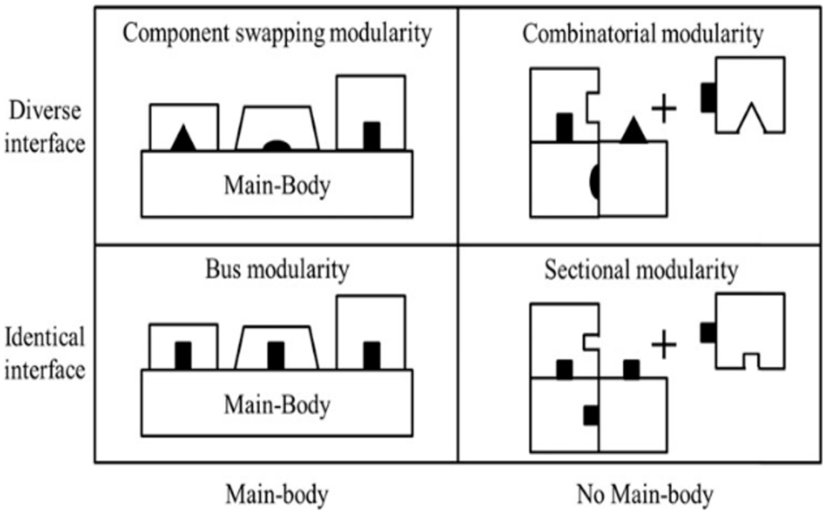

Figure 11 - Four types of Modularity based on interface diversity and primary body use

Following the above, modularity satisfies the principles of adaptability and flexibility described in Objective 1 (**O1). In T4.2, subject matter experts in the high-level analysis will assess the most appropriate type of modularity for each alternative, ensuring it meets future market needs and objectively ranking each alternative design accordingly.**

6.5 Safety Criterion

Under ABS Guidance Notes on Qualifying New Technologies, the focus will initially be on individual module safety (e.g., battery modules and electrical connections) and then expand to the integrated system and operational aspects. Risk analysis methodologies will align with the IMO's Formal Safety Assessment methods, incorporating Human Reliability Assessment to address human factors. The BlueBARGE safety assessment will use a systems approach to ensure comprehensive safety coverage.

Partners will determine the best strategy based on risk assessment needs, ultimately guiding the design alternatives and optimising the proposed solution.

ABS has released a Guidance Note ("Guidance Notes on Qualifying New Technologies," 2017) outlining its approach to qualifying new technologies, ensuring their capability to perform intended functions by established performance requirements. The note details the necessary submissions, the ABS review process, and the key interaction points with ABS throughout the development of new technologies (Advancing Innovation from Concept to Reality, n.d.; New-Technology-Qualification-Cutsheet-17100, n.d.). This document introduces a systems engineering approach to qualification, which facilitates a systematic and consistent evaluation of new technologies as they progress from the initial concept to the confirmation of operational integrity in their intended applications. The approach is organised into a multi-stage process aligned with a new technology's typical product development phases.

Qualification activities within each stage utilise risk assessments and engineering evaluations that build upon one another to assess whether the new technology meets acceptable safety levels in line with current offshore and marine industry practices. At every stage, the contributions of all stakeholders- including the vendor, system integrator, and end-user- are acknowledged and documented in a New Technology Qualification Plan (NTQP). The successful completion of qualification activities identified within each stage of the NTQP culminates in ABS issuing a Statement of Maturity, certifying the maturity level of the new technology.

