Ref. Ares(2025)7856521 - 19/09/2025

D4.2: Design alternatives evaluation report

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Co-funded by
the European Union

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Project data

Document	
Grant agreement n°	101138694
Acronym	BlueBARGE
Project title	Blue Bunkering of Anchored ships with Renewable Generated Electricity
Call	HORIZON-CL5-2023-D5-01
Start date	1st January 2024
Duration	36 months
Project URL	https://bluebarge.eu/

Document Info

Deliverable	
Document reference	D4.2
Due Date of Delivery to EC	20/09/2025
Actual Date of Delivery to EC	19/09/2025
Document type	Report
Dissemination level	Public
Work package	WP4
Lead beneficiary	DANAOS
Reviewers' Organization	ABS, REGBES

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Revision history			
Version	Date	Editor	Summary of Modifications
0.1	**17/4/2025**	**Evelina Bintevinou**	Table of Content
0.2	**2/5/2025**	**Dimitrios Kaklis**	First Draft
0.3	**3/9/2025**	**Dimitrios Kaklis**	Draft for review
0.4	**16/9/2025**	**Dimitrios Kaklis** **Evelina Bintevinou**	Incorporation of 1st round of reviewer's revision
0.5	**18/9/2025**	**Dimitrios Kaklis** **Evelina Bintevinou**	Incorporation of 2nd round of reviewer's revision
1.0	**19/8/2025**	**Dimitrios Kaklis**	Final Version

Quality control		
Role	**Approval date**	**Reviewer**
Reviewer	**18/9/2025**	Demetres Armanes (ABS)
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Reviewer	**18/9/2025**	Mert Doganli (REGBES)

Acronyms and Abbreviations	
Acronym/Abbreviation	**Meaning**
CAPEX	Capital Expenditures
CBA	Cost-Benefit Assessment
DSS	Decision Support System
KPI	Key Performance Indicator
MCDA	Multi-Criteria Decision Analysis
OPEX	Operational Expenditures
TRL	Technology Readiness Level

UC	Use Case
UUC	Umbrella Use Case

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1 - Executive Summary

This *report (Deliverable D4.2 – Design Alternatives Evaluation Report)* presents the structured assessment of six alternative design concepts for the BlueBARGE project, which aims to deliver a scalable and modular offshore power barge supplying clean energy to moored and anchored vessels. The work builds on the evaluation framework developed in D4.1 and the alternative concepts described in D5.1, applying a robust multi-criteria methodology to identify the optimum configuration for further development.

The evaluation process combined a web-based Decision Support System (DSS) with expert engagement through focus groups and bilateral discussions. Criteria included technical capacity and power, safety (assessed via HAZID), capital and operational expenditures, and environmental performance. The consolidated results ranked Design 1.2 highest overall, with Design 1.4 also performing strongly, particularly in terms of safety. Conversely, Designs 3.3 and 2.6 achieved the lowest scores. These findings provide the analytical basis for progressing to Task 4.4, where Design 1.2 will undergo detailed optimisation and techno-economic validation.

1.1 – Purpose of the Document

The purpose of this deliverable is to evaluate and compare alternative BlueBARGE design concepts in order to identify the most promising configuration for further development. By applying a structured multi-criteria methodology, the report establishes a transparent, evidence-based decision-making process that integrates stakeholder expertise and aligns with the project's decarbonisation objectives. The outcomes form the foundation for optimisation in Task 4.4, where the selected design will be further refined into a full-scale concept.

1.2 – Intended readership

The primary audience of this report includes project partners, stakeholders, and the European Commission, who require a clear and robust evaluation of the design options to support informed decision-making. It is also relevant to maritime authorities, classification societies, port operators, and technology providers interested in the feasibility and scalability of offshore power barge solutions.

2 - Introduction

The **BlueBARGE project** aims to develop a modular and scalable offshore power barge that supplies clean energy to anchored and moored ships, thereby supporting EU maritime decarbonisation objectives. The solution is expected to be commercially viable by 2030, enabling a significant contribution to port electrification and sustainable shipping.

This deliverable **D4.2 – Design Alternatives Evaluation Report** is part of **Work Package 4 (WP4)** and plays a pivotal role in narrowing down the configuration options of the BlueBARGE concept. It identifies and recommends the optimum design based on **technical feasibility, sustainability, safety, and economic viability**.

The work presented here builds on:

- **D4.1 – Evaluation Framework Definition:** which established the overall methodology, criteria, and assessment process for screening and ranking design alternatives.
- **D5.1 – BlueBARGE Alternative Design Concepts:** which introduced and described the set of candidate design configurations subjected to evaluation in this deliverable.

Accordingly, the evaluation conducted in D4.2 integrates the structured multi-criteria framework from **D4.1** with the design options proposed in **D5.1**, ensuring transparent, evidence-based, and comparable results across all alternatives.

The document is organised as follows:

- **Section 3** – Methodology: Describes the evaluation process, including the multi-criteria assessment approach, screening steps, and assessment tools.
- **Section 4** – Planning of the Evaluation: Defines evaluation criteria, stakeholder profiles, and development of the dedicated assessment tool.
- **Section 5** – Execution of the Evaluation: Summarises the evaluation process, expert engagement, and data collection activities.
- **Section 6** – Results: Presents the evaluation outcomes and ranking of alternative designs.
- **Section 7** – Conclusions and Recommendations: Highlights the final design choice and its justification
- **Annexes:** Provide supporting material, including detailed descriptions of the alternative designs (Annex 1) and safety assessments (Annex 2).

Through this structure, Deliverable D4.2 provides a comprehensive and systematic evaluation of the BlueBARGE design alternatives, serving as the decision-making basis for subsequent optimisation in **Task 4.4**.

3 - Design Alternatives Evaluation Methodology

3.1 - Methodology and Process

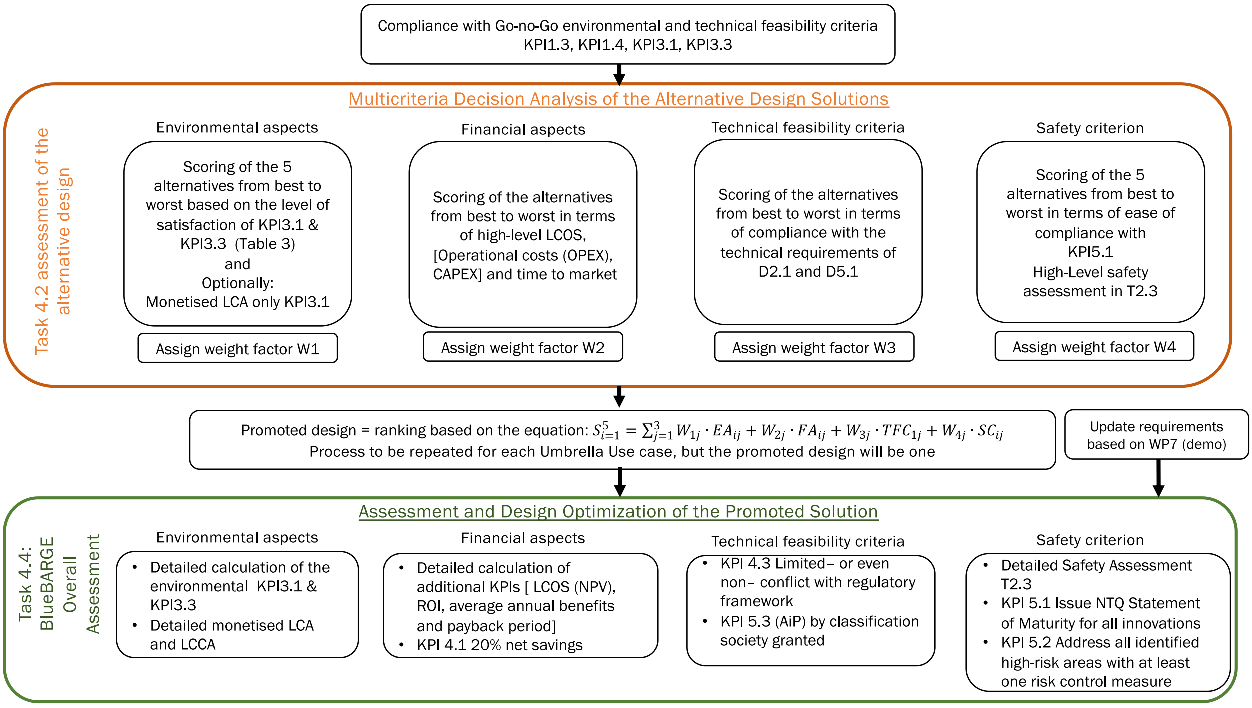


Figure 1 Evaluation Framework (captured from D4.1)

The evaluation process in Task 4.2 builds directly on the assessment methodology defined in Deliverable D4.1. This methodology provides a rigorous, multi-criteria foundation for screening, scoring, and ranking design alternatives through a structured sequence of goal definition, criteria identification, and performance measurement. It employs Multi-Criteria Decision Analysis MCDA techniques, complemented by sensitivity and cost-capability analyses, to balance environmental, technical, financial, and safety considerations. Importantly, this approach ensures that only alternatives meeting key threshold KPIs are advanced to full evaluation, thereby securing objectivity and comparability. The application of this methodology in Task 4.2 guarantees that the optimum BlueBARGE design is selected based on transparent, evidence-driven analysis, aligned with project decarbonisation goals

The overall goal in T4.2 is to come up with the best fit BlueBarge design among promoted alternatives as depicted and characterized in D5.1 while meeting the predefined KPIs and thresholds.

The promoted designs will be assessed in terms of their suitability to the Umbrella Use Cases (UUCs) defined in WP2. The purpose is to depict a single favorable design and most suitable to service the three umbrella cases

- **UUCs#1:** Charging anchored ships/Charging barge from offshore plants,
- **UUCs#2:** Barge as OPS for moored vessels,
- **UCCs#3:** From barge to land and offshore structure.

The assessment of the candidate designs will follow a multi-criteria approach and processed through an advanced assessment tool relying on subject expert judgement. The outcome is the identification of the most promising design, which will be further optimized in **Task 4.4**. The following schematic represents the steps for the alternative designs' evaluation

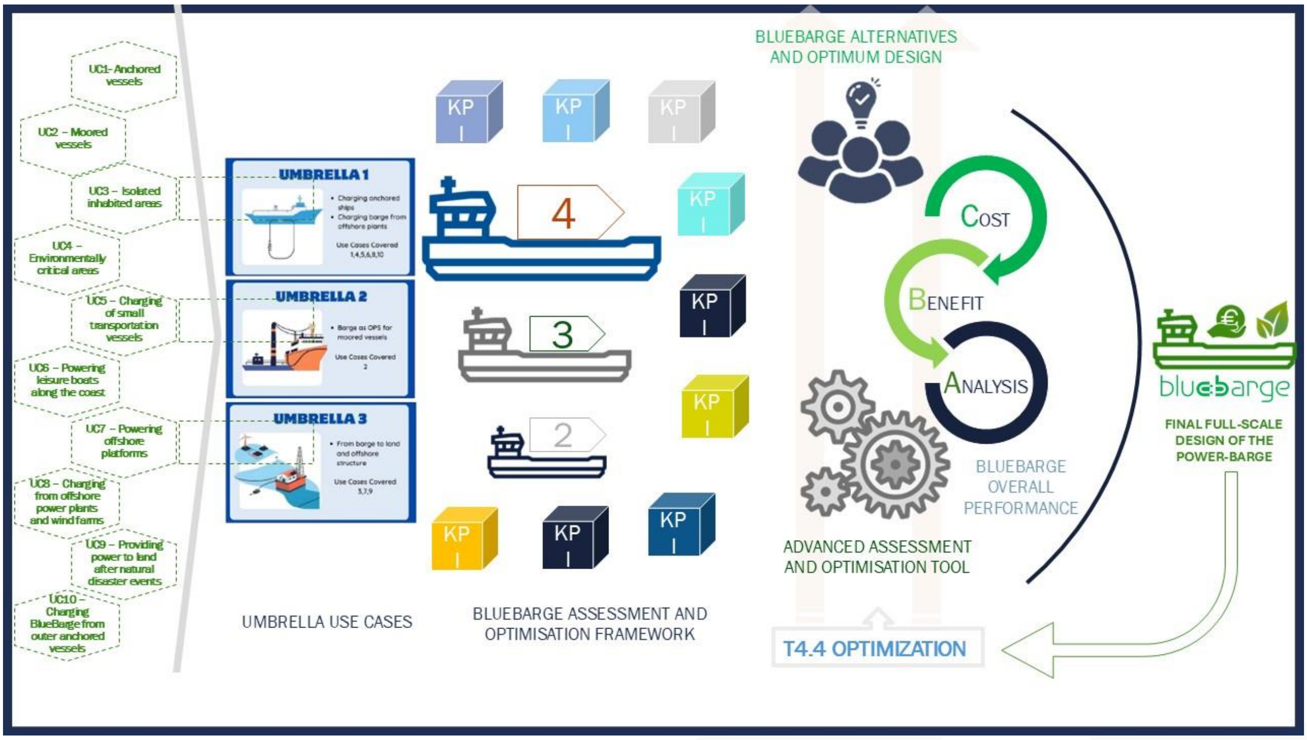


Figure 2 Evaluation Process of the Bluebarge Alternative Designs

3.2- The Design Alternatives

A total of six (6) BlueBARGE design alternatives were evaluated in order to identify the most promising configuration. These alternatives went through a screening process against the KPIs defined in the Grant Agreement (DoA).

