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# AENEAS

## innovAtive ENErgy storage systems onboArd vesselS

# Deliverable D6.3: Feasibility analyses in serving EU/IMO targets, including report on business cases

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## Project Abstract

AENEAS aims to contribute towards climate-neutral and environmentally friendly water transport through three new next generation clean energy storage solutions. Eventual impact is an increase of the global competitiveness of the EU waterborne transport sector by European technology leadership for energy storage solutions for diverse waterborne applications.

AENEAS will develop three innovative electric Energy Storage Solutions (ESS) for waterborne transport, which are advanced beyond the traditional battery systems, including Solid-state batteries (SSB), Supercapacitors (SC) and a Hybrid system which combines SSB and SC.

The solutions enable (partial or full) electric shipping, taking into account conditions specific ships might encounter, including adverse conditions outside sheltered waters or going upstream on rivers. AENEAS will evaluate them for a range of applications and end uses in short-sea shipping and in-land waterways. At the same time AENEAS will define the pathway for the three ESSs for application in different ship types, achieving a comprehensive understanding of the ESSs and their applicability for diverse waterborne transport.

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# Public Summary

This deliverable (D6.3) evaluates the technical, economic, and operational feasibility of the advanced Energy Storage System (ESS) solutions developed within the AENEAS project—namely Semi-Solid-State Batteries (SSSB), Supercapacitors (SC), and hybrid SSSB–SC configurations—for application in maritime and inland waterway transport. The objective is to identify where these technologies can deliver the highest value, under which conditions they are most effective, and how they can contribute to EU and IMO decarbonisation goals.

The work is structured around several key analytical steps. First, a global fleet segmentation is carried out to provide an objective basis for assessing ESS applicability across a wide range of vessel categories. This segmentation is complemented by a review of current battery deployment in shipping, allowing the identification of vessel types with the greatest potential for each ESS technology. In general, Ro-Ro vessels and ferries emerge as strong candidates for shore connection (SC/cold ironing), enabled port-stay electrification with SSSB, while container ships are explicitly retained as an additional SC application case and, together with other large vessels, are assessed for SC-enabled fuel reduction during manoeuvring; finally, large ferries remain relevant candidates for hybrid solutions combining both technologies.

Second, the deliverable addresses the needs and limitations of the maritime value chain. Due to the limited availability of public data on detailed vessel energy use, the analysis is informed by inputs from shipowners, system integrators, shipyards, and other stakeholders. These interactions are used to define realistic assumptions on installation constraints, system sizing, costs, lifetimes, maintenance requirements, and expected operational impacts.

Building on this foundation, a screening-level techno-economic assessment is performed across multiple vessel types. Simplified CAPEX and OPEX calculations are used to compare vessels with and without ESS, enabling a consistent evaluation of economic trends and the identification of the most promising applications. A key outcome of this analysis is that ESS integration is highly vessel- and use-case-specific and cannot be applied uniformly across the fleet.

For selected representative cases, a more detailed lifecycle economic assessment is carried out. The results show that, in general, ESS integration is economically more attractive for newbuild vessels than for retrofits, due to lower integration costs and fewer structural and operational constraints. Semi-Solid-State Batteries tend to deliver higher fuel and emission savings, particularly in vessels with significant energy demand during port-stay, but they require higher upfront investment. Supercapacitors, while offering lower capital expenditure and high durability, deliver more limited absolute emission reductions, as their impact is concentrated on short, high-power operational phases such as manoeuvring.

The deliverable also quantifies the environmental benefits of ESS deployment. SSSB systems provide the largest $CO_2$ reductions by replacing auxiliary engine operation during port-stay, while SC systems reduce emissions by improving efficiency during manoeuvring. Hybrid configurations allow both effects to be combined on a single vessel, providing a clear illustration of how different ESS technologies contribute to emission reduction in complementary ways.

Overall, the results provide a highly encouraging outlook for the use of advanced ESS technologies in specific maritime segments. While not all vessels or scenarios are economically viable under current assumptions, the analysis shows that when ESS are properly selected and dimensioned for the specific vessel and operational objective, they can deliver substantial environmental benefits and, particularly for newbuild vessels, attractive economic performance. This deliverable therefore provides a robust basis for informed

decision-making and supports the further development of deployment roadmaps and exploitation strategies within the AENEAS project.

# 1 Introduction

The maritime sector is facing increasing pressure to reduce greenhouse gas emissions and local pollutants in line with EU and IMO decarbonisation objectives. In this context, onboard ESS are emerging as a key enabling technology to improve energy efficiency, reduce fuel consumption, and support the gradual electrification of ship operations, particularly in energy-intensive phases such as port-stay and manoeuvring.

However, the integration of ESS in waterborne transport presents significant technical, economic, and operational challenges. The feasibility and impact of such systems depend strongly on vessel type, operational profile, integration constraints, and regulatory context. As a result, there is a clear need for evidence-based assessments that move beyond generic assumptions and evaluate ESS deployment under realistic maritime conditions.

Work Package 6 of the AENEAS project addresses this need by focusing on the impact assessment, market potential, and exploitation pathways of the advanced ESS technologies developed within the project. Its overarching objectives are to:

- Assess the environmental, economic, and safety performance of AENEAS ESS solutions in comparison with state-of-the-art battery technologies.
- Define technological and regulatory pathways aligned with EU and IMO decarbonisation strategies.
- Identify and quantify potential markets, develop tailored business models, and provide a roadmap for upscaling and deployment.

Within this framework, the present deliverable contributes by analysing the technical and economic feasibility of deploying AENEAS ESS solutions across a broad range of vessel categories. The study combines global fleet segmentation, operational profiling, stakeholder input, and screening-level CAPEX and OPEX assessments to identify promising vessel segments and application scenarios for Semi-Solid-State Batteries (SSSB) and Supercapacitors (SC).

The results presented in this deliverable establish a robust analytical foundation for subsequent detailed techno-economic evaluations, lifecycle assessments, and strategic planning activities within the project, and directly support the development of the fleet electrification roadmap addressed in later deliverables.

## 1.1 Rational of this deliverable

The decarbonisation of the maritime sector requires the deployment of technically feasible and economically viable solutions that can be integrated into existing and future vessels under real operational conditions. While ESS are widely recognised as a key enabler for reducing fuel consumption and emissions, their effective application in maritime contexts is highly vessel- and operation-specific and cannot be addressed through generic assumptions.

This deliverable is therefore necessary to provide a structured, evidence-based assessment of where and under which conditions advanced ESS technologies developed in the AENEAS project, SSSB and SC, can deliver meaningful environmental and economic benefits. By analysing the global fleet composition, operational profiles, and integration constraints, the deliverable bridges the gap between technology development and practical deployment scenarios.

The work presented here contributes to the overall project objectives by:

- Translating the technical capabilities of AENEAS ESS into realistic vessel-level applications, grounded in fleet data and operational constraints.
- Identifying promising vessel segments and use cases where ESS integration can have the highest impact in terms of fuel savings and emission reduction.
- Providing screening-level CAPEX and OPEX estimates that allow a consistent comparison across vessel types and technologies.
- Establishing a quantitative basis for subsequent detailed economic analyses, lifecycle assessments, and exploitation planning within the project.

In this way, the deliverable supports informed decision-making for technology developers, shipowners, and policymakers, and serves as a foundational input for downstream activities, including the detailed techno-economic assessments and the fleet electrification roadmap developed in later work packages.

# 2 Fleet segmentation

The fleet segmentation section provides a structured classification of the global commercial fleet by vessel type and gross tonnage (GT). This segmentation is designed to establish a clear baseline for assessing the suitability of different ship categories for the implementation of the AENEAS (ESS). By distinguishing vessel types and size ranges, the analysis identifies those segments where the integration of advanced battery systems is technically and operationally feasible, as well as those where significant limitations may arise. This step serves as a foundation for the subsequent evaluation of market potential, financial feasibility, and regulatory alignment, ensuring that the deployment of AENEAS technologies is targeted towards the most promising vessel segments.

## 2.1 Initial segmentation by vessel type and GT

A global segmentation of the commercial fleet was conducted using the IHS Maritime & Trade (Sea-web) database, which constitutes the most comprehensive reference source for technical and operational ship information. The dataset used in this analysis includes all vessels of 100 GT and above recorded as active in 2023, covering more than 220,000 ships across all major maritime segments.

The segmentation exercise aimed to:

- Provide a quantitative overview of the global fleet composition,
- Identify the relative importance of each vessel type in terms of number, size and power, and
- Support the identification of those segments most relevant for the deployment of advanced ESS developed within the AENEAS project.

### 2.1.1 Analytical framework and global fleet overview

The analysis presented in this deliverable relies primarily on the IHS Maritime & Trade – Sea-web database (2023), the world's most comprehensive and authoritative maritime reference tool. Sea-web contains over 600 data fields describing more than 220,000 ships of 100 GT and above, integrating information on ship particulars, ownership structures, classification, flag, construction details, ports, movements, fixtures, and performance records.

Originating from the *Fairplay* and *Lloyd's Register* collaboration, Sea-web serves as the sole global issuing body of IMO identification numbers, ensuring consistency and traceability across ship records. Its structure includes seven levels of ownership, covering over 290,000 owners, 300,000 companies, and 16,000 ports, with links to builders, shipyards, and technical management entities.

For the AENEAS project purposes, the dataset was filtered to include all active vessels registered in 2023, regardless of flag, region, or shipyard origin. The resulting dataset provided a reliable basis for quantitative segmentation and descriptive statistics of the global fleet, from which aggregated indicators have been derived.