KPI5.1 refers to "Issue NTQ Statement of Maturity for all innovations". The Classification Society, and coordinator of the BlueBARGE project, ABS, has outlined the documentation for issuing an NTQ Statement, as listed in Annex 4- Plans for NTQs. A thorough review of this documentation confirms that it meets all safety requirements related to the emerging technologies utilised in the proposed alternative designs. **The eligibility for the NTQ will act as a "Go/No-Go" Criterion for the innovations associated with each alternative design.** Therefore, the high-level analysis must determine if the specific design under consideration is eligible for the NQT Statement of Maturity. If the answer is negative, the design will be omitted and excluded from the next phase. In contrast, If the answer is affirmative, **a comparison of the time required to issue the NTQ,** as the subject matter experts will judge it. Furthermore, **each alternative's safety rating will follow as a desktop risk assessment that will calculate and compare risks between alternatives.** It encompasses all areas under consideration, including technological, operational, environmental, and human-made. The above-mentioned evaluation results **in a rating and ranking of the remaining alternatives** that will be used as input in the MCDA of T4.2.

7 Annex 2- Detailed Assessment and Optimisation of the Promoted Solution

Annex 2 incorporates all the facets for assessing and optimising the final, full-scale design. This promoted solution, after being refined by incorporating the lessons identified and learned from the prototype demonstration, will be further optimised through meticulous calculations of the specified environmental and additional financial KPIs (such as net present value, return on investment, average annual benefits, and payback period) associated with the investment to facilitate commercialisation. Safety will be further enhanced by integrating proposed risk mitigation measures (including risk control strategies and options) into the design process, adhering to the principles of risk-based design, thus obtaining an NTQ Statement of Maturity. As a result, technical feasibility will be improved and optimized after adopting the proposed modifications of the promoted design legacy systems. Finally, the solution will be fully reviewed through the issuance of an AiP from the classification society and complying with the prerequisite of limited or even conflict to the regulatory framework.

7.1 Environmental Assessment

The model for assessing environmental performance employs a bottom-up approach. It considers the growing impact on the ports outlined in D2.1 and compares results against the established KPIs for ecological footprint in the current context. WtW emissions encompass all emissions produced during the entire lifecycle of the fuel used on board the ship, from extraction to consumption. This step-by-step procedure typically involves calculating the total energy demand for 95% of container and passenger ships over 5,000 GT in the ports outlined in D2.1, with results updated during the assessment. After that, this energy demand will be converted into fuel oil consumption using the Specific Fuel Oil Consumption (SFOC) provided in the EMEP Guidelines for each engine type (2- and 4-stroke) and fuel. Following this, the calculation of GHG and local pollutants, as defined in KPI3.1, can be carried out in the case of ship GenSet electricity production based on the EMEP Guidelines, thereby establishing a specific threshold. Subsequently, assuming that the energy demand will be met by a fleet of barges possessing similar technical characteristics and operational capabilities, the electricity energy mix for each of the ports of D2.1 will be computed. This can be done either as a current sum for the ports of D2.1 (countries) or as a 2030 projection because, in the 2030 projection, renewables in the EU power mix are expected to reach 69% (REPowerEU Plan, 2022). Although the construction is expected to be completed in 2030, comparing the GenSets emissions with the existing situation for electricity production is not only challenging, since the problem is likely to improve over time due to restrictions imposed by the EU on the CI from electricity consumption, but also precise, due to the data availability, which prohibits the assumptions and uncertainty.

7.1.1 Emissions during onboard Genset Operation

The EMEP Tier 3 (Fontelle et al., 2023) ship movement methodology is recommended for estimating national and international emissions. Unlike Tier 1 and Tier 2 approaches, which rely on fuel sales and assume average vessel emission characteristics, Tier 3 is based on detailed ship movement data and technical information on individual ships, such as engine size, technology, power installed, and fuel use. This methodology is suitable for calculating emissions for commercial vessels by summing emissions on a trip-by-trip basis, considering different phases of the trip (cruise, hotelling, manoeuvring). While time-consuming, this method offers a comprehensive approach to estimating emissions in line with UNECE/EMEP definitions for national and international shipping. The Emission

Factors and SFOC per engine and fuel type found in Table 3 and Table 4 in Annex 1- High-Level Assessment of Design Alternatives, in combination with data from an updated inventory of all container and passenger vessels visiting ports as assumed during the derivation of D2.1, will be utilised to calculate the emissions produced during port calls for both hoteling and cargo operations. Emissions from hoteling will be computed based on the duration of time spent at the dock per call (in hours), the annual number of calls, generator load, and the pollutant Emission Factors of their auxiliary systems.