Table 1 Bluebarge KPIs according to DoA

OB#	KPI#	KPI description
01	1	KPI 1.1 Verify identified use cases and expand list, in a total of **6 concrete use cases**
	2	KPI 1.2 Complete at least **5 alternative design cases** for power-barge concept
	3	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 GT
	4	KPI 1.4 Achieve at least **3MW discharge power and 35MWh power capacity** through the BlueBARGE promoted design
02	5	KPI 2.1 Achieve an **at least 500kW** discharge power through the prototype
	6	KPI 2.2 Achieve an **at least 1.5MWh** capacity through the prototype
	7	KPI 2.3 Cover energy demand of demonstration vessel for at **least 1 hour**
03	8	KPI 3.1 Showcase emission reduction through **at least 10 environmental KPIs**
	9	KPI 3.2 **Reduction in GHG and other polluting emissions** from vessels in anchorage will be presented in detail for at least two use cases scenarios
	10	KPI 3.3 Showcase the **reduction of noises and vibrations up to 80%** during barge service, compared with the actual onboard energy generation
04	11	KPI 4.1 At least **20% net savings** from investing in BlueBARGE
	12	KPI 4.2 At least 10 stakeholders declared interest on the BlueBARGE concept and design
	13	KPI 4.3 Limited – or even non – conflict with regulatory framework
05	14	KPI 5.1 Issue NTQ Statement of Maturity for all innovations
	15	KPI 5.2 Address all identified high-risk areas with at least 1 risk control measure
	16	KPI 5.3 Approval-in-principle by classification society granted
	17	KPI 5.4 Operational and safety guidelines reviewed and verified by all relevant industry partners

The alternative designs that meet the KPI targets are presented in tabular form including numerical values (depicted from D5.1). Marks in green signifies that targets are met regardless of adoption of scalable solutions whereas marks in orange that targets met with adoption of scalable solutions.

Table 2 Promoted Alternative Designs (captured from D5.1)

Barge Size	Alternative Design Case	Achieved Maximum Power (MW)	Achieved Maximum Energy Capacity (MWH)	KPI1.3 Target						KPI1.4 Target		UCC1 Target		UCC2 Target		UCC3 Target	
				Cruise Ships		Container Ships		Ro-Pax									
				Power (MW)	Energy (MWH)	Power (MW)	Energy (MWH)	Power (MW)	Energy (MWH)	Power (MW)	Energy (MWH)	Power (MW)	Energy (MWH)	Power (MW)	Energy (MWH)	Power (MW)	Energy (MWh)
				Target Values													
				≥ 11	≥ 150	6	60	6.5	20	≥ 3.0	≥ 35.0	7	≥ 64.0	20	≥ 87.0	5	≥ 30.0
LARGE	1.1	88.3	70.3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	1.2	88.3	65.3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	1.3	20.3	147.3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	1.4	20.3	142.3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MEDIUM	2.6	8.6	38.8	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SMALL	3.3	13.8	43.3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

A consolidated visual representation of the alternatives is provided in Annex 1, which compiles the main particulars and concepts as described in D5.1: BlueBARGE Alternative Designs.

3.3 – Assessment Tools and Techniques

The evaluation and ranking of the alternative design solutions in Task 4.2 are supported by a combination of quantitative and qualitative tools and techniques, designed to ensure a robust, multi-criteria decision-making process.

Multi-Criteria assessment tool

To facilitate the evaluation process, a dedicated web-based assessment tool has been developed. This tool supports data collection, automated ranking, and transparent comparison of the alternative configurations. It also allows integration of inputs from different stakeholders in a structured manner.

The tool is an extended configuration of a prototype designed and developed by DANAOS. The prototype implements (MCDA) to systematically investigate the views of different stakeholders. It is based on subject matter experts and incorporates fuzzy set theory, represented by linguistic values or numbers, to address uncertainty in expert opinion (Fuzzy Multi-Attribute Group Decision Making). The alternatives are ranked by applying the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Taherdoost, 2023)

The tool allows each expert to grade the alternatives for each criterion either with crisp numbers (e.g. 1-10) or using linguistic values in a five-degree Likert scale ranging from Very Low (VL) to Very High (VH), or even with absolute numbers (e.g. cost). The criteria are characterized as cost or benefit and the assessment could be Numeric (N), Linguistic (L), Objective (O), or Subjective (S). Additionally, experts assign weights to reflect both the relative importance of criteria and their own expertise level. In a simplified example, if a safety manager and a financial manager are called to assess the procurement of alternative safety equipments in a shipping company, the score of the safety manager regarding safety particulars of the equipments under comparison would have a higher weight than those of a financial manager. The opposite applies to cost criteria, where the financial manager is considered more expert in the subject criteria than the safety manager. This ensures the reliability of the evaluation and the consistency in the interpretation of conclusions (expert judgement monitoring).

The final version meeting the evaluation purposes and framework of Bluebarge is described in **section 4.3**

Data Gathering and Analysis Techniques

Data gathering in our case is limited to the engagement of stakeholders (or subject matter experts) to assess and score the alternative designs with the use of the dedicated tool as described above. The stakeholders engagement was facilitated by

1. *Focus groups and interviews*

Focus Groups and Interviews are effective techniques for gathering in-depth feedback from experts, as they allow for structured yet flexible discussions that probe both individual perspectives and collective viewpoints. Through guided conversations, researchers can explore expert insights, validate assumptions, and uncover nuanced considerations that might not emerge through surveys or quantitative methods. These methods are particularly valuable when seeking to understand complex issues, as they capture both the diversity of expert opinion and the reasoning behind it.

2. *Workshops*

Workshops provide an interactive and collaborative environment where experts can co-create solutions, exchange knowledge, and critically evaluate ideas in real time. Unlike interviews or focus groups, workshops are designed to foster active participation through activities such as brainstorming, scenario building, and problem-solving exercises. This structured collaboration not only generates richer insights but also builds consensus, making workshops especially effective for refining concepts, testing frameworks, and developing practical strategies informed by expert input.

4 – Planning of the Evaluation

4.1 – Selection of Evaluation Criteria

The evaluation criteria are grouped into four (4) categories reflecting all feasibility aspects of the candidate designs against the defined UUCs while following the evaluation framework defined in D4.1.

1. **Technical aspects:**

- **Capacity.** The energy capacity (MWh) has been quantified by alternative design (see values in the consolidated **Error! Reference source not found.** above). Experts through the dedicated a ssessment tool will be requested to evaluate the feasibility of each promoted Bluebarge according to their measured capacity and crossed with the different umbrella cases (UUCs) KPI

- **Power.** The power (MW) has been also quantified per alternative design (see values in the consolidated **Error! Reference source not found.** above). Experts through the dedicated a ssessment tool will be requested to evaluate the feasibility of each promoted Bluebarge according to their measured power and crossed with the different umbrella cases (UUCs) KPI

- **Regulatory aspect.** These criteria reflect the compliance of each alternative against regulatory aspects. All alternatives are assumed to meet regulatory requirements; therefore, this aspect was considered equal for all designs and not open to expert judgment.

2. **Safety criterion:**

- **Safety** was assessed qualitatively through a **risk-based analysis** carried out in a dedicated HAZID (Hazard Identification) workshop led by NTUA (project partner). The results of this assessment are presented in **Annex 2**. Experts were asked to evaluate the relative importance of safety across the different UUCs using the assessment tool.

3. **Financial aspects:**

- **CAPEX.** Bluebarge consortium has conducted a preliminary estimation of the CAPEX per design alternative (led by VPF, with inputs from Hydrus, CORVUS, ENEROX, REGBES, and NTUA). The estimation has not resulted in concrete and accurate numbers due to lack of available data for such an exercise (accurate calculation will be performed in T4.4). The estimates are expressed as **relative factors** compared to the reference design (Barge 1.1). Therefore, barge design 1.1 is set to 1.0-unit cost as a reference value and the CAPEX for the rest of the barges is a multiply factor (x1.1) of the reference barge.

  - Barge Design 1.1=1.0 (the reference barge)
  - Barge Design 1.2= x1.22 (this means that the CAPEX of the respective barge is 1.22 multiplied by the cost of the reference Barge 1.1)
  - Barge Design 1.3= x1.97 (this means that the CAPEX of the respective barge is 1.97 multiplied by the cost of the reference Barge 1.1)
  - Barge Design 1.4= x2.33 (this means that the CAPEX of the respective barge is 2.33 multiplied by the cost of the reference Barge 1.1)
  - Barge Design 2.6= x1.22 (this means that the CAPEX of the respective barge is 1.22 multiplied by the cost of the reference Barge 1.1)

- Barge Design 3.3= x0.91 (this means that the CAPEX of the respective barge is 0.91 multiplied by the cost of the reference Barge 1.1)

Experts through the dedicated assessment tool will be requested to rate the suitability of each Bluebarge design according to the relative estimation of CAPEX and crossed with different umbrella cases (UUCs). Their rating will also reflect their view on the replacement costs (not included in the estimated CAPEX), the possible return of investments and revenues as well as their considerations for the time to market of each alternative until 2030.