Based on the IHS Maritime & Trade (Sea-web) database and as is illustrated in **Error! Reference source not found.**1, the global fleet remains dominated by a few key vessel categories. Bulk carriers represent the largest category, accounting for approximately 28% of the total fleet, followed by tankers (24%) and containerships (12%). Other relevant segments include general cargo (8%), oil tankers (10%), and passenger-oriented vessels such as Ro-

Pax (5%), Ro-Ro (3%), and cruise ships (2%). The remaining 8% corresponds to specialised vessels such as refrigerated, fishing or offshore support ships.

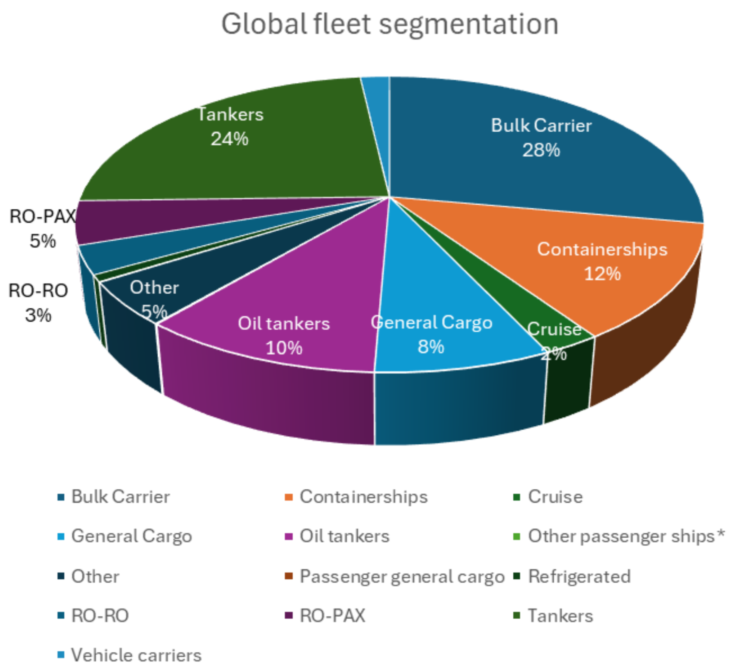


**Figure 1. Global fleet segmentation**

This distribution reflects the predominance of bulk and liquid cargo transport in global maritime trade, while also highlighting the growing presence of passenger and short-sea shipping vessels, segments where electrification and hybridisation initiatives have gained momentum in recent years due to regulatory and public pressure for emission reduction.

Figure 2 illustrates the geographical distribution of shipbuilding origins, with China, Japan, and South Korea representing the three largest shipbuilding nations. Together, these countries account for more than 60% of the world's fleet, confirming their strategic influence over the deployment of new technologies, including energy storage systems (ESS). European countries such as Italy, Germany, and Romania play a smaller yet significant role, particularly in specialised shipbuilding (Ro-Pax, offshore support, and small ferries), which are key segments for future electrification pathways.

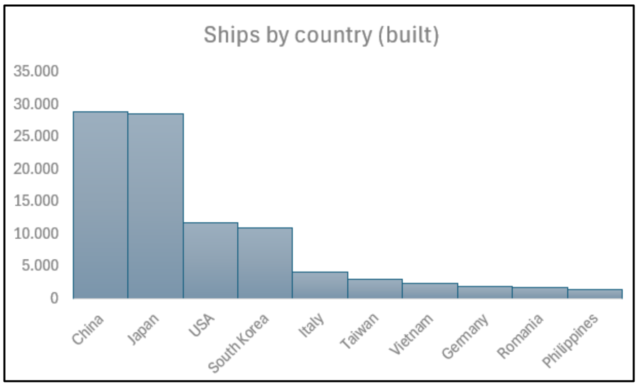


**Figure 2: Ships by country (built)**

Regarding the age distribution of the global fleet (see Figure 3), a significant proportion of vessels have an unknown year of build, but among those with available data, a large share are older than 15 years, indicating a mature fleet with limited energy efficiency performance. Only a minor fraction (less than 15% of all ships) are younger than 10 years, representing the portion of the fleet most likely to incorporate modern hybrid or battery systems. This observation is important, as the retrofit potential for older vessels may be limited by design constraints, whereas newer ships are increasingly prepared for **modular electrical architectures** compatible with ESS technologies.

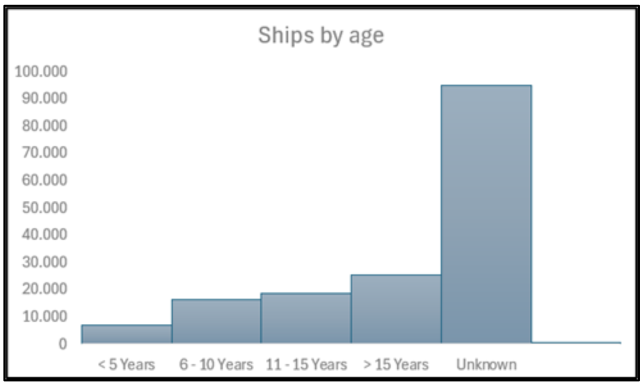


**Figure 3: Ships by age**

Finally, to ensure a more comprehensive representation of vessel categories, the dataset was complemented with information from the Fourth IMO Greenhouse Gas Study (2020), which provides detailed statistics on fleet composition, operational activity, and energy consumption patterns across ship types. This source was particularly useful to expand the characteristics of the “Other vessels” category, which in Sea-web aggregates multiple specialised ship types (e.g. fishing, offshore support, research, and service vessels), but it also served to broaden and validate the segmentation across all major fleet segments. By integrating both datasets, a more balanced and representative picture of the global fleet was achieved, improving the accuracy of subsequent analyses on the technical and economic feasibility of AENEAS energy storage solutions.

### 2.1.2 Technical segmentation criteria

To better reflect the technical heterogeneity and operational characteristics of the analyzed fleet segments, a secondary classification based also on was applied considering three complementary parameters: fuel type, GT range, and main engine power range (kW). Together, these parameters offer a comprehensive view of the technological maturity and energy demand profiles within each vessel category, enabling a clearer assessment of their suitability for integration of AENEAS ESS.

The description and analysis of this classification is provided below, while the corresponding details and tables can be found in the following chapters.

**Fuel type**

This indicator provides insight into the readiness of different segments to integrate low- or zero-emission power systems, including battery-based ESS.

Most vessels continue to operate on conventional fossil fuels, primarily Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO). Bulk carriers, general cargo ships, and oil tankers remain almost entirely dependent on distillate fuels (over 95%), showing very limited diversification and low readiness for alternative propulsion. Containerships and tankers show the highest degree of LNG adoption, ranging between 1% and 5%, indicating the first steps toward dual-fuel operation and gradual decarbonization within these technically advanced segments. Ro-Pax ferries also display moderate uptake of LNG, reflecting early adoption in the passenger transport sector. In contrast, cruise vessels present the most diverse fuel mix, combining distillate, residual, and limited LNG or nuclear use, linked to their higher energy needs and stricter environmental requirements in port areas. Ro-Ro and vehicle carriers continue to rely heavily on distillate fuels with minimal experimentation in alternative systems. However, there is a visible increase in vessels registered with LNG or dual-fuel propulsion, particularly in containerships and Ro-Pax segments.

This distribution highlights the uneven readiness of each fleet segment to integrate low- or zero-emission power systems.

**GT range**

The GT range was used as a proxy for vessel size and overall energy demand.

Larger ships (>50,000 GT), such as containerships, tankers, and vehicle carriers, dominate the upper range, often exceeding 100,000 GT, and, due to their high and continuous power requirements, face strong limitations for full electrification while showing potential for auxiliary or port-based ESS use. Medium-sized vessels (5,000–50,000 GT), including general cargo, Ro-Ro, and many Ro-Pax ferries, present more balanced power-to-storage ratios, positioning them as promising candidates for hybrid configurations. Smaller vessels (<5,000 GT), although representing only a minor share in most categories, offer the best technical feasibility for full-electric operation, as they mainly comprise short-route passenger or service vessels whose limited range and power requirements align well with current battery technologies.

**Main engine power range (kW)**

This parameter provides an estimate of the propulsion demand and allows preliminary matching with ESS configurations.

Engine power varies widely across fleet segments, reflecting differences in operational profiles and energy intensity. For instance, the average engine power of Ro-Pax vessels lies between 5 and 20 MW, while bulk carriers and containerships often exceed 10 MW, limiting the feasibility of full-electric solutions but leaving room for supercapacitor-based systems to support manoeuvring and hoteling phases.

### 2.1.3 Observations from the 2023 dataset

The global fleet segmentation reveals a highly diverse landscape in terms of ship size, installed power and operational profile. Large ocean-going vessels such as bulk carriers, containerships and tankers dominate the fleet in absolute numbers and tonnage, reflecting their central role in international trade. In contrast, passenger and short-sea shipping vessels (including Ro-Pax and Ro-Ro) represent a smaller share of the fleet but typically operate on regular routes and predictable schedules, which can be advantageous for the adoption of battery-based ESS.

From a purely technical perspective, the segmentation also highlights that cruise ships and other large passenger vessels present very high-power demands and continuous hotel loads, often exceeding tens of megawatts. This scale of consumption, combined with space and safety constraints, makes full electrification through current ESS technologies unrealistic in the short term. Nevertheless, these vessels could benefit from partial electrification strategies, such as port-stay power supply or peak shaving, where advanced battery systems can complement conventional generation to reduce emissions in sensitive areas (e.g., ports or emission control zones).