7.1.2 BlueBARGE's Emissions

The calculation procedure for the emissions of the BlueBARGEs will match the description provided in the high-level assessment in Annex 1- High-Level Assessment of Design Alternatives.

7.2 Financial Viability Assessment

Ship owners may be open to paying a higher price for electricity sales than they initially anticipated in their business models. This increased willingness could stem from a desire to showcase environmental responsibility or enhance passenger comfort by reducing noise and pollution while docked. Additionally, total electricity charges at various ports will probably be inversely related to the ship owners' willingness to pay for electricity. Focusing solely on the financial aspects of the project, O4 outlines the evaluation of the economic viability and commercial appeal of the power-barge solution. This evaluation incorporates all relevant costs and includes a commercialisation plan for deployment before 2030. To that extent, a dedicated KPI has been introduced in the GA, called **KPI4.1, which means at least 20% net savings from investing in BlueBARGE**, compared to operating the ship's generators when it is moored. Task 4.1 documents that financial aspects- e.g., CAPEX, OPEX, NPV, ROI, etc.- must be based on technical parameters (e.g., capacity, power output, charging time, etc.). As a crucial outcome of the assessment, it is expected that while electricity prices are anticipated to rise, OPS will become more cost-effective due to increasing fuel costs and the EU-ETS.

Levelised Costs of Electricity (LCoE) and Storage (LCoS) are the discounted lifetime cost of building and operating a power generation asset, expressed as the cost per unit of electricity generated or stored (€/MWh). It covers all relevant costs associated with the generator or storage unit, including pre-development, capital, operating, and financing expenses. This concept is called a life-cycle cost, highlighting its comprehensive "cradle-to-grave" nature. The LCoE and LCoS of technology is the ratio of the total costs of a standard plant to the total amount of electricity expected to be produced or stored over the plant's lifetime; both are expressed in net present value terms, thus fulfilling the demands of quantifying KPI4.1, in terms of technical parameters.

In the proposed framework, the financial assessment model utilises LCoE to represent the operational cost per unit of energy a ship produces while at berth, anchored, and moored (€/MWh). On the other hand, LCoS represents the unit cost of discharging energy stored on a barge (€/MWh). As a standard, promoted design's final unit electricity charge (€/MWh) must be at least 20% higher than LCoS (i.e., at least equal to 1.2 x LCoS). Simultaneously, the final unit electricity charge and LCoS must be lower than LCoE.

7.2.1 Levelised Cost of Electricity

To conduct accurate analyses, it is essential to understand the current operational costs incurred when a ship is in port. Specifically, this involves determining the cost of running a diesel generator while docked. All associated expenses must be considered, including maintenance costs (spare parts and labour), fuel consumption during the port stay, and lubrication oil usage. Additionally, since fuel prices are quoted in US Dollars, converting this currency into Euros is necessary.

Table 8 presents a typical analysis of the parameters considered for the computation of LCoE (Electricity Generation Costs, 2023). The study will focus on existing vessels assumed to be already retrofitted for shoreside power due to measures imposed by the EU on container and passenger ships, without considering the possibility of being retrofitted for exhaust control/clean diesel technologies since GHG emissions abatement technologies where EU-ETS applies, are still under consideration. The former cases are considered a must-have ship infrastructure for connecting to the BlueBARGE, since they also have resolved the operational, safety, and engineering challenges through retrofitting, so the cost of modifications will be included in the CAPEX. The experts will define the project's and vessels' life over which costs are accumulated and amortised during Task 4.2.