- **OPEX.** No detailed cost data was available. Experts therefore assessed OPEX based on qualitative considerations, applied to specific **Use Cases (UCs)** within each umbrella category. Guidance tables were provided, covering navigation, towage, mooring, energy origin, and maintenance costs

Table 3 Explanatory notes shared with experts regarding OPEX of the alternative barge designs

UUCs	UC	OPEX considerations
#1	UC1: Anchored Vessels	Operating costs during manuevering toward the anchored area and charging/loading electricity/hydrogen area. Towage costs if not self-propelled. Mooring boat involved costs. Maintenance costs should be taken into account
	UC4: Environmental critical areas	Operating costs during manuevering toward the Marine Protected Areas (autonomy of the barge) and charging/loading electricity/hydrogen area. Towage costs if not self-propelled. Mooring boat involved costs. Maintenance costs should be taken into account
	UC5: Charging of small transportation vessels	Assisting inland waterways transport. Towage operating costs if not self-propelled. Mooring boat involved costs. Services alongside the river and at inland ports. Electric barge concept included. Maintenance costs should be taken into account
	UC8: Charging from offshore power plants and wind farms.	Operating costs from offshore power plants and wind farms (renewable electricity charged but maybe not hydrogen charging there) to vessels in the surroundings. Towage assistance if not self-propelled and mooring both costs. Maintenance costs should be taken into account
	UC10: Charging Bluebarge from outer anchored vessels	Transfer electricity from one vessels to the barge in order to provide with electricity different customers. OPEX during manuevering to outer port areas. Towage assistance if not self-propelled and mooring boat OPEX. Can be combined with other use cases.
#2	UC2: Moored Vessels	OPEX during manuevering within the port area and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled. Mooring boat involved. Origin of the energy. Important to take into account that, compared with anchored areas, the navigation distance is lower. Maintenance costs should be taken into account
#3	UC3: Isolated inhabited areas	OPEX during manuevering toward the inhabited areas and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled OPEX. Mooring boat involved OPEX. Origin of the energy. Maintenance costs should be taken into account
	UC7: Powering offshore platforms – oil rigs	OPEX during manuevering toward the offshore platforms should balance the emissions avoided powering those offshore platforms. Towage and mooring OPEX. Maintenance costs should be taken into account
	UC9: Providing power to land after natural disaster events	Temporary assistance to specific locations with damage in power grids and transmission lines. OPEX due to transition to those areas (maybe long distances) with towage and mooring and to be charged or load with electricity and hydrogen respectively. Maintenance costs should be taken into account

An informative table with the average Hydrogen and electricity cost will also be shared with experts to support their evaluation

1 Kg H2	33.33 kWh
Produce 1 Kg H2	58 kWh
Average Hydrogen cost	0.30 €/kWh
Average Electricity cost	0.19 €/kWh
Hydrogen cost (1Kg) (without logistics)	10€
Hydrogen final price in the customer	16-25€ kg

4. Environmental aspects

- **Emissions (CO2, NOx, SOx, PM).** Experts assessed the environmental performance of each design with respect to emissions. As with OPEX, this evaluation was performed per UC, with reference materials provided to ensure consistency. Environmental considerations per use case will be shared with experts to assist them in their ratings

Table 4 Explanatory notes shared with experts regarding emmissions of the alternative barge designs

UUCs	UC	Emmissions considerations
#1	UC1: Anchored Vessels	Emissions during maneuvering toward the anchored area and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled. Mooring boat involved. Origin of the energy
	UC4: Environmental critical areas	Emissions during manuevering toward the Marine Protected Areas (autonomy of the barge) and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled. Mooring boat involved. Origin of energy
	UC5: Charging of small transportation vessels	Assisting inland waterways transport. Towage emissions if not self-propelled. Mooring boat involved. Origin of energy. Services alongside the river and at inland ports. Electric barge concept included
	UC8: Charging from offshore power plants and wind farms.	Emissions from offshore power plants and wind farms (renewable electricity charged but maybe not hydrogen charging there) to vessels in the surroundings. Towage assistance if not self-propelled and mooring both sides.
	UC10: Charging Bluebarge from outer anchored vessels	Transfer electricity from one vessels to the barge in order to provide with electricity different customers. Emissions during during manuevering to outer port areas. Towage assistance if not self-propelled and mooring boat emissions. Can be combined with other use cases.
#2	UC2: Moored Vessels	Emissions during manuevering within the port area and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled. Mooring boat involved. Origin of the energy. Important to take into account that, compared with anchored areas, the navigation distance is lower
#3	UC3: Isolated inhabited areas	Emissions during manuevering toward the inhabited areas and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled. Mooring boat involved. Origin of the energy
	UC7: Powering offshore platforms – oil rigs	Emissions during manuevering toward the offshore platforms should balance the emissions avoided powering those offshore platforms. Towage emissions if not self-propelled. Mooring boat involved

	UC9: Providing power to land after natural disaster events	Temporary assistance to specific locations with damage in power grids and transmission lines. Emissions due to transition to those areas (maybe long distances) with towage and mooring and to be charged or load with electricity and hydrogen respectively.

4.2 – Experts Profile

The experts selected to proceed with the assessment of the promoted designs against the evaluation criteria comprise of consortium representatives and external subject matter advisors. The selection is based on the following criteria:

- End users, both external and internal to the project, reflecting all aspects of the BlueBarge Concept.
- Hold good and diverse knowledge/experience of the Bluebarge technologies.
- Have fair expectations for the Bluebarge innovations (i.e. they need to be aware of the project objectives) and high interest in the project outcomes.
- Obtain future engagement with the technologies as members of organizations that will play a role in the Bluebarge exploitation or even have direct or indirect connection to the specific BlueBarge business case.

Figure 3 Experts profile

4.3 – Configuration and Development of the Assessment Tool

Multi-Criteria Decision Support System for Evaluation and Ranking of Alternative Barge Designs

Overview

This module describes the implementation and methodology of the Decision Support System (DSS) designed to evaluate and rank alternative BlueBARGE configurations. The DSS integrates multiple evaluation criteria (**see section 4.**1) user-defined weightings, and feasibility assessments structured across umbrella use cases (UC1–UC10). The evaluation process incorporates both individual expert judgments and consolidated multi-user rankings, ensuring that technical, financial, and environmental dimensions are considered in a systematic, transparent, and participatory manner.
The DSS thus provides an evidence-based platform for decision-making in the BlueBARGE project, ensuring that the final selection of barge configurations is aligned with both engineering performance and stakeholder preferences.

System Architecture and Workflow

The DSS follows a web-based architecture consisting of:

- Front-End (AngularJS):
  Enables submission of new barge design proposals with associated KPI values; provides dynamic forms for expert users to specify preferences and feasibility ratings; displays interactive tables and charts summarizing rankings and consolidated results.

- Back-End (Flask,Python):
  Stores data in a MongoDB database; processes KPI values, user weightings, and feasibility modifiers; computes rankings using a multi-criteria decision analysis approach; serves RESTful API endpoints consumed by the front-end.

- Database (MongoDB):
  Stores all barge designs with evaluation criteria values and optional blueprint files; stores user profiles with expertise, importance ratings, and feasibility assessments per evaluation criteria, barge, and umbrella case.

Workflow:

1. Experts submit barge designs and provide structured feasibility evaluations.
2. The back-end normalizes evaluation criteria data, calculates weights, and applies a scoring model.
3. Rankings are computed per user and aggregated across users.
4. Results are visualized interactively on the front-end.

Evaluation Criteria Structure and Categorization

The DSS evaluates barge designs using a selected set of criteria grouped under technical, safety, financial, and environmental dimensions.

- Technical: Capacity (MWh); Power (MW)
- Safety: Safety (categorical scale: Low, Medium, High → mapped to numerical values)
- Financial: CAPEX (€); OPEX (€/year, with feasibility across umbrella cases)
- Environmental: Environmental performance (aggregate representation of CO_2, NO_x, SO_2, PM, evaluated across umbrella cases)

Unlike conventional MCDA frameworks, *efficiency over time* and individual pollutant indicators (CO_2, NO_x, SO_2, PM) were excluded as standalone criteria and instead aggregated under the Environmental group of emissions.

User Preferences and Weighting Model

Each expert provides structured input consisting of:

1. Expertise (EXP): A self-assessment of the user's knowledge in the specific criteria domain (scale 1–5).

2. Importance (IMP): The perceived criticality of the evaluation criteria for decision-making (scale 1–5).
3. Feasibility Assessments: For each evaluation criteria and barge, feasibility is rated across umbrella use cases:
   • For most criteria → three aggregated umbrella cases (UUC1, UUC2, UUC3).
   • For OPEX and Environmental → expanded per-umbrella case structure (UC1–UC10).

These inputs reflect both subjective weighting and objective feasibility constraints for each barge design.

Scoring and Ranking Methodology

The DSS implements a Multi-Criteria Decision Analysis (MCDA) approach inspired by TOPSIS

Decision Matrix Construction

Let the sets of alternatives and criteria be:

$$A = a_1, a_2, \dots, a_m$$

$$C = c_1, c_2, \dots, c_n$$

Let the performance of barge a_i on KPI c_j be x_{ij}.
The raw decision matrix is:

$$X = [x_{ij}]_{m\times n}$$

Cost–Benefit Adjustment and Normalization

Classify evaluation criteria as benefit-type (higher is better) or cost-type (lower is better). Convert cost-type by sign inversion:

(benefit-type) $x'ij = xij$
(cost-type) $x'ij = -xij$

Normalize each KPI column with Min–Max scaling:

$$r_{ij} = \left(x'_{ij} - \min(x'_j)\right) / \left(\max(x'_j) - \min(x'_j)\right)$$

Weight Calculation

For evaluation criteria c_j, the user provides Expertise E_j and Importance I_j.
Raw weight: $w_j^{raw} = E_j \times I_j$
Normalize weights so they sum to one: $w_j = w^{raw} j / \sum k = 1^n w_k^{raw}$

Feasibility Integration

For barge a_i and criteria c_j, aggregate feasibility over the relevant umbrella cases (count p):

$$f_{ij} = (1/p), \sum_{u=1}^{p} g(u)$$

where $g(u)$ is the mapped feasibility score for umbrella case u scaled to $[0,1]$.

Compute the feasibility-adjusted weighted score:

$$v_{ij} = r_{ij}, w_j, f_{ij}$$

TOPSIS Scoring

Form the matrix $V = [v_{ij}]$. For each criteria j, define the ideal best and worst:$v^{+}j = \max_{i} v_{ij}$ and $v_j^{-} = \min_{i} v_{ij}$

Compute distances for each barge a_i:

$$D_i^{+} = \sqrt{\sum j = 1^n \left(v_{ij} - v_j^{+}\right)^2}$$

$$D_i^{-} = \sqrt{\sum j = 1^n \left(v_{ij} - v_j^{-}\right)^2}$$

Finally, the **relative closeness score** for each barge a_i is:

$$S_i = \frac{D_i^{-}}{D_i^{+} + D_i^{-} + \epsilon}$$

A higher S_i indicates that the barge design is closer to the ideal solution and therefore more favorable.

(ε is a small constant for numerical stability, ε > 0)

User Interface

The tool is accessed through the web in the following URL (DANAOS, n.d.): https://bargedss.danaos.gr:5007/ . The landing page includes two tables. The first is listing the KPIs thresholds (go-no go criteria) that the alternative barges met in order to go through the first screening process and promote themselves to the evaluation stage.

Decision Support System

Go / No-Go Criteria

Criterion	Threshold
Capacity (MWh)	≥ 35
Power (MW)	≥ 3
Safety	≤ Medium

Figure 4: DSS web tool screenshot - Go-no go Criteria

The second table provides basic particulars of each promoted alternative design (satisfying the screening thresholds) derived from deliverable D5.1 and calculations from the technology and design onwers

Promoted Barge Designs – General Info

Design	Length (m)	Breadth (m)	Draft (m)	Concept	Engineering Principle	Propulsion	Installation	Theoretical Delivered Power (MW)	Theoretical Delivered Energy (MWh)	Overall Efficiency (%)	Equipment Area Coverage (%)
1.1	97	23	4	Batteries Only	Full Charging Ashore	Non-self Propelled	On Deck	88.3	70.3	73.7	10.4
1.2	97	23	4	Batteries Only	Full Charging Ashore	Self-Propelled	On Deck	88.3	65.3	68.4	10.4
1.3	97	23	4	Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	In Hull & on Deck	20.3	147.3	35.5	11.8
1.4	97	23	4	Combination of FC & Batteries	Hydrogen Fuel	Self-Propelled	In Hull & on Deck	20.3	147.3	34.3	11.8
2.6	48	17.7	2.75	Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	On Deck	8.6	38.8	36.4	16.4
3.3	61.5	12	4.5	Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	In Hull & on Deck	13.8	43.3	38.5	13.2

Figure 5: DSS web tool screenshot - Bluebarge Alternative Designs general information

Following there is the expert's registry page.