Finally, although the datasets used in this analysis are highly comprehensive and reliable for quantitative segmentation, they do not provide direct insight into onboard electrical systems, operational profiles, or auxiliary load distributions, factors that are critical for energy storage feasibility studies. In particular, the available data lack operational detail at the level needed to identify the most suitable battery use-cases per vessel segment. Missing parameters include:

- Operational profiles at phase level (share of time in port-stay, manoeuvring, low-load transits, hotel loads).
- Load curves and duty cycles for auxiliary systems and manoeuvring peaks.
- Port-call frequency and duration, shore-power availability, and charging opportunities.
- Space, weight and voltage constraints for retrofit installations (available volume, deck loading, MV/LV distribution).
- Safety and class constraints relevant to battery rooms, ventilation, monitoring and fire protection.
- Economic context (fuel prices by route, port fee structures, incentives, grid tariffs).

Because these details are critical to match ESS technology capabilities (SSSB, SC, hybrid) to practical ship operations, we complemented the fleet census with two targeted evidence streams:

(i) A current adoption scan, which captures all known vessels in operation with battery installations.

(ii) An orderbook review, which examines newbuilds under construction or on order that include declared ESS capacity.

Therefore, to complement the static fleet segmentation, additional analyses were conducted, drawing on complementary sources and literature, to identify vessels already equipped with batteries and those under construction with such systems. Together, these complementary analyses bridge the gap between a static fleet picture and the use-case specificity needed for the AENEAS assessment, supporting the identification of the most promising vessel segments for the integration of AENEAS ESS.

## 2.2 Segmentation of Vessels with Batteries

The second stage of the segmentation focuses on identifying and classifying vessels that are already equipped with battery systems or that are under construction with such systems declared in their specifications. This step is essential to move from a theoretical understanding of fleet composition (as outlined in Section 2.1) to a practical picture of the current state of energy storage deployment in the maritime sector. By mapping existing and emerging applications, it becomes possible to validate the technical assumptions of AENEAS and to identify those market niches where ESS adoption is already taking place or likely to expand in the short term.

The analysis was conducted through two complementary evidence streams: (i) a current adoption scan, which captures all known vessels in operation with battery installations, and (ii) an orderbook review, which examines newbuilds under construction or on order that include declared ESS capacity. Together, these datasets provide both a retrospective and forward-looking view of market evolution, helping to distinguish between mature, experimental, and emerging adoption patterns.

The analysis is structured around two primary evidence streams:

- Current adoption scan: the identification of vessels already operating with battery installations (retrofits and in-service newbuilds), including their installed capacity, function (e.g., hotel loads, peak shaving, manoeuvring support), and integration architecture.

- Order-book review: the analysis of vessels under construction or on order with declared battery systems, to capture near-term market signals and technology commitments by segment, size and power class.


**Figure 4: Current Status of the Global Fleet Equipped with ESS**

**Source: Maritime Battery Forum (2026)**

Data sources for the segmentation included the Maritime Battery Forum (MBF, 2025) register of battery-powered ships, the DNV Alternative Fuels Insight database, public ship-registries and yard announcements, and classification-society records and manufacturer disclosures. Whenever possible, the analysis was complemented by project-level and manufacturer data.

According to the MBF (2025) ship registry, in 2023, the number of battery-powered vessels reached 1,000 in operation and 500 on order, and this number continues to increase.

Preliminary results show that battery adoption remains highly concentrated in a limited number of vessel categories. Passenger-oriented segments, particularly ferries, Ro-Pax vessels and small cruise ships, dominate the installed base of marine battery systems. Their short-route operation, high frequency of port calls and exposure to emission-control zones favour early battery integration. In turn, offshore support vessels (OSVs) have emerged as another significant adopter group: battery hybrid systems are used to stabilise dynamic-positioning loads and reduce engine cycling.

Smaller but growing adoption is also visible in harbour tugs, research vessels and coastal service craft, where limited size, moderate energy demand and predictable operational profiles align well with currently available ESS technologies.

In contrast, large ocean-going vessels, such as bulk carriers, containerships and tankers, continue to exhibit negligible battery deployment outside pilot or demonstration projects. In those cases where energy storage is installed, it is typically limited to auxiliary hybrid systems or shore-power readiness rather than full propulsion or large-scale battery capacity, reflecting current barriers in storage density, retrofit cost, and integration complexity (CIMAC and Maritime Battery Forum, 2024). Shore connection (shore power/cold ironing) is considered across multiple vessel classes, including container ships, where it is typically framed as a shore-power readiness and auxiliary electrification pathway rather than a ferries-only application. Consistently with the partner-level assessment, shore connection was also evaluated on a representative container vessel, with the primary focus on fuel reduction during manoeuvring and operational energy optimisation.

The orderbook review reinforces these patterns. Most newbuilds featuring battery systems belong to the passenger transport and offshore support segments, while other vessel types are slowly evolving toward “battery-ready” designs. Several shipyards in Northern Europe and East Asia have begun integrating modular hybrid platforms, which can be equipped with battery packs at later stages, indicating a gradual move toward hybridisation across multiple vessel classes (CIMAC and Maritime Battery Forum, 2024).

From a technical perspective, most current and near-term marine battery installations fall within the 1-10 MWh capacity range, primarily supporting hoteling, shore-stay, or hybrid propulsion configurations rather than full electric propulsion. Observed power-to-energy ratios suggest that the focus remains on stability, fuel savings and emission reduction, while full-electric operation remains feasible largely for small vessels (<5,000 GT) operated on short routes.

These findings indicate that short-sea shipping and service-vessel segments represent the most technically accessible and strategically promising entry points for the deployment of advanced battery systems. Their predictable operational profiles, frequent port calls, and moderate power requirements make them ideal candidates for the early adoption of AENEAS ESS solutions. Meanwhile, the increasing prevalence of hybrid configurations among larger vessel types points to a gradual yet meaningful transition toward electrification in deep-sea shipping. Together, these insights form the analytical foundation for Section 2.3, where the most promising vessel segments for AENEAS ESS integration are systematically identified and prioritised.

## 2.3 Selection of the most promising segments

The identification of the most promising vessel segments for the integration of AENEAS ESS builds upon the empirical insights from the previous analyses. After establishing the overall composition and technical characteristics of the global fleet (Section 2.1) and examining the current deployment of batteries across vessel types (Section 2.2), this section focuses on translating those findings into actionable selection criteria.

The selection of promising vessel segments for the integration of AENEAS ESS requires a clear understanding of the operational and technical parameters that determine the suitability of each technology. Rather than identifying specific ship types at this stage, this section establishes the functional boundaries and decision criteria guiding the deployment of Semi-Solid-State Batteries (SSSB), Supercapacitors (SC), and hybrid configurations (SSSB + SC) across different maritime applications.

This approach ensures that the selection process is grounded in both quantitative fleet data and practical operational realities, enabling a structured prioritisation of vessel segments where AENEAS ESS solutions can deliver the greatest impact in terms of energy efficiency, emission reduction, and market readiness.

The operational suitability of each energy storage technology was synthesised into a comparative framework (Annex 19, Table 25), summarising their key characteristics, advantages, limitations, and most relevant maritime applications

### 2.3.1 For SSSB

Semi-Solid-State Batteries are designed for applications that require high energy capacity and moderate power output, providing stable discharge over relatively long durations. Their characteristics make them especially suitable for operations involving steady energy consumption rather than instantaneous high-power peaks.

The key operational parameters that favour the use of SSSB include:

- High total energy demand over extended time periods (several minutes to hours).
- Predictable operational phases, such as hotel loads or port-stay operations.
- Limited space and weight constraints, since SSSB systems have higher energy density than conventional Li-ion but lower than liquid-fuel energy carriers.
- Moderate peak power requirements, where transient power demand can be managed by other systems or avoided through operational planning.

In this context, the most representative application of SSSB technology is port-stay electrification, where main and auxiliary engines can be switched off while maintaining hotel loads, cargo handling equipment, or onboard systems. In some cases, SSSB could also be employed during manoeuvring or low-speed transit phases, provided that the power peaks remain within the technology's rated limits. Such use, however, depends strongly on the vessel's energy profile and maximum power demand (Pmax) during these phases.

Based on these criteria, vessel types characterised by significant energy demand during port-stay, combined with relatively stable and predictable load profiles, are expected to benefit most from SSSB integration. Typical examples include ferries, Ro-Ro and Ro-Pax vessels, which require sustained auxiliary power while alongside and often operate on fixed routes with regular port calls.

In addition, moderate-size containerships may also represent suitable candidates for SSSB deployment, particularly for port-stay electrification or auxiliary load coverage, where energy requirements are substantial, but peak power levels remain within manageable limits. In these cases, SSSB systems can effectively reduce fuel consumption and emissions without the need to address highly transient power demands.

### 2.3.2 For SC

Supercapacitors exhibit very high-power density but limited energy storage capacity, which makes them ideal for short-duration, high-intensity operations. They can rapidly charge and discharge, providing immediate power assistance or absorbing transient loads that would otherwise burden the main engines.

The operational parameters that define their optimal use are:

- High instantaneous power demand over short durations (seconds to minutes).
- Frequent load fluctuations, typical of manoeuvring, dynamic positioning, or propulsion acceleration.
- Desire to reduce engine load variability, thereby improving efficiency and extending engine life.
- Opportunity for frequent recharge, either through regenerative braking, shaft generators, or power recovery systems.