Table 8 - Indicative Costs and Electric Generation Data for LCoE Computation

No	Title	Description
1	Investments	Pre-development
2		Construction
3		Infrastructure
4	OPEX	Fixed operating
5		Variable operating
		Maintenance
6		Cost of Fuel
7		Decommissioning
8	Expected generation data	Capacity of plant
9		Expected availability
10		Expected efficiency
11		Expected load factor

To calculate the LCOE Generation Estimate, the NPV of all costs associated with the construction, operation, and maintenance of the GenSets is determined. This amount is then divided by the total electricity generated throughout the unit's lifetime. Net electricity generation is defined as gross generation minus any internal plant losses or usage prior to electricity being exported to the electricity network.

$$NPV\ of\ Total\ Costs = \frac{\sum_1^n (Total\ Capex + Opex\ Costs)_n}{(1 + discount\ rate)^n}$$

$$NPV\ of\ Electricity\ Generation = \frac{\sum_1^n (net\ electricity\ generation)_n}{(1 + discount\ rate)^n}$$

$$Levelised\ Cost\ of\ Electricity\ Generation\ Estimate = \frac{NPV\ of\ Total\ Costs}{NPV\ of\ Electricity\ Generation}$$

$$n = period\ of\ time$$

The primary cost savings associated with external electricity provision include reduced fuel expenses for auxiliary engines and lower maintenance costs. However, additional costs include modifications, electricity, taxes, and standing charges. The equipment that must be installed on board a ship for its power supply from the BlueBARGE is the same as those from OPS. The expense of modifying a vessel for shore connection is dependant on the vessel's design and ability to adjust voltage and frequency as required. Additionally, it's crucial to clarify that the investment costs mentioned refer only to the ship itself. They do not include the expenses related to establishing the connection at the port, as detailed in Table 9 (Shore Power, n.d.) for containerships and passenger vessels. The expected cost per type and size of the ship will be calculated as a linear function in slope-intercept form of cost and gross tonnage, i.e. y=a*x+b. The expenses related to the loss of service of a vessel during retrofitting are not included due to the lack of reliable data.

Table 9 - Estimated Cost for Implementing OPS on Board Vessels

No	Deadweight Range in 10^3 GT	Investment Costs in 10^3 $
1	5 – 9,999	50 –350
2	10 – 24,999	100 - 400
3	25 – 49,999	300 – 750
4	50 – 99,999	300 – 750
5	>= 100	300–750

7.2.3 Levelised Cost of Storage

The corresponding LCoS for Lithium-ion and Flow Batteries are given from the following formulas respectively (Cost of Storage, n.d.):

$$LCoS[€/MWh] = \frac{Capex[€] + Opex[€] - Residual\ value[€]}{Lifetime[cycles] \cdot DoD[\%] \cdot Capacity[MWh] \cdot Roundtrip\ efficiency[\%]}$$

$$LCoS[€/MWh] = \frac{Capex[€] + Opex[€] - Residual\ value[€]}{Lifetime[cycles] \cdot Capacity[MWh] \cdot Roundtrip\ efficiency[\%]}$$

The unique approach to the LCoS equation for flow battery systems arises from their continued accessibility for service, upgrades, and refurbishment. Cell stacks can be readily replaced at the end of their lifespan. Unlike other storage technologies that do not support full charge/discharge between 0% and 100%, flow batteries allow for a Depth of Discharge (DoD) of nearly 100% without impacting their longevity (Li et al., 2024). The DoD's influence on LCoS calculations is significant because the practically usable storage capacity equates to the purchased capacity's DoD. Therefore, a 70% DoD results in a 43% higher LCoS, as only 70% of the purchased capacity is effectively utilised. Factoring in the DoD effect further emphasises the disparity in LCoS between conventional storage systems and flow batteries.

The investment cost for BlueBARGE comprises two primary components: the power barge itself and the charging system for the onshore electricity supply. The expenses related to the onshore charging infrastructure can vary depending on the specific port facilities and equipment available. BlueBARGE will incorporate its cable management system, and the port infrastructure is expected to include high-voltage inverters, converters, connectors, and a shore junction box. Quotes from various suppliers calculate the costs for these components. Additionally, direct connections from the power barge to the ships, bypassing SSE systems, can potentially reduce imposed costs to ship owners due to the economy of scale that a BlueBARGE solution can achieve since it serves as a significant consumer and long-term client to the local grid.