Add New User Weights

Enter User Name

Figure 6: DSS web tool screenshot - Expert Registration

The expert proceeds to the evaluation stage. First the expert assings weights to his experience against the evaluation criteria and the importance or criticality of the criteria from the expert's perspective. Following the expert rate the suitability of each Bluebarge design either against the UUCs (as in the case of Capacity) or against the individual use cases under each UUC as in the case of the environmental evaluation criteria.

Capacity

Toggle

Exp.

3 - Medium

Imp.

3 - Moderately Important

Barge Size	Alternative Design Case	UCC1 Energy (MWH)	UCC2 Energy (MWH)	UCC3 Energy (MWh)
LARGE	1.1	✓	✓	✓
	1.2	✓	✓	✓
	1.3	✓	✓	✓
	1.4	✓	✓	✓
MEDIUM	2.6	✓	✓	✓
SMALL	3.3	✓	✓	✓

Feasibility Assessment

Please, evaluate the suitability of each Bluebarge design according to their Capacity and crossed with the different umbrella cases. It is important to take into account the profile of vessels that the alternative design could address, and the table above related to the different Umbrella Use Cases

Alternative Design	Energy Capacity (MWh)	Umbrella Cases		
		UCC1 UC1: Anchored Vessels UC4: Environmental critical areas UC5: Charging of small transportation vessels UC8: Charging from offshore power plants and wind farms UC10: Charging Bluebarge from outer anchored vessels	UCC2 UC2: Moored Vessels	UCC3 UC3: Isolated Inhabited Areas UC7: Powering offshore platforms – oil rigs UC9: Providing power to land after natural disaster events
Barge Design 1.1	70.3	3 - Neither agree nor disagree	3 - Neither agree nor disagree	3 - Neither agree nor disagree
Barge Design 1.2	65.3	3 - Neither agree nor disagree	3 - Neither agree nor disagree	3 - Neither agree nor disagree
Barge Design 1.3	147.3	3 - Neither agree nor disagree	3 - Neither agree nor disagree	3 - Neither agree nor disagree
Barge Design 1.4	142.3	3 - Neither agree nor disagree	3 - Neither agree nor disagree	3 - Neither agree nor disagree
Barge Design 2.6	38.8	3 - Neither agree nor disagree	3 - Neither agree nor disagree	3 - Neither agree nor disagree
Barge Design 3.3	43.3	3 - Neither agree nor disagree	3 - Neither agree nor disagree	3 - Neither agree nor disagree

1. Strongly disagree 2. Disagree 3. Neither 4. Agree 5. Strongly agree 6. N/A

Figure 7: DSS web tool screenshot - Evaluation criteria assessment against Umbrella Use Cases

ENVIROMENTAL

Toggle

Exp.

3 - Medium

Imp.

3 - Moderately Important

Feasibility Assessment

Please, rank the Barges from an Environmental point of view (CO2, NOx, SOx, PM) and per Use Case:

UMBRELLA CASE 1					
ENVIROMENTAL	**UC1: Anchored Vessels** Emissions during navigation toward the anchored area and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled. Mooring boat involved. Origin of the energy.	**UC4: Environmental critical areas** Emissions during navigation toward the Marine Protected Areas (autonomy of the barge) and charging/loading electricity/hydrogen area. Towage emissions if not self-propelled. Mooring boat involved. Origin of energy.	**UC5: Charging of small transportation vessels** Assisting inland waterways transport. Towage emissions if not self-propelled. Mooring boat involved. Origin of energy. Services alongside the river and at inland ports. Electric barge concept included.	**UC8: Charging from offshore power plants and wind farms** Emissions from offshore power plants and wind farms (renewable electricity charged but maybe not hydrogen charging there) to vessels in the surroundings. Towage assistance if not self-propelled and mooring both sides.	**UC10: Charging Bluebarge from outer anchored vessels** Transfer electricity from one vessels to the barge in order to provide with electricity different customers. Emissions during navigating distances. Towage assistance if not self-propelled and mooring boat emissions. Can be combined with other use cases.
Barge Design 1.1	3° Medium of emissions saved	4° Lower of emissions saved	2° Higher of emissions saved	1° The Highest of emissions saved	3° Medium of emissions saved
Barge Design 1.2	3° Medium of emissions saved	4° Lower of emissions saved	2° Higher of emissions saved	1° The Highest of emissions saved	3° Medium of emissions saved
Barge Design 1.3	3° Medium of emissions saved	4° Lower of emissions saved	2° Higher of emissions saved	1° The Highest of emissions saved	3° Medium of emissions saved
Barge Design 1.4	3° Medium of emissions saved	4° Lower of emissions saved	2° Higher of emissions saved	1° The Highest of emissions saved	3° Medium of emissions saved
Barge Design 2.6	3° Medium of emissions saved	4° Lower of emissions saved	2° Higher of emissions saved	1° The Highest of emissions saved	3° Medium of emissions saved
Barge Design 3.3	3° Medium of emissions saved	4° Lower of emissions saved	2° Higher of emissions saved	1° The Highest of emissions saved	3° Medium of emissions saved

1° The Highest of emissions saved ... 6° N/A

Figure 8:DSS web tool screenshot - Evaluation criteria assessment against Use Cases

The visualization of the results with the ranking of designs (in order from top to bottom) is displayed both per expert and in a consolidated format aggregating all expert's preferences and assessments.

User-Specific Barge Rankings

Rank	Barge Name	Score
1	1.2	0.641
2	1.4	0.5957
3	1.1	0.4992
4	1.3	0.4979
5	3.3	0.196
6	2.6	0.1918

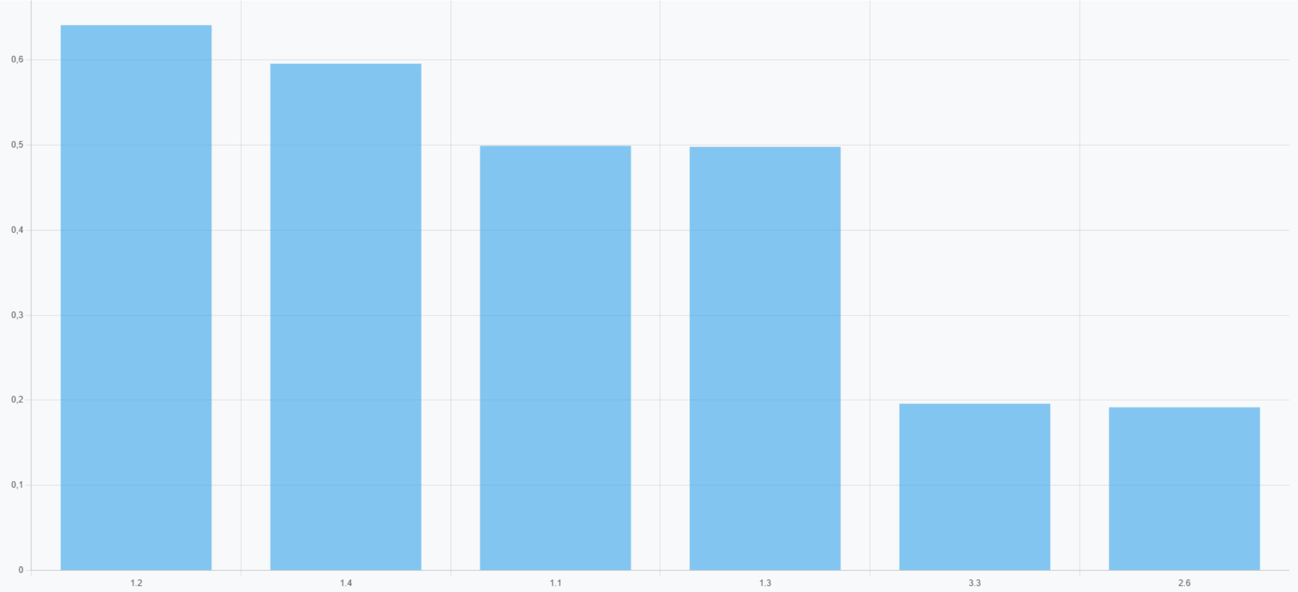


Figure 9: DSS web tool screenshot - Expert specific barge ranking. Bar chart with results

Consolidated Barge Rankings

Rank	Name	Score
1	1.2	0.6429
2	1.1	0.5877
3	1.3	0.4613
4	1.4	0.4592
5	3.3	0.377
6	2.6	0.3325

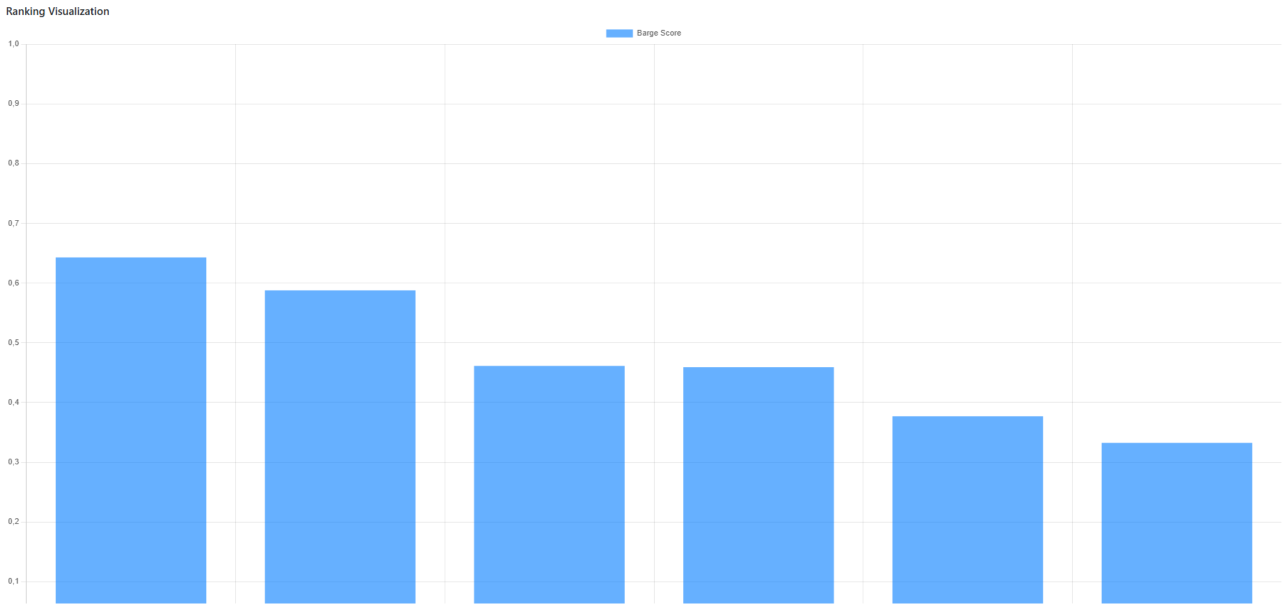


Figure 10: DSS web tool screenshot - Consolidated barge ranking. Bar chart with overall results

5 – Execution of the Evaluation

The evaluation of the alternative designs was carried out through two complementary approaches:

1. **Web-based tool assessment** – Experts were invited to provide their scoring directly using the dedicated assessment tool developed by DANAOS.
2. **Focus groups and bilateral discussions** – Structured sessions were organized by consortium members to collect additional expert input.

Development of the Tool and Initial Engagement

The assessment tool was designed and progressively refined through an iterative process led by a working team from NTUA, VPF, and DANAOS. The first version was presented to the consortium on 10 July 2025 during an online workshop, which included key stakeholders and end users (e.g., ABS, Columbia Shipmanagement, Multi Marine Services, Valencia Port Foundation). Participants were guided through the tool and the design alternatives, after which they performed live scoring and provided structured feedback.

Following this workshop, the tool was updated based on recommendations and released for internal testing in early September. The final version was then opened to selected experts for evaluation at: 👉 https://bargedss.danaos.gr:5007/ (DANAOS, n.d.)

The evaluation period lasted two weeks, until 16 September 2025. Expert inputs were automatically processed by the tool's algorithm, producing consolidated rankings of the alternatives from most to least favorable.