Consequently, SC systems are best suited as secondary technologies integrated alongside combustion engines or other energy storage systems to optimise propulsion efficiency and transient response. Their most promising application is in manoeuvring, where they can deliver power boosts or absorb regenerative energy. In some configurations, they may also assist during short navigation phases, acting as load levelling or peak shaving systems.

Supercapacitor-based solutions are particularly advantageous for vessels whose operational profiles during manoeuvring are characterised by frequent and rapid power fluctuations, resulting in demand curves with pronounced peaks and valleys over short time intervals. These conditions are typically observed in vessels with high installed propulsion power and complex port operations.

As a result, large ferries, cruise ships, and containerships stand out as vessel categories where SC systems can deliver substantial benefits by supporting manoeuvring phases, reducing engine load variability, and improving overall propulsion efficiency. In such vessels, supercapacitors can mitigate transient loads during acceleration, deceleration, and thrust reversals, thereby optimising engine operation and reducing fuel consumption and emissions in port areas.

### 2.3.3 For hybrid SSSB and SC

Hybrid configurations combine both technologies, exploiting the high energy density of SSSB and the high-power density of SC. This integration can be implemented following two distinct operational philosophies:

1. Phase-specific operation – where each technology supports a distinct phase of the operational cycle:
    - SSSB covers low-power, long-duration phases (e.g. port-stay, hotel loads, or low-speed transit).
    - SC provides short-duration, high-power assistance during manoeuvring or acceleration.
2. Concurrent operation (integrated hybrid mode) – where both technologies operate together within a shared power management architecture. In this case:
    - SSSB acts as the primary energy reservoir, maintaining a stable state-of-charge and supplying the baseline load.
    - SC functions as a continuous peak-shaving buffer, supplying or absorbing transient power fluctuations to protect the battery from high current rates, extending its lifetime and maintaining high system efficiency.

Hybrid SSSB–SC configurations are best suited for vessels that combine high cumulative energy demand with significant short-term power peaks across different operational phases. This is typically the case for ships that require both extended low-power operation (e.g. during port-stay) and high-power responsiveness (e.g. during manoeuvring).

Vessel categories such as Ro-Pax vessels, ferries, and other small to medium-sized ships with intensive operational cycles can particularly benefit from hybrid architectures. In these cases, SSSB systems can provide the bulk of the required energy, while SC units manage transient loads and peak power demands.

For smaller vessels such as escort tugboats with limited range requirements and predictable duty cycles, hybrid configurations may also enable full or near-full electrification, where the

SSSB acts as the main energy carrier and the SC ensures adequate power response during peak-load events. This dual approach enables deeper levels of electrification, improved system efficiency, and extended battery lifetime, while maintaining operational flexibility across diverse operating conditions.

# 3 Understanding the needs and limitations in the value chain

The deployment of advanced Energy Storage Systems (ESS) in the maritime sector depends not only on technical feasibility but also on the alignment of the technologies with the needs, expectations, and constraints of key stakeholders along the value chain.

Understanding the needs and limitations of the maritime sector with respect to Energy Storage Systems (ESS) is not straightforward, as it requires detailed knowledge of fuel consumption, energy use, and operational profiles across different vessel types. Such information is rarely available in the public domain and is often considered commercially sensitive by shipowners and operators, as it is directly linked to operating costs and emission performance.

To address this challenge, the AENEAS project combined the analysis of available public sources with a structured effort to collect qualitative and quantitative inputs directly from the market. This was achieved through targeted engagement with project partners and external stakeholders, including shipowners, ship operators, shipyards, technology providers, and ports. Dedicated meetings, interviews, and workshops were organised to capture realistic operational practices, cost assumptions, and perceived constraints related to ESS integration. This section summarises the work carried out through dedicated meetings and workshops with project partners and external stakeholders, aimed at identifying the main requirements, barriers, and opportunities for the adoption of AENEAS technologies.

## 3.1 The stakeholders in the value chain of ESS

The value chain for maritime ESS involves a wide spectrum of actors, ranging from technology developers and integrators to shipowners, operators, classification societies, ports, and regulatory authorities.

- Technology providers and integrators (e.g. battery manufacturers, system integrators, and power management experts) focus on the scalability, reliability, and safety of ESS installations.
- Shipowners and operators represent the primary end users, whose operational and economic decisions determine the viability of integrating ESS onboard.
- Ports and energy suppliers influence the availability of charging infrastructure, grid access, and shore power standards.
- Classification societies and regulators define the framework for certification, safety requirements, and compliance with IMO and EU regulations.

Each stakeholder group plays a different role in shaping the technical and market potential of AENEAS technologies, and their coordinated involvement is essential to ensure realistic pathways for deployment.

## 3.2 Workshops inputs from a broad perspective of stakeholders

Given the limited availability of public data on vessel-specific fuel consumption and operational energy profiles, stakeholder engagement was essential to define realistic assumptions for the AENEAS assessment. Through a series of workshops and bilateral meetings with project partners and external stakeholders (including shipowners, system integrators, and technology providers), a consistent set of technical, economic, and operational inputs was established to support the scenario definition and subsequent techno-economic calculations.

**Technical characteristics and applicability limits**

Stakeholders highlighted that the information they could reliably provide relates primarily to small and medium-sized vessels. As a result, it was agreed that extrapolating these inputs to very large vessels (e.g. large cruise ships or ultra-large container vessels) would introduce significant uncertainty. To avoid misleading conclusions, a maximum installed volume for SSSB systems of approximately 70 m³ was defined as an upper boundary for the analyses performed in this deliverable. This constraint reflects practical limitations related to space availability, safety segregation, ventilation, and fire protection, and ensures consistency with the vessel sizes for which data could be robustly validated.

During consultations with shipowners, it was confirmed that the average operational lifetime of commercial vessels typically ranges between 20 and 30 years, depending on vessel type and operational profile. For consistency across scenarios, a reference vessel lifetime of 25 years was adopted for the economic analysis.

The retrofit, installation, and fire-fighting system cost associated with ESS integration was estimated at 95,500 € per m³, reflecting the fixed nature of marine-grade safety and integration requirements.

For SSSB, the following technical and economic parameters were adopted:

- Battery cost: 0.60 M€ per MWh of installed capacity
- Volumetric energy density: 0.18 MWh/m³
- Gravimetric energy density: 112 Wh/kg
- Annual maintenance cost: 25 €/kWh·year
- Cycle life: approximately 4,000 full charge/discharge cycles
    - Depending on the operational profile, this corresponds to an effective annual depreciation of around 10%, which is used as a reference value in the economic assessment.

These values reflect the balance between energy density, safety requirements, and integration constraints discussed with technology providers and shipyards, and are consistent with the limitations on available space identified for small and medium-sized vessels.

For SC, the following parameters were defined:

- Battery cost: 5.00 M€ per MWh of installed capacity
- Volumetric energy density: 1.40 Wh/l
- Gravimetric energy density: 2.50 Wh/kg
- Fuel saving impact during manoeuvring: 10%
- Annual maintenance cost: 10 €/kWh·year
- Cycle life: up to 1,000,000 charge/discharge cycles
    - Based on WP2 simulations, this translates into an estimated technical lifetime of approximately 25 years under typical maritime manoeuvring conditions.

**Space availability and integration constraints**

Discussions with shipowners, shipyards, and system integrators highlighted that space availability is one of the main limiting factors for the integration of onboard energy storage systems.

- **Medium and large vessels** typically do not have readily available “free” space suitable for battery rooms. Installing ESS in these ships would generally require the displacement of cargo, auxiliary services, or other critical systems, implying major internal rearrangements and increased retrofit complexity and cost.
- **Small vessels**, by contrast, often allow for a limited but usable volume for ESS integration. Stakeholders indicated that a practical upper limit of approximately 40 $m^3$ of usable volume can frequently be identified without requiring drastic retrofit measures, provided that appropriate layouts and class-compliant safety protections (segregation, ventilation, fire protection) are applied. This volume constraint was therefore adopted as a realistic boundary for small-vessel scenarios.

**Energy valuation by operational phase**

The workshops also enabled a clear distinction between the energy value and cost implications of ESS use across different operational phases:

- Port-stay energy supplied by SSSB: Internal modelling partners indicated that energy stored during navigation and subsequently used during port-stay can be considered to have zero marginal cost and zero associated emissions, when it originates from:
    - Improved engine efficiency achieved by operating the main engine closer to its nominal design point during navigation, and/or
    - Regenerative braking on the shaft or propulsion line.

  This assumption supports the use of SSSB for hoteling and cargo-handling loads during port-stay without introducing additional fuel consumption or emission penalties.
- Manoeuvring supported by SC: Stakeholder inputs and partner simulations indicate that deploying supercapacitors for transient power support during manoeuvring can yield a fuel consumption reduction in the range of approximately 10% for the manoeuvring phase. The width of this range reflects differences in port layout, manoeuvring complexity, frequency of thrust reversals, and vessel-specific characteristics.

**Operational impact of ESS technologies**

For SSSB, stakeholders confirmed that their primary operational contribution lies in supplying electrical energy during port-stay, charged during the navigation phase. Due to capacity and operational constraints, it was assumed that only one full discharge cycle per port call is feasible. Consequently, the fuel-saving impact of SSSB is directly linked to the installed energy capacity and the duration of port-stay, after which auxiliary generators must be restarted to cover remaining energy demand.