The proposed barge designs provide considerable flexibility, allowing power output, voltage, and frequency adjustments to meet customer needs. Each power barge can be customised to deliver energy across various outputs and charge multiple moored vessels simultaneously. Furthermore, the barge can be constructed as either self-propelled or non-propelled. Although the non-propelled option requires a lower initial investment, it incurs higher operational costs due to the need for transportation (e.g., tugboats) during relocation.

7.3 Safety Assessment

The safety assessment activities go hand in hand with the technical feasibility assessment and optimization, employing risk assessment and engineering evaluations to determine if the promoted design provides acceptable levels of safety in line with current offshore and marine industry practices. It will cover all technical and operational aspects of the power-barge solution and assess regulatory compliance, fulfilling the KPI5.2 to address all identified high-risk areas with at least one risk control measure. The assessment is captured within a new technology qualification plan (NTQP). Completion of qualification activities identified within the NTQP results in a Statement of Maturity being issued by ABS attesting to the maturity level of the new technology, as per KPI5.1. While individual new technologies can be qualified by following the ABS new technology qualification (NTQ) process KPI5.3 Approval-in-principle by classification society granted, the classification of a novel concept that includes these new technologies may have additional requirements to address the integration/interfacing with existing conventional technologies as well as the asset itself that may not be satisfied through the NTQ process by its own.

7.4 Technical Feasibility Assessment

In this regard, the entire BlueBARGE concept will be reviewed following the ABS Guidance Notes on Review and Approval of Novel Concepts provisions. This approval is performed on the basis that special consideration through appropriate engineering evaluations and risk assessments have been given to the novel features to determine if the concept provides acceptable levels of safety in line with current offshore and marine industry practice, satisfying KPI4.3 Limited- or even non- conflict with the regulatory framework. At the same time, the qualification of individual new technologies will cover safety and extend to additional functional requirements as identified through the project's timeline. As part of this process, ABS will grant an AiP to the BlueBARGE concept, as per KPI5.3, which will confirm that the proposed novel concept that includes the new technology complies with the intent of the most applicable ABS Rules and Guides as well as required appropriate industry codes and standards, subject to a list of conditions. These conditions, herein referred to as an Approval Road Map, typically define a list of submittals necessary to be completed in later phases of the project to obtain final class approval.

8 Annex 3- Complementary Technical Feasibility Criteria

Establishing complementary, supporting criteria and metrics is crucial for ensuring alignment with the identified parent requirements derived from baseline capabilities. Incorporating clear thresholds and objective values in the assessments will effectively mitigate any credibility concerns that may arise later in the study due to ambiguous designs. The afformentioned criteria are described in Table 10. If additional supplementary criteria arise, they will also be considered.

Table 10 -Complementary technical feasibility criteria

No	Criterion	Metric	Description
1	Charging time (30% to 90% SoC)	<5hr	Charging duration from 30% to 90% SoC
2	Peak discharge power capability	>15MW	The maximum amount of electrical power that BlueBARGE promoted design can output over a limited period without overheating or otherwise suffering damage.
3	Lifetime expectation (calendar)	>7yr	How long the battery system expected to last in terms of calendar years
4	Cycles (equivalent full cycle at 70% of DoD)	4000 cycles	How many charging-discharging cycles the battery systems expected to last
5	SOH after 4years (ageing degradation)	>90%	SOH is defined as the status of battery health to supply power and energy compared to its capability at the initial state"
6	Overall efficiency	>80%	BlueBARGE promoted design efficiency
7	Operating temperature range (°C)	-25 to 45°C	Lower and upper temperature limit
8	Power distribution units' area percentage	<20%	Percentage of barge's area that inverters, converters, transformers etc. will cover
9	PSM Maturity State	Mode	Operative
			In construction
			Planned
10	Average downtime	Minimum	Ratio of hours per year each power module is down due to planned maintenance to total operational hours.
11	Forced outage rate	Minimum	Ratio of hours per year each power module is shut down due to unplanned issues to total operational hours.
12	Capacity Factor	Maximum	Ratio of actual output to the maximum possible output a power module can produce during a given period
13	Recycling efficiency	Maximum	Ratio obtained by dividing the mass of output fractions by the mass of the input fractions, expressed as a percentage