The experts (20 in total) who evaluated the alternatives directly in the tool, were drawn from both consortium partners (at least 1 representative per partner) and external stakeholders (see table 5), consistent with the profiles defined in Section 4.2.

Focus Groups and Bilateral Sessions

In parallel, focus groups and one-to-one discussions were held in the first week of September 2025. These sessions followed a structured agenda:

- Presentation of the design alternatives and evaluation framework.
- Demonstration of the assessment tool.
- Real-time assessment (input of their values in the tool) and discussion of expert ratings.

These sessions ensured wider participation and provided qualitative insights to complement the structured scoring process. Experts were coded for anonymity and listed in the table below.

Table 5 List of external stakeholders participated in focus group and one-to-one discussions

ID	Organization	Stakeh. group	Role in the organization
Exp1	PIRAEUS PORT AUTHORITY	Port authority	Safety and Security Manager
Exp2	LEVANTE FERRIES	Shipping company	DPA and HSQE director
Exp3	DNV	Class. Society	RnD manager and business consultant
Exp4	DANAOS SHIPPING LTD.	Shipping company	Technical Manager
Exp5	DANAOS SHIPPING LTD	Shipping company	Marine engineer with experience in barge maintenance
Exp6	DANAOS SHIPPING LTD.	Shipping company	RnD Manager
Exp7	DANAOS SHIPPING LTD/FREELANCER-SEAFARER	Shipping company	Captain, experienced with barge operation
Exp8	Attica Group	Shipping company	Corporate Development Director

6 – Results

The evaluation campaign, carried out through the web-based Decision Support System (DSS) and complemented by focus groups and bilateral discussions, produced a consolidated ranking of the six BlueBARGE design alternatives. The DSS algorithm applied the multi-criteria decision analysis (MCDA) approach defined in Section 4.3, normalising expert scores and weighting them according to expertise and importance.

The results of the consolidated ranking are summarised in Table 6 and visualised in Figure 11.

Table 6 Consolidated Barge Ranking

Consolidated Barge Rankings

Rank	Name	Score
1	1.2	0.661
2	1.4	0.5648
3	1.1	0.4893
4	1.3	0.4233
5	3.3	0.2517
6	2.6	0.2301

The analysis indicates that **Design 1.2** achieved the highest overall score, demonstrating balanced performance across technical, environmental, financial, and safety dimensions per UUCs and single UCs. **Design 1.4** followed closely, also scoring favourably across most criteria, particularly in terms of safety performance. Conversely, **Designs 3.3 and 2.6** obtained the lowest scores, reflecting comparatively weaker alignment with the evaluation criteria and stakeholder expectations.

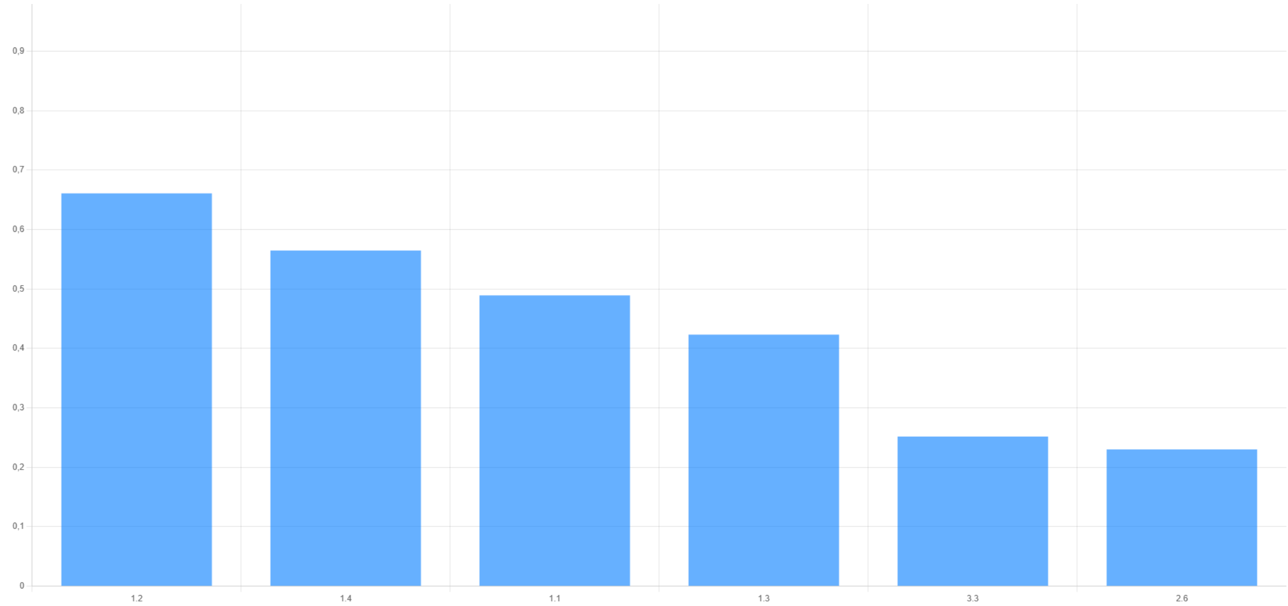


Figure 11 Ranking of the Alternative Designs visualized in a bar chart

The consolidated results **highlight Design 1.2** as the most promising candidate for optimisation under **Task 4.4,** where further detailed design and techno-economic analyses will be performed to validate its feasibility and scalability.

7 – Conclusions and Recommendations

The evaluation of the six BlueBARGE design alternatives, as presented in this deliverable, followed a structured process that combined the methodology defined in D4.1 with the design options introduced in D5.1. Through the application of a multi-criteria decision analysis framework, supported by a dedicated web-based DSS and complemented by focus groups and bilateral discussions, the assessment integrated technical, financial, environmental, and safety considerations. This systematic approach ensured transparent and evidence-based results, enabling meaningful comparison among the candidate designs and validation of stakeholder perspectives.

The consolidated results identified **Design 1.2** as the most favorable configuration overall.

These findings establish a clear pathway for Task 4.4, where Design 1.2 will undergo detailed optimisation and techno-economic validation

6- References

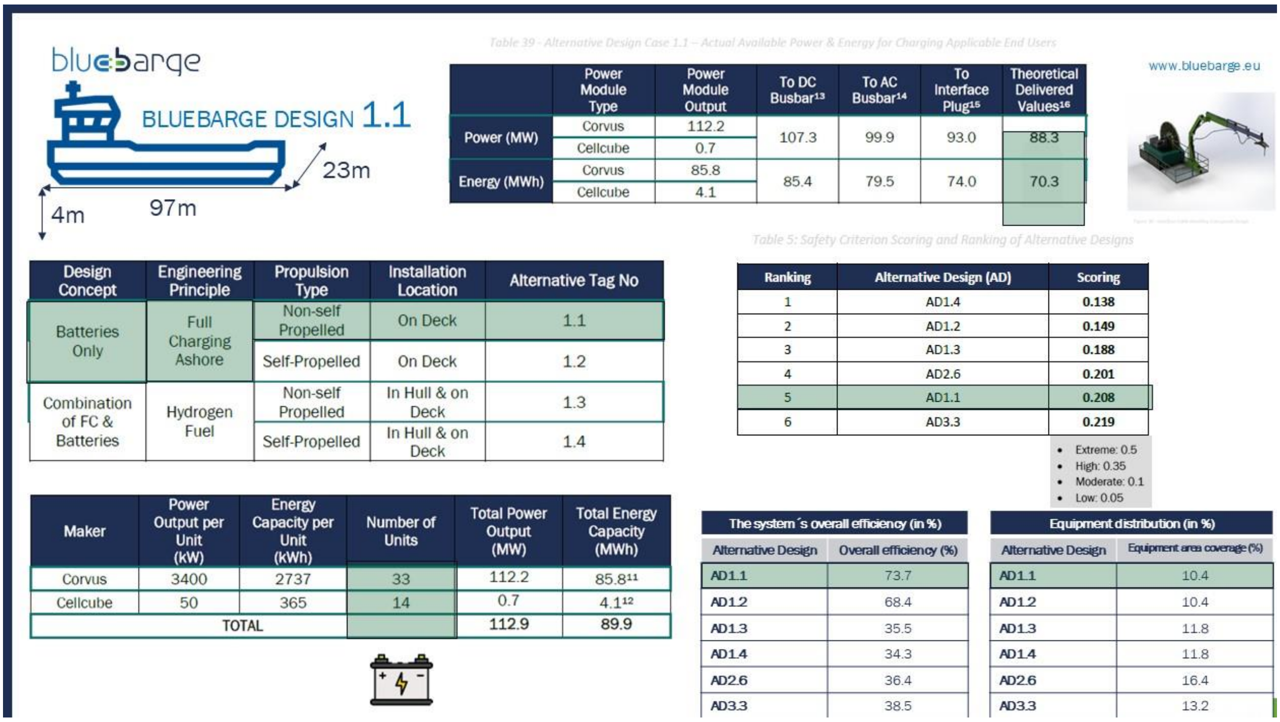
American Bureau of Shipping (ABS). (2022). *Preliminary HAZID for Emission Control Barge.* Spring: ABS.

DANAOS. (n.d.). *BlueBarge Alternative Designs Evaluation* . Retrieved from https://bargedss.danaos.gr:5007/

Taherdoost, M. &. (2023). A comprehensive guide to the TOPSIS method for multi-criteria decision making. *Sustainable Social Development*.

ANNEX 1- The Alternative Designs

A visualization of main data and particulars of each alternative design has been shared with experts accumulating and highlighting all necessary information in one picture



	Power Module Type	Power Module Output	To DC Busbar[13]	To AC Busbar[14]	To Interface Plug[15]	Theoretical Delivered Values[16]
Power (MW)	Corvus	112.2	107.3	99.9	93.0	88.3
	Cellcube	0.7				
Energy (MWh)	Corvus	85.8	85.4	79.5	74.0	70.3
	Cellcube	4.1				

Design Concept	Engineering Principle	Propulsion Type	Installation Location	Alternative Tag No
Batteries Only	Full Charging Ashore	Non-self Propelled	On Deck	1.1
		Self-Propelled	On Deck	1.2
Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	In Hull & on Deck	1.3
		Self-Propelled	In Hull & on Deck	1.4

Ranking	Alternative Design (AD)	Scoring
1	AD1.4	**0.138**
2	AD1.2	**0.149**
3	AD1.3	**0.188**
4	AD2.6	**0.201**
5	AD1.1	**0.208**
6	AD3.3	**0.219**