For SC, the impact assessment was based on the simulation results developed in WP2 (Task 2.4). These simulations show that SC systems deployed for transient power support during manoeuvring can achieve a reduction of 10% of the total fuel consumption associated with the manoeuvring phase. This reduction is driven by smoothing power peaks, reducing engine load variability, and improving propulsion efficiency. The actual savings depend on port characteristics, manoeuvring complexity, and vessel-specific operational profiles.

**Fuel price and emissions assumptions**

To perform consistent economic and environmental calculations, a fuel and emissions price trajectory was established based on the LR “Fuel for Thought – LNG” outlook, which was found to be coherent with internal projections developed by FV. These trajectories were applied uniformly across all scenarios (Lloyd’s Register, 2025).

The thermal efficiency of the main engine was set at 48%, and the lower heating values (LHV) and $CO_2$ emission factors for each fuel were fixed as shown in Table X, to be used consistently in all subsequent calculations:

- HFO: 40,200 MJ/t, 3.11 $tCO_2$/t fuel
- MGO: 43,300 MJ/t, 3.21 $tCO_2$/t fuel
- MDO: 42,700 MJ/t, 3.21 $tCO_2$/t fuel
- LNG: 48,000 MJ/t, 2.75 $tCO_2$/t fuel

**Port fee incentives and treatment in the economic assessment**

As part of the stakeholder consultations and complementary desk research, the project also reviewed the availability of port fee incentives linked to the use of decarbonisation technologies. This analysis indicates that, at present, Spanish ports are the only ones offering systematic reductions in port fees for vessels implementing emission-reduction or decarbonisation measures, (with potential discounts of up to 40%)

From a conceptual perspective, such incentives could significantly improve the business case for onboard energy storage solutions, particularly for vessels with frequent port calls. However, stakeholders confirmed that similar schemes are not yet widely adopted in other European or international ports, and there are currently no clear signals of near-term harmonised implementation at EU or global level. Given the limited geographical scope of these incentives and the uncertainty regarding their future replication, port fee discounts were not included in the quantitative economic calculations of this deliverable.

## 3.3 Operational constraints for the techno-economic assessment

Based on consultations with stakeholders and the workshops described in section 3.2, a consolidated set of operational constraints and cost assumptions was defined. These parameters are applied consistently across all AENEAS scenarios and form the quantitative basis for the technical-economic feasibility analysis.

**Table 1: Key Technical Characteristics of ESS**

| Parameter | SSSB | SC | Notes/Source |
|---|---|---|---|
| **Operational phase** | Port-stay | Manoeuvring | Defined by workshops |
| **Energy use** | Charged during navigation | Charged/Discharged continuously in Manoeuvring | Engine efficiency + regeneration |
| **Fuel saving impact** | 1 SSSB Capacity/Portstay | 10% Manoeuvring Fuel | Defined by workshops and WP2 |
| **Battery Cost** | 0.6 M€/MWh | 5.0 M€/MWh | Workshops output |
| **Retrofit & installation** | 95,500 €/m³ | 95,500 €/m³ | Retrofit + installation + FFS |
| **Maintenance cost** | 25 €/kWh·year | 10 €/kWh·year | Workshops output |
| **Battery Lifetime** | ~4,000 cycles | ~1,000,000 cycles | Tech Partners |
| **Volumetric energy density** | ~180Wh/l | 1,4 Wh/l | Tech Partners |
| **Gravimetric energy density** | 112 Wh/kg | 2,5 Wh/kg | Tech Partners |

# 4 Economic and Technical Feasibility Analysis

This chapter assesses the economic and technical feasibility of integrating SSSB and SC across a broad range of vessel categories. The analysis covers the following representative vessel types, selected to reflect the diversity of the global fleet and the segmentation presented in Section 2:

- Bulk Carrier
- Chemical Tanker
- Container Ship
- Cruise Ship
- Ferry (Passenger)
- Ferry (Ro-Pax)
- Ro-Ro
- General Cargo
- Liquefied Gas Tanker
- Offshore Vessel
- Oil Tanker
- Other Liquid Tanker
- Other Miscellaneous Vessels
- Other Service Vessels
- Refrigerated Bulk
- Vehicle Carrier
- Service Tug

For each vessel category, the CAPEX and OPEX associated with the installation and operation of SSSB and SC systems are calculated as part of a screening-level assessment. The calculations are based on the consolidated technical, economic, and operational assumptions defined in Section 3, including space constraints, cost parameters, lifetime assumptions, fuel and emission price trajectories, and technology-specific performance characteristics.

At this stage, the economic evaluation deliberately adopts a simplified approach, in which off-hire costs and loss of vessel availability during installation are not considered, and the annual depreciation of ESS equipment is treated using simplified assumptions. This approach is intended to enable a consistent comparison across a wide range of vessel categories and to identify the most promising applications without introducing vessel-specific complexities.

Once the most promising vessel segments have been identified, a more detailed and vessel-specific economic assessment is subsequently performed for the selected cases, incorporating refined depreciation schemes and additional cost elements as appropriate.

## 4.1 Financial viability assessment

Following the definition of vessel categories and boundary conditions, the financial viability assessment proceeds by quantifying the capital and operational implications of integrating each AENEAS ESS into the selected vessel types. For each vessel category and ESS technology (SSSB, SC) the analysis calculates:

- The CAPEX associated with ESS deployment, including equipment costs, retrofit and installation works, and safety-related systems.
- The baseline annual fuel consumption of the vessel, derived from representative operational profiles and fuel assumptions defined in Section 3.
- The impact of ESS integration on fuel consumption, considering technology-specific operational effects:
  - Fuel savings associated with generator shutdown during port-stay when using SSSB, and
  - Fuel savings achieved through load smoothing and peak shaving during manoeuvring when using SC.

For hybrid solutions combining SSSB and SC, the resulting CAPEX and OPEX are highly sensitive to the relative share of each technology installed, which in turn depends on vessel-specific factors such as the fuel consumption profile, installed propulsion power, operational pattern (time spent in port-stay, manoeuvring, and navigation), trading routes, and port-call characteristics. The economic performance of hybrid configurations therefore cannot be meaningfully assessed through a single generic sizing assumption.

For this reason, the assessment first quantifies the standalone cost and operational impact of SSSB and SC for each vessel category. These results are subsequently used to derive hybrid configurations tailored to specific vessel profiles, by combining the two technologies in proportions that best match the intended use.

Based on these elements, the assessment estimates the annual operational expenditure (OPEX) with and without ESS, capturing changes in fuel consumption, maintenance costs, and emission-related expenses. This approach enables a transparent comparison between reference vessels and ESS-enabled configurations, while preserving flexibility for vessel-specific hybrid optimisation.

### 4.1.1 CAPEX

The estimation of capital expenditure (CAPEX) for the integration of ESS requires, as a first step, the definition of the battery size to be installed for each vessel category. This is a multifactorial and highly complex process, as the optimal ESS size depends on a combination of technical and operational parameters, including vessel type, installed propulsion power, operational profile, trading routes, port-call frequency, intended ESS use and available onboard space.

To ensure consistency and technical realism, the sizing approach adopted in this deliverable builds extensively on the AENEAS Use Cases A, B and C, which represent validated reference configurations developed within the project. These use cases provide detailed information on ESS capacity, integration architecture, and operational role, and therefore constitute a robust basis for extrapolation.

Based on the discussions held with project partners and external stakeholders, it was agreed to estimate the ESS size for each vessel category by relating the battery capacities defined in the AENEAS use cases to the total installed propulsion power of the vessels. This power-based scaling approach allows the derivation of representative battery sizes for different vessel types, while remaining consistent with the operational logic and technical constraints identified in Section 3. Once the ESS size was defined, the total CAPEX was calculated by combining:

- the technology-specific equipment cost, set at 0.6 M€ per MWh for Semi-Solid-State Batteries (SSSB) and 5 M€ per MWh for Supercapacitors (SC), and

- the retrofit, installation, and safety-related costs, which were assumed to be proportional to the occupied volume. In line with the assumptions established in Section 3, these costs were fixed at 95,500 € per m³, covering installation works, cabling, structural adaptations, and fire-fighting and safety systems.

The results of the CAPEX calculations for the different vessel categories are presented in Annex 3 and 4, Tables 9 and 10.

### 4.1.2 OPEX

The estimation of operational expenditure (OPEX) was performed by quantifying the annual fuel consumption and operating costs of each vessel category, both with and without ESS integration, and by explicitly accounting for the technology-specific impacts of SSSB and SC systems on fuel use, emissions, and maintenance requirements.

As a first step, the operational profiles of the different vessel types were derived using the Decarbonizer tool, which provides representative distributions of vessel activity across the main operational phases: port-stay, manoeuvring, and navigation. These profiles were combined with the load factors of main and auxiliary engines reported in the 4th IMO GHG Study, allowing the estimation of engine utilisation levels for each phase (Sustainable Ships, n.d.; IMO, 2020).

Using these inputs, the total annual fuel consumption for each vessel category was calculated and disaggregated by operational phase (port-stay, manoeuvring, navigation). The calculations were performed consistently using the parameters defined in Section 3, including:

- a thermal efficiency of the main engine of 48%,
- the lower heating values (LHV) of the different fuels, and
- the fuel-specific $CO_2$ emission factors. (SENDECO2, 2026)
- $CO_2$ emission cost of 74,00 €/tCo2 eq (SENDECO2, 2026)

Although the $CO_2$ emission cost was calculated as part of the operational expenditure (OPEX) framework for all vessel categories, it was only applied from the year 2023 onwards. Accordingly, Section 4 presents the annual OPEX including the $CO_2$ cost, whereas in Section 5 the total cost of ownership (TCO) assessment accounts for the impact of $CO_2$ costs exclusively from 2030 onwards.