14	Power quality	Minimum	Frequency and duration of voltage sags, spikes, and harmonic distortion incidents.
15	Degree of Autonomy by Alternative Design	IMO Degree 1	Ship with automated processes and decision support. Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
		IMO Degree 2	Remotely controlled ship with seafarers on board. The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
		IMO Degree 3	Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
		IMO Degree 4	Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.
16	Modularity	Component swapping modularity	Interfaces are specific to the module type, thus allowing for different configurations and rapid refit, but with a predefined location for each equipment type where the appropriate interface slot is available.
		Combinational modularity	A variant of component-swapping modularity, also has diverse interfaces but no main body.
		Bus modularity	The interface is standardized across several module types, thus allowing different selections and combinations of (equipment) modules to customize the product for different purposes.
		Sectional modularity	It is a no "platform" module to which the other modules attach. All modules have one or a few common interfaces (such as piping and HVAC systems in ships, which usually permit a greater variety in the physical layout of the product.

9 Annex 4- Plans for NTQs

This Annex illustrates the list of plans to be submitted for the NTQ process for the BlueBARGE, as prepared by the engineering department of ABS. The compilation of drawings is based on the Rules for Building and Classing Marine Rules (2024), the Guidance Notes on Review and Approval of Novel Concepts (2017), and the Requirements for the Use of Lithium-ion Batteries in the Marine and Offshore Industries (2022), which address the electrical integration of the battery installation.

1. Preliminary conceptual design information.
2. Preliminary functional and performance requirements.
3. Experimental data (input, approach, definitions, procedures, results, etc).
4. Risk assessment report.
5. HAZOP/HAZID.
6. Evidence for marine suitability.
7. Battery Management System (BMS) functional description and test reports.
8. Battery System technical specifications include nominal voltage and operational limits (e.g., voltage, current, and temperature), safety devices, cell/battery configuration, battery chemistry, method of activation, discharge and recharge rates for the batteries, etc.
9. Battery System capacity calculation for the intended application.
10. Battery System electrical schematic drawing (block diagram with system interface).
11. Emergency Shutdown (ESD) arrangement.
12. Battery System location and arrangement plan.
13. Battery System Risk Analysis document (i.e., Failure Modes and Effects Analysis (FMEA)) and the associated sea-trial/commissioning safety procedures (i.e., Design Verification Test Procedures (DVTP) and Periodic Safety Test Procedures (PSTP)).
14. Battery System installation and sea-trial/commissioning procedures.
15. The ventilation arrangement of the battery space includes fire dampers and emergency shutdown from outside space.
16. Environmental control arrangement, if applicable (temperature sensors, air conditioning unit).
17. Fixed fire extinguishing system (FFES) arrangements, details, and validation of suitability for the battery chemistry involved.
18. Fire detection and alarm system arrangement.
19. Detailed stage-by-stage Fire Fighting Procedure/CONOPS.
20. Combustible gas detection and alarm system arrangement.
21. Battery installation/mounting arrangement and associated drawings and information. This includes battery weights, weight of the battery cabinets and connection details between battery cabinets and deck and/or bulkhead structure.
22. Operations and Maintenance manual for battery system and BMS.
23. Battery System Maintenance Schedule.
24. Structural Fire Protection details, joiner work details, insulation arrangements approved structural fire protection materials and equipment.
25. On-board documentation:
    a. Operations and Maintenance Manual for battery system and BMS
    b. Battery System Maintenance Manual and Schedule
    c. Detailed stage-by-stage Fire Fighting Procedure/CONOPS