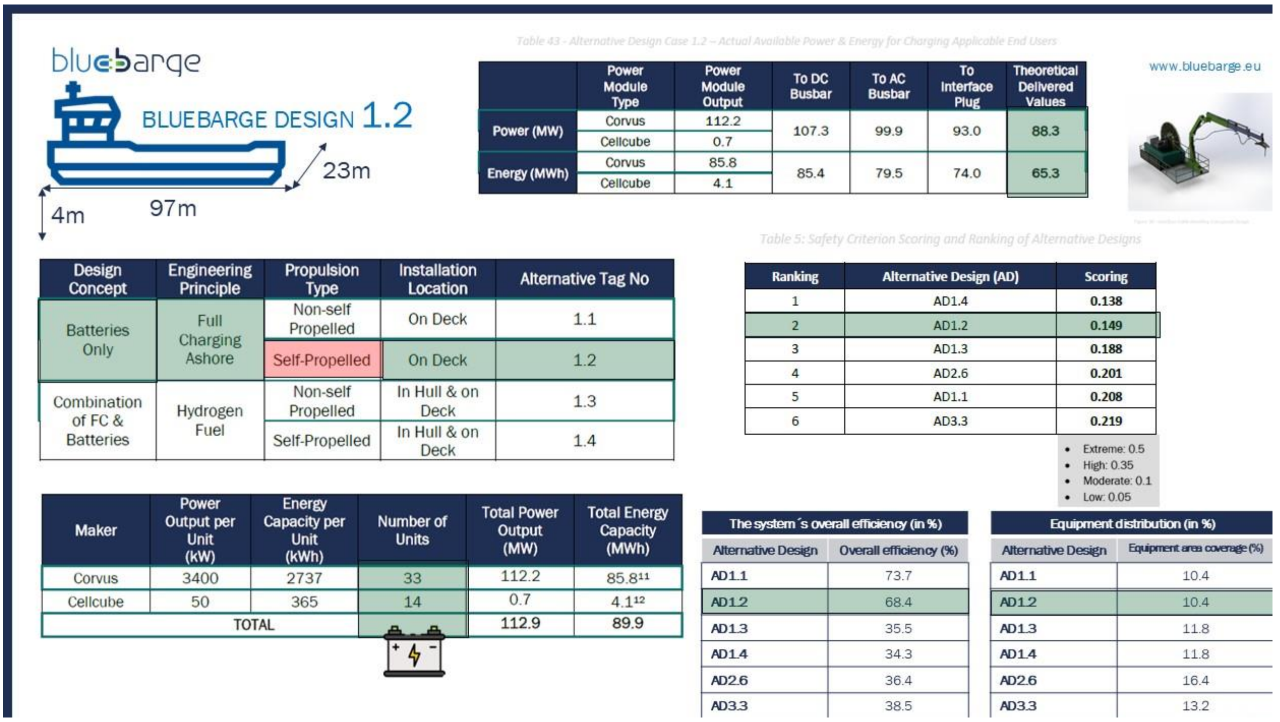
- Extreme: 0.5
- High: 0.35
- Moderate: 0.1
- Low: 0.05

Maker	Power Output per Unit (kW)	Energy Capacity per Unit (kWh)	Number of Units	Total Power Output (MW)	Total Energy Capacity (MWh)
Corvus	3400	2737	33	112.2	85.8[11]
Cellcube	50	365	14	0.7	4.1[12]
TOTAL				112.9	89.9

The system´s overall efficiency (in %)	
Alternative Design	Overall efficiency (%)
AD1.1	73.7
AD1.2	68.4
AD1.3	35.5
AD1.4	34.3
AD2.6	36.4
AD3.3	38.5

Equipment distribution (in %)	
Alternative Design	Equipment area coverage (%)
AD1.1	10.4
AD1.2	10.4
AD1.3	11.8
AD1.4	11.8
AD2.6	16.4
AD3.3	13.2

Figure 12: BlueBarge alternative design 1.1 data



	Power Module Type	Power Module Output	To DC Busbar	To AC Busbar	To Interface Plug	Theoretical Delivered Values
Power (MW)	Corvus	112.2	107.3	99.9	93.0	88.3
	Cellcube	0.7				
Energy (MWh)	Corvus	85.8	85.4	79.5	74.0	65.3
	Cellcube	4.1				

Design Concept	Engineering Principle	Propulsion Type	Installation Location	Alternative Tag No
Batteries Only	Full Charging Ashore	Non-self Propelled	On Deck	1.1
		Self-Propelled	On Deck	1.2
Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	In Hull & on Deck	1.3
		Self-Propelled	In Hull & on Deck	1.4

Ranking	Alternative Design (AD)	Scoring
1	AD1.4	**0.138**
2	AD1.2	**0.149**
3	AD1.3	**0.188**
4	AD2.6	**0.201**
5	AD1.1	**0.208**
6	AD3.3	**0.219**

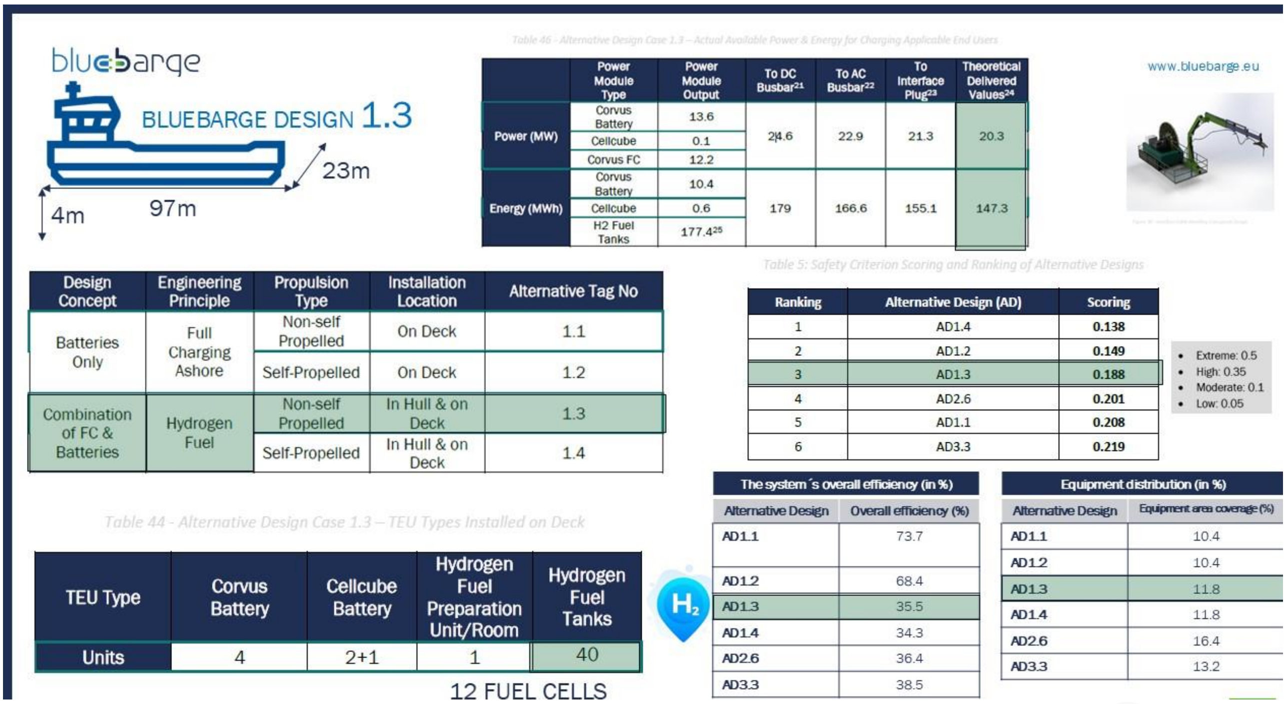
- Extreme: 0.5
- High: 0.35
- Moderate: 0.1
- Low: 0.05

Maker	Power Output per Unit (kW)	Energy Capacity per Unit (kWh)	Number of Units	Total Power Output (MW)	Total Energy Capacity (MWh)
Corvus	3400	2737	33	112.2	85.8[11]
Cellcube	50	365	14	0.7	4.1[12]
TOTAL				112.9	89.9

The system´s overall efficiency (in %)	
Alternative Design	Overall efficiency (%)
AD1.1	73.7
AD1.2	68.4
AD1.3	35.5
AD1.4	34.3
AD2.6	36.4
AD3.3	38.5

Equipment distribution (in %)	
Alternative Design	Equipment area coverage (%)
AD1.1	10.4
AD1.2	10.4
AD1.3	11.8
AD1.4	11.8
AD2.6	16.4
AD3.3	13.2

Figure 13: BlueBarge alternative design 1.2 data



	Power Module Type	Power Module Output	To DC Busbar[21]	To AC Busbar[22]	To Interface Plug[23]	Theoretical Delivered Values[24]
Power (MW)	Corvus Battery	13.6	24.6	22.9	21.3	20.3
	Cellcube	0.1				
	Corvus FC	12.2				
Energy (MWh)	Corvus Battery	10.4	179	166.6	155.1	147.3
	Cellcube	0.6				
	H2 Fuel Tanks	177.4[25]				

Design Concept	Engineering Principle	Propulsion Type	Installation Location	Alternative Tag No
Batteries Only	Full Charging Ashore	Non-self Propelled	On Deck	1.1
		Self-Propelled	On Deck	1.2
Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	In Hull & on Deck	1.3
		Self-Propelled	In Hull & on Deck	1.4

Ranking	Alternative Design (AD)	Scoring
1	AD1.4	**0.138**
2	AD1.2	**0.149**
3	AD1.3	**0.188**
4	AD2.6	**0.201**
5	AD1.1	**0.208**
6	AD3.3	**0.219**

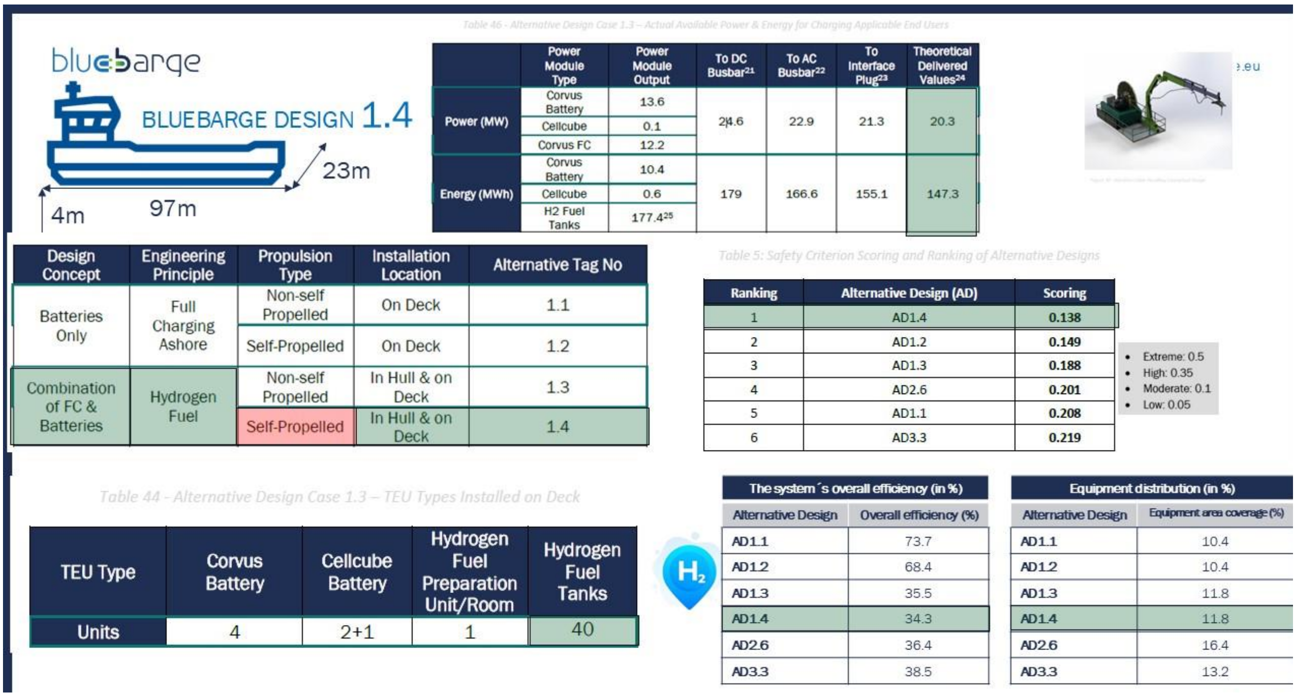
- Extreme: 0.5
- High: 0.35
- Moderate: 0.1
- Low: 0.05

TEU Type	Corvus Battery	Cellcube Battery	Hydrogen Fuel Preparation Unit/Room	Hydrogen Fuel Tanks
Units	4	2+1	1	40

The system´s overall efficiency (in %)	
Alternative Design	Overall efficiency (%)
AD1.1	73.7
AD1.2	68.4
AD1.3	35.5
AD1.4	34.3
AD2.6	36.4
AD3.3	38.5

Equipment distribution (in %)	
Alternative Design	Equipment area coverage (%)
AD1.1	10.4
AD1.2	10.4
AD1.3	11.8
AD1.4	11.8
AD2.6	16.4
AD3.3	13.2