The impact of ESS integration on fuel consumption was then applied in accordance with the technology-specific assumptions established in Section 3:

- For SSSB, the fuel savings were calculated based on the available battery energy per port call, assuming one full discharge cycle per call to supply electrical demand during port-stay. Once the battery capacity is depleted, auxiliary generators are assumed to resume operation.
- For SC, a fuel consumption reduction of 10% during the manoeuvring phase was applied, reflecting the effect of peak shaving and load smoothing as identified in WP2 (Task 2.4).

In addition to fuel savings, the annual amortisation of the ESS equipment was included in the OPEX calculation, considering the different lifetimes of SSSB and SC systems, as well as the lifetime of auxiliary integration components, in line with the assumptions defined in Section 3.

By combining fuel costs, maintenance costs, emission-related costs, and annualised capital recovery, an annual OPEX value was derived for each vessel type:

- for the reference configuration (without ESS), and
- for configurations equipped with SSSB and SC, respectively.

The resulting OPEX values for the different vessel categories and technologies are presented in the tables 11 and 12 (Annex 5 and 6), which summarise the operational costs for SSSB- and SC-equipped vessels and enable a direct comparison with the reference configurations.

## 4.2 Promising Vessel Characteristics

The CAPEX and OPEX calculations presented in the previous sections provide a quantitative basis to identify the most promising vessel applications for the deployment of AENEAS energy storage solutions. Rather than assessing all vessel categories in equal detail, this section focuses on selecting representative case studies where ESS integration is expected to deliver the highest impact over the vessel lifetime, while remaining consistent with the technical and operational constraints defined in Section 3.

**Selection criteria for SSSB applications**

For SSSB, the selection focused on vessel types where the energy demand during port-stay is sufficiently high for the installed battery capacity to be fully utilised during each call, thereby maximising the fuel-saving and emission-reduction impact per port stay. At the same time, all selections comply with the space, volume, and applicability limits established in Section 3, which excludes very large vessels such as cruise ships from further consideration.

Within these constraints, **Ro-Ro vessels** and **ferries** emerged as particularly attractive candidates. In addition to their significant **auxiliary loads during port-stay**, Ro-Ro vessels are of specific interest because **they are not systematically required to install Onshore Power Supply (OPS)** under current regulatory frameworks. As a result, onboard battery systems represent one of the most effective near-term solutions to reduce port emissions for this segment.

Both retrofit applications on existing vessels and integration in newbuilds were considered, recognising that the technical feasibility and cost structure may differ between these two cases, while the underlying operational benefit of SSSB during port-stay remains comparable.

**Selection criteria for SC applications**

For SC, the selection prioritised vessel types with a **high share of fuel consumption during the manoeuvring phase**, where frequent power peaks and rapid load variations occur. As with SSSB, the applicability constraints defined in Section 3 were applied, excluding very large vessels such as cruise ships from the detailed assessment.

Under these conditions, **containerships** were identified as a representative case where SC deployment can achieve measurable fuel savings through **peak shaving and load smoothing** during manoeuvring, without requiring large energy storage capacities.

**Selection criteria for hybrid SSSB–SC applications**

Finally, a combined hybrid configuration was considered for vessels that exhibit both high energy demand during port-stay and significant fuel consumption during manoeuvring. In this context, a large ferry was selected as a representative case, allowing the assessment of the cumulative benefits of using:

- SSSB to supply electrical energy during port-stay, and
- SC to reduce fuel consumption during manoeuvring.

This hybrid case enables the evaluation of the combined operational impact of both technologies within a single vessel profile, while remaining within realistic space and integration limits.

**Definition of representative scenarios**

Based on the above criteria, the following representative scenarios were selected for detailed lifetime assessment:

- Scenario 1: SSSB for port-stay electrification on an existing Ro-Ro or ferry (retrofit).
- Scenario 2: SSSB for port-stay electrification on a newbuild Ro-Ro or ferry.
- Scenario 3: SC for achieving approximately 10% fuel savings during manoeuvring on a containership without batteries.
- Scenario 4: Hybrid SSSB–SC configuration on a large ferry, combining port-stay and manoeuvring benefits.

These scenarios provide a focused yet representative set of applications that capture the diversity of operational profiles and ESS use cases considered in the project. They form the basis for the lifetime economic assessment (TCO) presented in the subsequent section, where the long-term cost and emission impacts of ESS integration are evaluated for the most promising vessel types.

# 5 Business Cases for each ESS: Economic Viability and Environmental Impact of ESS Applications

The evaluation of the AENEAS solutions is based on a comprehensive LCC analysis, comparing the traditional "business-as-usual" maritime operations against the integration of SSSB and SC. The methodology integrates technical assumptions with market projections, specifically focusing on fuel price evolution and carbon taxation under the EU Emissions Trading System (EU ETS).

The analysis covers both retrofit and newbuild scenarios, considering four representative cases: SSSB retrofits for port-stay electrification on Ro-Ro and ferry vessels, SC retrofits for fuel savings during manoeuvring on containerships, and hybrid SSSB–SC retrofits on large ferries.

## 5.1 Economic evaluation

This section contains the results of the Financial Analysis of the AENEAS solutions, transitioning from theoretical assumptions to financial outcomes. The financial analysis measures the project desirability for the investor. This step is thereby of significant interest as it analyses the viability of the project from a financial point of view.

As explained above, to ensure a representative assessment of the diverse operational profiles within the maritime industry, the analysis has been structured around four distinct scenarios. These scenarios compare SSSB and SC across different vessel types and integration methods, focusing on their ability to mitigate operational costs and carbon-related taxes over a twenty-five-year horizon.

This section presents the results of the Financial Analysis of the AENEAS solutions, moving from the theoretical assumptions introduced previously to quantified financial outcomes. The purpose of this analysis is to evaluate the attractiveness of the project from an investor’s perspective by assessing its financial viability through key economic indicators. As such, this step is of relevance, as it provides a realistic appraisal of the feasibility of the proposed solutions under representative operational conditions.

Building on the criteria described above, and to reflect the diversity of operational profiles within the maritime sector, the financial assessment has been structured around four representative scenarios. These scenarios compare the performance of Solid-State Batteries (SSSB) and Supercapacitors (SC) across different vessel types and integration approaches, with a specific focus on their potential to reduce operational costs and carbon-related taxes over a twenty-five-year lifetime.

Unlike the preceding high-level assessment, this section adopts a more detailed and vessel-specific approach, explicitly accounting for the technical and operational particularities of each ship type.

### 5.1.1 Methodology

The objective of the financial analysis is to assess the viability of the AENEAS solutions by calculating key financial performance indicators across four selected scenarios. As detailed in chapter 4.2, the analysis considers three different vessel types, each characterized by the specifications defined in the following table, which are applied consistently within each scenario.

**Table 2: Technical specifications by vessel type of the scenarios studied**

| | | IMO type | | |
|---|---|---|---|---|
| | | Container | Ferry Ro- Pax | RoRo |
| | Fuel type main engine | LNG | Heavy Fuel Oil | LNG |
| | MCR main engine (KW) | 50.972 | 25.361 | 14.670 |
| | Ratio AUX/MAIN | 0,27 | 0,39 | 0,39 |
| | Aux Power (kW) | 13.762 | 9.891 | 5.721 |
| | Total power (kW) | 64.734 | 35.252 | 20.391 |
| | DWT (TN) | 168.505 | 4.927 | 14.775 |
| Operation modes (Decarbonizer (Rotterdam)) | Sailing | 0,671 | 0,466 | 0,411 |
| | Manoeuvring | 0,082 | 0,082 | 0,041 |
| | Hotelling | 0,247 | 0,452 | 0,548 |
| Load factor main engine (IMO) | Sailing | 0,800 | 0,800 | 0,800 |
| | Manoeuvring | 0,200 | 0,200 | 0,200 |
| | Hotelling | 0,200 | 0,200 | 0,200 |
| Load factor aux engine (IMO) | Sailing | 0,300 | 0,300 | 0,300 |
| | Manoeuvring | 0,500 | 0,500 | 0,500 |
| | Hotelling | 0,400 | 0,400 | 0,400 |

Source: own elaboration based on Marine Traffic (2025)

The financial analysis has been carried out following the Discount Cash Flow method in compliance with section III (Method for calculating the discounted net revenue of operations generating net revenue) of Commission Delegated Regulation (EU) No 480/2014.

In addition, the methodology used in this financial analysis follows the basic principles outlined in the "*Guide to Cost-Benefit Analysis of Investment Projects*" by the Evaluation Unit of the European Commission (Directorate General of Regional Policy- DG REGIO).

As per the Guide instructions, a nominal financial discount rate must be used with current prices when the Financial Analysis is going to be applied. The discount rate that the Guide recommends, in real terms, is equal to 4%, according to Article 19 (Discounting of cash flows) of Commission Delegated Regulation (EU) No 480/2014, for the programming period 2014-2020. The formula for the calculation of the nominal discount rate is defined as:

$$(1+n)=(1+r)*(1+i)$$

Where: n – nominal rate, r – real rate, I – inflation rate

Once the formula has been applied, the nominal financial discount rate is equal to 4%.

Only cash inflows and outflows are considered in the analysis, i.e., depreciation, reserves, price and technical contingencies and other accounting items, which do not correspond to actual flows, are disregarded. Moreover, all the flows considered are net of VAT and direct taxes.

To determine the financial viability of each scenario, three following indicators have been calculated: financial net present value, FNPV (C), financial rate of return, FRR (C), on investment, and payback.

The Financial net present value on investment is defined as the sum that results when the expected investment and operating costs of the project (discounted) are deducted from the discounted value of the expected revenues. It indicates how much the investor's wealth has increased after recovering their initial investment. The minimum required return on the investment is implicit in the discount rate, which represents the cost of capital, or opportunity cost of relinquishing the return on alternatives involving the same level of risk.

NPV is calculated using the following formula:

$$FNPV(C) = -I_o + \sum_{j=1}^{n} \frac{Fj}{(1+r)^j}$$

Where Fj is the balance of cash flow for t = j; Io is the investment in t = 0; r is the discount rate and n is the time horizon or lifespan of the project (25 years in our study).

FNPV is one of the most used measures to decide whether or not to go ahead with a project. A project is profitable for an investor if FNPV is greater than zero. Therefore, the decision-making rule is as follows:

NPV > 0 Þ Profitable Project (go-ahead recommended)

NPV < 0 Þ NON-Profitable Project (should be rejected)

NPV = 0 Þ Going ahead with the project would yield the same return as the alternative that was used to calculate the opportunity cost.

The second indicator used is the FRR, which is defined as the discount rate that produces a zero FNPV. Mathematically speaking, the FRR is calculated based on the following expression:

$$0 = -I_o + \sum_{j=1}^{n} \frac{Fj}{(1+IRR)^j}$$

Where Fj is balance of cash flows in t = j; Io is investment in t = 0 and n is the time horizon or lifespan of the project.

The FRR is frequently used to evaluate projects. The decision-making rule would be to give the go-ahead to a project if the FRR is higher than the opportunity cost of the investor (discount rate), but not to set the project in motion when the FRR is lower than the discount rate.

The return on investment has been calculated considering:

- Investment costs and operating costs as outflows.
- Revenues and residual value as inflows.

Finally, the payback period identifies the specific year in which the cumulative savings equal the initial investment expenditure.

### 5.1.2 Assumptions

The financial analysis is based on several general assumptions that should be highlighted and which are in line with the Guide. This chapters gather all relevant hypotheses and assumptions considered in this financial evaluation.

The first hypothesis defined in the financial analysis is the time horizon of the project, which has been estimated at 25 years. Consequently, the financial feasibility assessment for each scenario has been carried out for the period 2025–2050, both years included.

All shipyard-related expenditures associated with installation and retrofit activities are treated as capital expenditures (CAPEX) and are therefore subject to depreciation. The total investment considered in the financial analysis comprises three main components: energy storage systems (batteries), other onboard systems and integration costs ("others"), and shipyard costs. More details as follows:

- SSSB battery investments are assumed to have a useful life of 10 years. Accordingly, the initial battery investment is accounted for in the year of installation and subsequently renewed every 10 years over the project lifetime. Depreciation of SSSB batteries is applied on a linear basis over a 10-year period for each replacement cycle.
- SC system is assumed to have a useful life of 25 years, covering the entire project horizon. The associated investment is therefore depreciated linearly over 25 years, with no intermediate replacement required.
- Investments classified as "other systems" (retrofit works, installation activities, and fuel flexibility systems) are assumed to have a useful life of 25 years and are depreciated on a linear basis over the same period.
- Shipyard costs linked to the initial installation and retrofit investment are depreciated linearly over 25 years, in line with the useful life of the associated non-battery systems.
- In contrast, shipyard costs associated with SSSB battery replacement activities follow the same depreciation schedule as the batteries themselves. These costs are therefore depreciated linearly over 10 years, reflecting the shorter lifetime of the SSSB technology and the recurring nature of the replacement interventions.
- Shipyard costs associated with installation and retrofit activities have been defined monthly and differentiated by vessel type, reflecting differences in technical complexity, vessel size, and scope of intervention. A shipyard stay of four months is assumed for the initial installation of both SSSB battery and SC systems. In the case of SSSB batteries, an additional one month of shipyard stay is required for each battery replacement. The following monthly shipyard cost reference values have been applied:
    - 250,000 € per month for Ro-Ro vessels,
    - 200,000 € per month for ferries, and
    - 300,000 € per month for containerships.
- For the hybrid SSSB–SC configuration, it is assumed that 5% of the initial investment costs are shared, due to common ship adaptation and integration requirements. All other assumptions follow those defined for the individual SSSB and SC systems, with the specific adjustment applied to the initial capital expenditure.

For retrofit scenarios, it is assumed that the retrofit is decision is taken shortly after entry into service, so it is implemented during the first operational year of the vessel. This reflects situations where new regulatory requirements, operational optimisation strategies, or early adoption of innovative technologies motivate an early retrofit, while avoiding the need to align the intervention with major life-cycle overhauls. A retrofit investment cost of 95,500 €/m³ has been considered.

Regarding the main engine thermal efficiency, it has been assumed at 48% as explained in chapter 4.1.2.

On the other hand, in addition to direct shipyard costs, loss of revenues due to vessel downtime has been explicitly considered. Monthly revenue losses have been differentiated by vessel type:

- Ro-Ro vessels: 780,000 € per month,
- Ferries: 487,500 € per month,
- Containerships: 585,000 € per month.

Fuel price assumptions for HFO, MDO/MGO, and LNG, as well as $CO_2$ costs under the EU ETS, have been defined on a yearly basis for the period 2025–2050. These values reflect projected market trends and regulatory developments and are applied consistently across all scenarios. For clarity, the $CO_2$ price is defined as a reference ETS value over the full 2025–2050 horizon, but ETS charges are applied in the OPEX only from 2030 onwards. Therefore, $CO_2$-related costs are not included in the OPEX calculations for the period 2025–2029 but are fully accounted for thereafter.

**Table 3: Fuel cost (€/t fuel) and t CO2eq cost for the period 2025–2050.**

| Year | Fuel cost (€/t fuel) | | | t CO2eq Cost |
|---|---|---|---|---|
| | HFO | MDO/MGO | LNG | |
| **2025** | 737,00 € | 940,00 € | 690,00 € | 74,00 € |
| **2026** | 816,00 € | 1.024,00 € | 763,00 € | 87,00 € |
| **2027** | 904,00 € | 1.117,00 € | 844,00 € | 86,20 € |
| **2028** | 912,00 € | 1.126,00 € | 852,00 € | 89,00 € |
| **2029** | 923,00 € | 1.138,00 € | 862,00 € | 92,60 € |
| **2030** | 1.026,00 € | 1.252,00 € | 872,00 € | 96,30 € |
| **2031** | 1.038,00 € | 1.264,00 € | 883,00 € | 100,11 € |
| **2032** | 1.050,00 € | 1.277,00 € | 894,00 € | 104,12 € |
| **2033** | 1.063,00 € | 1.291,00 € | 906,00 € | 108,53 € |
| **2034** | 1.076,00 € | 1.305,00 € | 918,00 € | 112,61 € |
| **2035** | 1.286,00 € | 1.535,00 € | 931,00 € | 117,12 € |
| **2036** | 1.300,00 € | 1.551,00 € | 944,00 € | 121,80 € |
| **2037** | 1.315,00 € | 1.567,00 € | 958,00 € | 126,68 € |
| **2038** | 1.331,00 € | 1.583,00 € | 972,00 € | 131,74 € |
| **2039** | 1.347,00 € | 1.600,00 € | 987,00 € | 137,01 € |
| **2040** | 1.744,00 € | 2.037,00 € | 1.516,00 € | 142,49 € |
| **2041** | 1.761,00 € | 2.056,00 € | 1.532,00 € | 148,19 € |
| **2042** | 1.779,00 € | 2.075,00 € | 1.548,00 € | 154,12 € |
| **2043** | 1.798,00 € | 2.095,00 € | 1.566,00 € | 160,28 € |
| **2044** | 1.818,00 € | 2.116,00 € | 1.584,00 € | 166,69 € |
| **2045** | 2.553,00 € | 2.926,00 € | 2.698,00 € | 173,36 € |
| **2046** | 2.574,00 € | 2.949,00 € | 2.718,00 € | 180,29 € |
| **2047** | 2.596,00 € | 2.972,00 € | 2.738,00 € | 187,51 € |
| **2048** | 2.619,00 € | 2.996,00 € | 2.759,00 € | 195,01 € |
| **2049** | 2.643,00 € | 3.021,00 € | 2.781,00 € | 202,81 € |
| **2050** | 3.083,00 € | 3.506,00 € | 3.439,00 € | 210,92 € |

Source: own elaboration based on SENDECO2 (2026) and Lloyd's Register (2025)

For SSSB systems, the remain following assumptions apply:

- Battery investment cost: 0.60 M €/ MWh.
- Annual maintenance cost of 15 € / kWh·year.

For Supercapacitor (SC) systems, the remain adopted assumptions were:

- Investment cost: 5.00 M€/MWh,
- Fuel savings during manoeuvring operations of approximately 10%.
- Annual maintenance cost of 10 € / kWh·year.

Finally, a reference operational profile of 330 port calls per year has been assumed where relevant, in order to quantify fuel savings and operational benefits consistently across scenarios.

### 5.1.3 Investment and operational costs by study and type of vessel

This chapter presents a detailed assessment of the CAPEX and OPEX associated with AENEAS advanced energy storage solutions across different vessel types and integration strategies.