Figure 14: BlueBarge alternative design 1.3 data



	Power Module Type	Power Module Output	To DC Busbar[21]	To AC Busbar[22]	To Interface Plug[23]	Theoretical Delivered Values[24]
Power (MW)	Corvus Battery	13.6	24.6	22.9	21.3	20.3
	Cellcube	0.1				
	Corvus FC	12.2				
Energy (MWh)	Corvus Battery	10.4	179	166.6	155.1	147.3
	Cellcube	0.6				
	H2 Fuel Tanks	177.4[25]				

Design Concept	Engineering Principle	Propulsion Type	Installation Location	Alternative Tag No
Batteries Only	Full Charging Ashore	Non-self Propelled	On Deck	1.1
		Self-Propelled	On Deck	1.2
Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	In Hull & on Deck	1.3
		Self-Propelled	In Hull & on Deck	1.4

Table 5: Safety Criterion Scoring and Ranking of Alternative Designs

Ranking	Alternative Design (AD)	Scoring
1	AD1.4	**0.138**
2	AD1.2	**0.149**
3	AD1.3	**0.188**
4	AD2.6	**0.201**
5	AD1.1	**0.208**
6	AD3.3	**0.219**

- Extreme: 0.5
- High: 0.35
- Moderate: 0.1
- Low: 0.05

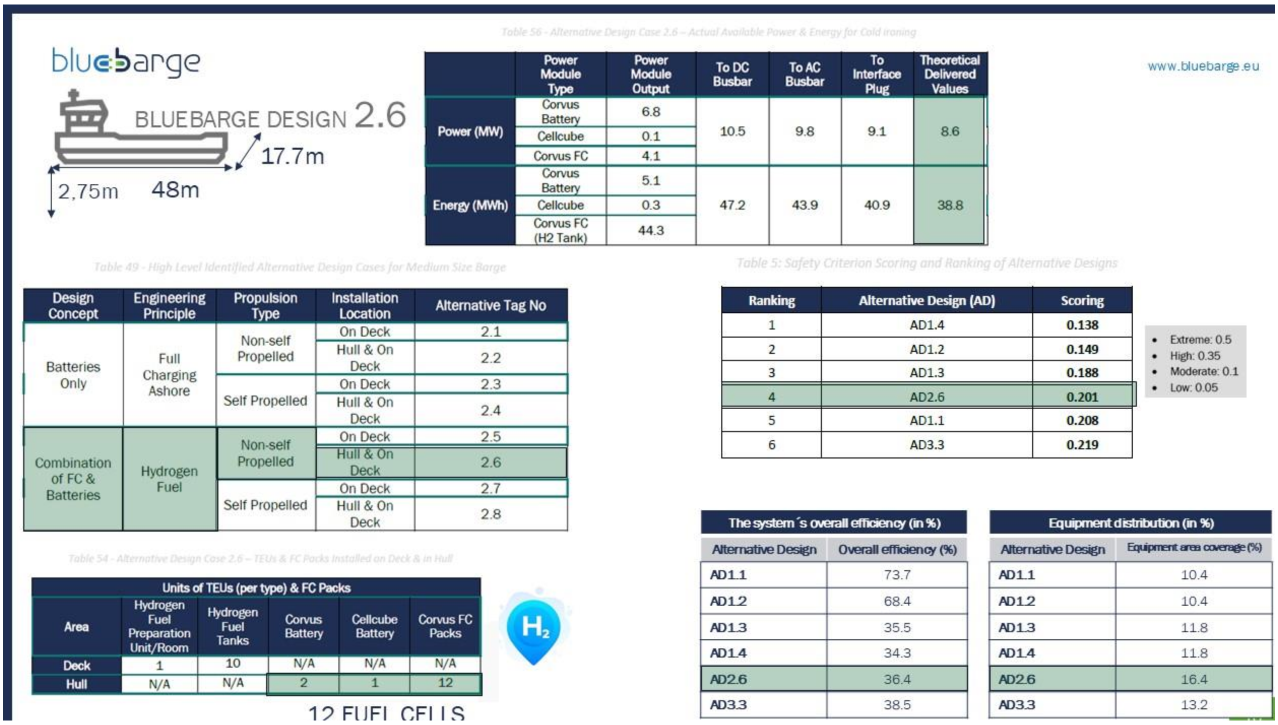
Table 44 - Alternative Design Case 1.3 – TEU Types Installed on Deck

TEU Type	Corvus Battery	Cellcube Battery	Hydrogen Fuel Preparation Unit/Room	Hydrogen Fuel Tanks
Units	4	2+1	1	40

The system´s overall efficiency (in %)	
Alternative Design	Overall efficiency (%)
AD1.1	73.7
AD1.2	68.4
AD1.3	35.5
AD1.4	34.3
AD2.6	36.4
AD3.3	38.5

Equipment distribution (in %)	
Alternative Design	Equipment area coverage (%)
AD1.1	10.4
AD1.2	10.4
AD1.3	11.8
AD1.4	11.8
AD2.6	16.4
AD3.3	13.2

Figure 15: BlueBarge alternative design 1.4 data



	Power Module Type	Power Module Output	To DC Busbar	To AC Busbar	To Interface Plug	Theoretical Delivered Values
Power (MW)	Corvus Battery	6.8	10.5	9.8	9.1	8.6
	Cellcube	0.1				
	Corvus FC	4.1				
Energy (MWh)	Corvus Battery	5.1	47.2	43.9	40.9	38.8
	Cellcube	0.3				
	Corvus FC (H2 Tank)	44.3				

Table 49 - High Level Identified Alternative Design Cases for Medium Size Barge

Design Concept	Engineering Principle	Propulsion Type	Installation Location	Alternative Tag No
Batteries Only	Full Charging Ashore	Non-self Propelled	On Deck	2.1
			Hull & On Deck	2.2
		Self Propelled	On Deck	2.3
			Hull & On Deck	2.4
Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	On Deck	2.5
			Hull & On Deck	2.6
		Self Propelled	On Deck	2.7
			Hull & On Deck	2.8

Table 5: Safety Criterion Scoring and Ranking of Alternative Designs

Ranking	Alternative Design (AD)	Scoring
1	AD1.4	**0.138**
2	AD1.2	**0.149**
3	AD1.3	**0.188**
4	AD2.6	**0.201**
5	AD1.1	**0.208**
6	AD3.3	**0.219**

- Extreme: 0.5
- High: 0.35
- Moderate: 0.1
- Low: 0.05

Table 54 - Alternative Design Case 2.6 – TEUs & FC Packs Installed on Deck & in Hull

Area	Units of TEUs (per type) & FC Packs: Hydrogen Fuel Preparation Unit/Room	Hydrogen Fuel Tanks	Corvus Battery	Cellcube Battery	Corvus FC Packs
Deck	1	10	N/A	N/A	N/A
Hull	N/A	N/A	2	1	12

The system´s overall efficiency (in %)	
Alternative Design	Overall efficiency (%)
AD1.1	73.7
AD1.2	68.4
AD1.3	35.5
AD1.4	34.3
AD2.6	36.4
AD3.3	38.5

Equipment distribution (in %)	
Alternative Design	Equipment area coverage (%)
AD1.1	10.4
AD1.2	10.4
AD1.3	11.8
AD1.4	11.8
AD2.6	16.4
AD3.3	13.2

Figure 16: BlueBarge alternative design 2.6 data

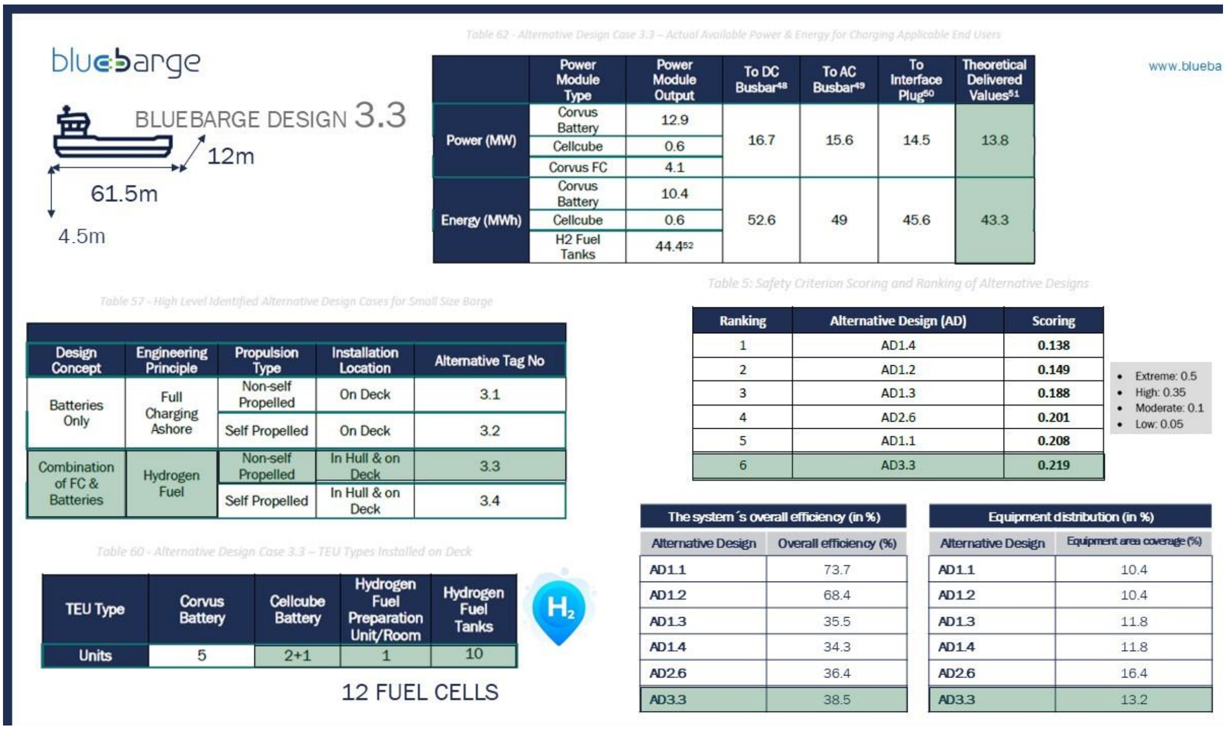


Table 62 - Alternative Design Case 3.3 – Actual Available Power & Energy for Charging Applicable End Users

	Power Module Type	Power Module Output	To DC Busbar[48]	To AC Busbar[49]	To Interface Plug[50]	Theoretical Delivered Values[51]
Power (MW)	Corvus Battery	12.9	16.7	15.6	14.5	13.8
	Cellcube	0.6				
	Corvus FC	4.1				
Energy (MWh)	Corvus Battery	10.4	52.6	49	45.6	43.3
	Cellcube	0.6				
	H2 Fuel Tanks	44.4[52]				

Table 57 - High Level Identified Alternative Design Cases for Small Size Barge

Design Concept	Engineering Principle	Propulsion Type	Installation Location	Alternative Tag No
Batteries Only	Full Charging Ashore	Non-self Propelled	On Deck	3.1
		Self Propelled	On Deck	3.2
Combination of FC & Batteries	Hydrogen Fuel	Non-self Propelled	In Hull & on Deck	3.3
		Self Propelled	In Hull & on Deck	3.4

Table 60 - Alternative Design Case 3.3 – TEU Types Installed on Deck

TEU Type	Corvus Battery	Cellcube Battery	Hydrogen Fuel Preparation Unit/Room	Hydrogen Fuel Tanks
Units	5	2+1	1	10

Table 5: Safety Criterion Scoring and Ranking of Alternative Designs

Ranking	Alternative Design (AD)	Scoring
1	AD1.4	**0.138**
2	AD1.2	**0.149**
3	AD1.3	**0.188**
4	AD2.6	**0.201**
5	AD1.1	**0.208**
6	AD3.3	**0.219**

- Extreme: 0.5
- High: 0.35
- Moderate: 0.1
- Low: 0.05

The system´s overall efficiency (in %)	
Alternative Design	Overall efficiency (%)
AD1.1	73.7
AD1.2	68.4
AD1.3	35.5
AD1.4	34.3
AD2.6	36.4
AD3.3	38.5

Equipment distribution (in %)	
Alternative Design	Equipment area coverage (%)
AD1.1	10.4
AD1.2	10.4
AD1.3	11.8
AD1.4	11.8
AD2.6	16.4
AD3.3	13.2

Figure 17 BlueBarge alternative design 3.3 data

ANNEX 2- Evaluation of Safety Criterion for the Alternative Designs

As part of T2.3: Technical and operational safety assessment led by NTUA, a desktop risk assessment was conducted from NTUA, in order to evaluate and compare the safety ratings and performance of each alternative design presented in D5.1: BlueBARGE design alternatives, addressing all pertinent factors, including technological, operational, environmental, and human-related aspects. The initial Hazard Identification (HAZID) study, carried out as part of this desktop risk assessment performed by NTUA, identified risks associated with the various alternative designs (6), engaged in multiple operations and operational scenarios. These designs were ranked based on their performance during the subsequent risk assessment. The study assessed which proposed conceptual designs best align with the objectives and functional requirements outlined in the preliminary Concept of Operations (ConOps) document, with respect to safety. The overall methodology was developed according to a comprehensive risk assessment plan, referred to as the Terms of Reference (TOR), which was circulated to the involved partners prior to the risk assessment. It served as guidance for the subsequent risk analysis, aimed at identifying potential hazards associated with the operational configurations of the BlueBARGE alternative designs, in the early stages of concept development. The TOR defined and established the requirements for planning, conducting, and documenting the preliminary HAZID study, detailing the process for evaluating and ranking the alternative designs in terms of safety.

This concept study was organized from NTUA into distinct phases, as outlined in the rationale briefly described above. Prior to the commencement of the study, the drawings referenced in D5.1 were thoroughly reviewed, indicating that the designs remain in a preliminary and conceptual stage. To maximize the utility and benefits of this assessment, a decision was made to focus on the baseline capabilities related to the General Arrangement, along with associated design challenges, issues and operational aspects of the concept. As a result, this desktop risk assessment specifically targeted ConOps-related hazards across various operating modes, that will be described below, and configurations of the alternative barge designs, including a generic universal representation.

The preliminary HAZID study identified risks associated with a spectrum of alternative power barge designs engaged in various operations. These designs were subsequently evaluated and ranked based on their safety performance. Thus, the study assessed which of the proposed conceptual designs best meets the goals and functional requirements specified in the ConOps document, with respect to safety. Documented scenarios included recommendations wherever feasible. It is essential to emphasize that this study did not address hazards or operability concerns related to standard hull and marine systems, including auxiliary systems or potential fuel oil systems, which are not directly tied to operational activities. It was presumed that such hazards would be managed and controlled by operators in compliance with relevant requirements, including Flag State regulations, International Maritime Organization (IMO) mandates, and the standards established by classification societies.

Procedure

The risk assessment was performed through the implementation of a preliminary online HAZID workshop hosted and coordinated from NTUA. The kickoff meeting took place on the 5th of May 2025, followed by two sessions on the 19th and 20th of May 2025. All WP2 partners participated, providing their valuable feedback.

The modes of operation that were studied- serving as nodes in the procedure-were:

1. Moored-charging
2. Moored-bunkering
3. Mooring/unmooring
4. Manoeuvering
5. Sea-going navigation
6. Connect/disconnect vessel
7. Operations
8. Emergencies

The detailed procedure applied in the workshop followed the steps outlined below:

- **Node Briefing:** To ensure that all HAZID team members have a shared understanding of the design and intended operation of the node, offered an introduction to the node in question.
- **Identification of Hazards and Hazardous Events:** The HAZID team identified hazards and hazardous events upon the documents and drawings provided. Along with previous experience, the team considered each node in sequence.
- **Identification of Causes:** For each hazardous event identified, all potentially relevant causes of the hazard being realised were identified and discussed. However, double jeopardy, which refers to a combination of multiple independent events occurring simultaneously, were not be considered during the HAZID workshop.
- **Identification of Consequences:** For each hazardous event and cause identified, all potential consequences concerning people, assets, and the environment, were assessed.
- **Identification of Preventive and Mitigating Measures (Safeguards):** For each accident scenario, existing measures expected to prevent a hazardous event from occurring (i.e., preventive

measures), as well as those intended to control its development or mitigate its consequences (i.e., mitigating measures), were identified.

- **Risk Ranking:** Risk ranking categorizes the identified accident scenarios, in terms of likelihood and severity.
- **Identification of Recommendations:** During the HAZID workshop, recommendations were raised in cases where the current provision of preventive or mitigating measures is considered insufficient to manage risks or if further assessments are required to better understand the hazard or hazardous event. These recommendations will be further studied, shared and be assigned to the responsible parties at a later stage of the project, in order to be taken into account for the detailed design of the promoted BlueBARGE solution.

The procedure that was followed is illustrated in **Figure 18**

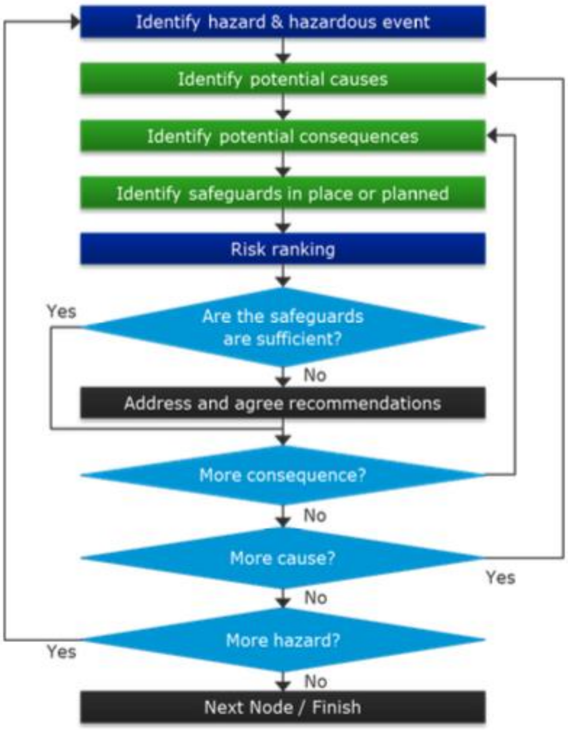


Figure 18: The HAZID Procedure

The risk ranking was performed based on the risk matrix illustrated in **Table 5**. (American Bureau of Shipping (ABS) 2022) (American Bureau of Shipping (ABS), 2022).

Table 7: HAZID risk matrix (American Bureau of Shipping (ABS), 2022)

		Consequence Severity				
		Low	Minor	Moderate	Major	Critical
		1	2	3	4	5
Likelihood	Almost Certain **(E)** Occurs 1 or more times a year					
	Likely **(D)** Occurs once every 1-10 years	**Moderate**		High		Extreme
	Possible **(C)** Occurs once every 10-100 years	**Low**	**Moderate**	High		Extreme

	Unlikely **(B)** Occurs once every 100-1000 years	**Low**	**Low**	**Moderate**
	Rare **(A)** Occurs once every 1000-10000 years	**Low**	**Low**	**Moderate**
Action Key Description	Low	No action is required, unless change in circumstances		
	Moderate	No additional controls are required, monitoring is required to ensure no changes in circumstances		
	High	Risk is high and additional control is required to manage risk		
	Extreme	Intolerable risk, mitigation is required		

Results

As a crucial part of the process, a multidisciplinary risk assessment team carefully documented potential safety, health, and environmental impacts related to the operations of various power barge alternative designs, through structured brainstorming, at a desktop level. The outcome of this desktop risk assessment was the establishment of safety ratings for each alternative design, determined by calculating and comparing their associated risks. The identified elements were ranked in terms of Likelihood and Severity, as shown in Table 7. Furthermore, additional insights and feedback on the risk ranking from the WP2 partners, based on their fields of expertise were taken into account. The design with the lowest risk score was deemed the most favorable. The findings from this evaluation, which involved assessing and ranking associated risks, serves as input to T4.2: BlueBARGE alternatives and optimum design and are summarized **Error! Reference source not found.**. In addition, the study identified any potentially u nresolvable or unmitigable risks that could hinder the successful advancement of the concept. As the design progresses, the risks identified in the HAZID Risk Registry will be addressed by implementing the recommended actions and will undergo re-evaluation during the risk assessment of the detailed design, once it becomes available at a later stage of the project.

The number of ranked elements per risk ranking category and per alternative design along with the relevant percentages are shown in **Table 6** and **Table 7** respectively. The statistical analysis was performed in order to normalize the results, since the number of ranked elements for each alternative design differs.

Table 8:Number of ranked elements per alternative design

Risk Ranking	AD1	AD2	AD3	AD4	AD5	AD6
Extreme	31	8	33	9	33	40
High	61	39	68	47	77	88
Moderate	47	57	52	65	71	59
Low	80	79	122	122	94	94
Total	219	183	275	243	275	281

Table 9: The percentage of risks per risk ranking category and alternative design

Risk Ranking	AD1	AD2	AD3	AD4	AD5	AD6
Extreme	14.2%	4.4%	12.0%	3.7%	12.0%	14.2%
High	27.9%	21.3%	24.7%	19.3%	28.0%	31.3%

Moderate	21.5%	31.1%	18.9%	26.7%	25.8%	21.0%
Low	36.5%	43.2%	44.4%	50.2%	34.2%	33.5%

The final step of the process was the assignment of weighting factors to each risk ranking category, in order to emphasize the importance of addressing the elements ranked as “Extreme” and “High”, compared to those ranked as “Moderate” and “Low”. Weighting factors values were established through expert judgment, reflecting a reasoned consensus among domain specialists, concerning the relative criticality and urgency associated with addressing each identified risk level. They were determined based on standard risk management and common good ship handling and engineering practices along with relevant classification societies guidelines, ensuring that higher-risk categories receive proportionally greater emphasis due to their potential impact and urgency, while maintaining a balanced approach to the rest identified risk levels. Specifically, a weight of 0.5 was assigned to “Extreme” risks to reflect their critical impact and immediate need for mitigation, consistent with best practices in risk prioritisation. Lower weight values were proportionally allocated to ensure a rational emphasis across all categories while preserving focus on the most severe threats.

The weighting factors were assigned as follows:

- Extreme: 0.5
- High: 0.35
- Moderate: 0.1
- Low: 0.05

The final outcome of the risk assessment (i.e., the scoring of the 6 alternative designs in terms of safety) of the alternative designs performed through the preliminary HAZID workshop is presented in **Table 8.**

Table 10: Distribution of risk rankings across the 6 Alternative Designs, with corresponding weighting factors applied to each risk category

Risk Ranking	Weighting factor	AD1	AD2	AD3	AD4	AD5	AD6
Extreme	0.5	14.2%	4.4%	12.0%	3.7%	12.0%	14.2%
High	0.35	27.9%	21.3%	24.7%	19.3%	28.0%	31.3%
Moderate	0.1	21.5%	31.1%	18.9%	26.7%	25.8%	21.0%
Low	0.05	36.5%	43.2%	44.4%	50.2%	34.2%	33.5%
Weighted score		**0.208**	**0.149**	**0.188**	**0.138**	**0.201**	**0.219**

The alternative designs were ranked from the one considered safest to the one considered less safe as show in **Table 9**

Table 11: Safety Criterion Scoring and Ranking of Alternative Designs

Ranking	Alternative Design (AD)	Scoring
1	AD1.4	**0.138**
2	AD1.2	**0.149**
3	AD1.3	**0.188**
4	AD2.6	**0.201**
5	AD1.1	**0.208**

6	AD3.3	**0.219**

In conclusion, the alternative design scored as the safest through the preliminary HAZID workshop procedure is Alterative Design 1.4.