CAPEX accounts for the initial investment and mid-life replacements or upgrades required to maintain the performance and safety of the energy storage systems over the vessel lifetime. OPEX includes the total fuel consumption, $CO_2$-equivalent emissions, and battery maintenance costs, reflecting the recurring operational expenses associated with each configuration.

By examining the combined CAPEX and OPEX evolution, this chapter highlights the financial implications of technology choice, vessel type, and integration strategy, and provides insights into which solutions deliver the most robust economic performance over the 25-year horizon. The subsequent sections present a narrative discussion of each scenario, illustrating how investment and operational factors interact to shape long-term financial viability.

All details regarding the investment can be found in Annex 7-10 Tables (13-16)

**Table 4: CAPEX by scenario and vessel type (2025-2050).**

| Year | CAPEX | | | | | |
|---|---|---|---|---|---|---|
| | Ro-Ro Study 1 (retrofit - SSSB) | Ro-Ro Study 2 (newbuild - SSSB) | Ferry Study 1 (retrofit - SSSB) | Ferry Study 2 (newbuild - SSSB) | CONTAINER - Study 3 (retrofit - SC) | Ferry - Study 4 (retrofit - hybrid) |
| **2025** | 3.908.363,21 € | 3.092.081,88 € | 7.328.731,43 € | 5.952.358,64 € | 2.917.712,86 € | 7.733.998,26 € |
| **2026** | - € | - € | - € | - € | - € | - € |
| **2027** | - € | - € | - € | - € | - € | - € |
| **2028** | - € | - € | - € | - € | - € | - € |
| **2029** | - € | - € | - € | - € | - € | - € |
| **2030** | - € | - € | - € | - € | - € | - € |
| **2031** | - € | - € | - € | - € | - € | - € |
| **2032** | - € | - € | - € | - € | - € | - € |
| **2033** | - € | - € | - € | - € | - € | - € |
| **2034** | - € | - € | - € | - € | - € | - € |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2035** | 1.342.756,94 € | 1.342.756,94 € | 2.262.073,89 € | 2.262.073,89 € | - € | 2.262.073,89 € |
| **2036** | - € | - € | - € | - € | - € | - € |
| **2037** | - € | - € | - € | - € | - € | - € |
| **2038** | - € | - € | - € | - € | - € | - € |
| **2039** | - € | - € | - € | - € | - € | - € |
| **2040** | - € | - € | - € | - € | - € | - € |
| **2041** | - € | - € | - € | - € | - € | - € |
| **2042** | - € | - € | - € | - € | - € | - € |
| **2043** | - € | - € | - € | - € | - € | - € |
| **2044** | - € | - € | - € | - € | - € | - € |
| **2045** | 1.342.756,94 € | 1.342.756,94 € | 2.262.073,89 € | 2.262.073,89 € | - € | 2.262.073,89 € |
| **2046** | - € | - € | - € | - € | - € | - € |
| **2047** | - € | - € | - € | - € | - € | - € |
| **2048** | - € | - € | - € | - € | - € | - € |
| **2049** | - € | - € | - € | - € | - € | - € |
| **2050** | - € | - € | - € | - € | - € | - € |

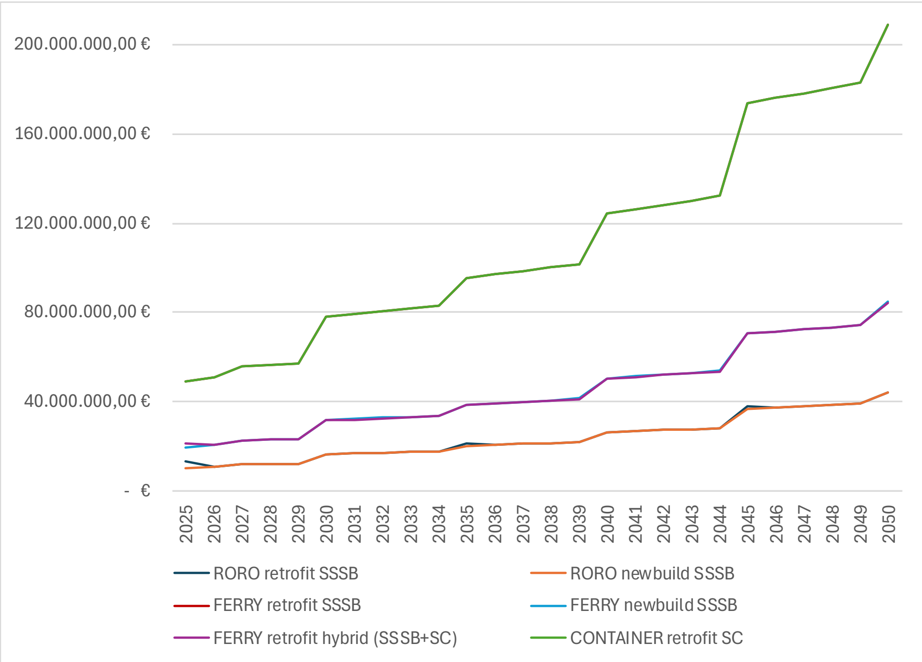


**Figure 5: Cumulative OPEX by scenario and vessel type (2025-2050).**

## SSSB

For the Ro-Ro retrofit, the initial CAPEX of €3.91M in 2025, combined with mid-life battery replacements of €1.34M in 2035 and 2045, represents a substantial upfront and recurring investment. Operationally, the vessel benefits from reduced fuel consumption and $CO_2$ emissions during port stays; however, the retrofit layout constraints and the high degradation rate of the batteries lead to significant maintenance costs, driving OPEX steadily upward over time. As a result, the combination of high CAPEX and rising OPEX explains the negative NPV and limited IRR for this scenario, indicating that the retrofit SSSB configuration is not financially attractive under current assumptions.

In the newbuild Ro-Ro scenario, the CAPEX is slightly lower than in the retrofit case, with €3.09M in 2025 and the same mid-life replacements of €1.34M in 2035 and 2045. Thanks to full integration of the energy storage system at the design stage, operational efficiency is maximized, leading to lower fuel consumption, reduced $CO_2$eq emissions, and minimized battery maintenance costs. The result is a more stable OPEX trajectory over the vessel's lifetime.

**SC**

The container ship retrofit using supercapacitors requires a relatively modest CAPEX of €2.92M in 2025, with no mid-life replacement costs, reflecting the long lifetime and high durability of SC systems. Operationally, the supercapacitors provide around 10% fuel savings during high-power manoeuvring, directly lowering both fuel costs and $CO_2$eq emissions. Since no batteries are involved, maintenance costs are negligible.

**HYBRID**

The hybrid configuration for a large ferry involves a higher initial investment of €7.73M in 2025, with mid-life replacements of €2.26M in 2035 and 2045. This approach combines SSSB for port-stay electrification with supercapacitors for manoeuvring, achieving fuel and $CO_2$eq reductions across multiple operational modes. The SCs absorb high-power cycling, which reduces battery degradation and lowers maintenance costs relative to a pure SSSB retrofit. While the overall OPEX remains higher than in newbuild scenarios, the hybrid approach moderates cost growth over time, offering a borderline financially viable solution. Its value is primarily strategic, providing regulatory compliance, operational flexibility, and optimized battery lifetime rather than immediate profitability.

### 5.1.4 AENEAS financial assessment results

The results of the AENEAS financial assessment demonstrate that financial viability is highly sensitive to vessel type, integration strategy, and technology choice, with newbuild applications and SC-based solutions offering the most robust business cases under current cost and regulatory assumptions. The following table summarizes the results while Annex 13-18 (Tables 19-24) provides all the information.

**Table 5: Comparative analysis of AENEAS solutions by scenario and vessel type.**

| SEGMENT | STRATEGY | SOLUTION | VAN | TIR | PAYBACK |
|---|---|---|---|---|---|
| **Ro-Ro** | Retrofit | SSSB | -3,606,188 € | -0.49% | 0 |
| **Ro-Ro** | Newbuild | SSSB | 4,851,777 € | 6.51% | 2041 |
| **Ferry** | Retrofit | SSSB | -2,331,985 € | 2.04% | 2048 |
| **Ferry** | Newbuild | SSSB | 7,899,426 € | 5.71% | 2042 |
| **Ferry** | Retrofit | Hybrid | 817,214 € | 4.61% | 2042 |
| **Container** | Retrofit | SC | 1,663,201 € | 6.22% | 2040 |

Newbuild applications consistently outperform retrofit options, confirming the economic advantage of integrating energy storage systems at the design stage. In particular, the Ferry (Newbuild) with SSSB achieves the strongest overall performance, with a Net Present Value (NPV) of 7,899,426 € and an Internal Rate of Return (IRR) of 5.71%, followed by the Ro-Ro (Newbuild) with SSSB, which reaches an NPV of 4,851,777 € and an IRR of 6.51%. These results reflect the benefits of design-in integration, which avoids costly structural modifications and minimizes revenue losses associated with extended shipyard stays.

By contrast, retrofit scenarios show more mixed results. The Ro-Ro (Retrofit) with SSSB exhibits a negative NPV of −3,606,188 € and a negative IRR, indicating that this configuration is not financially viable under the assumed conditions. Similarly, the Ferry (Retrofit) with SSSB remains marginal from a financial perspective, with a negative NPV of −2,331,985 € despite a positive IRR of 2.04%, and a late payback beyond 2045. These outcomes underline the strong impact of retrofit-related CAPEX and downtime costs on overall project economics.

The Hybrid SSSB–SC configuration applied to a Ferry retrofit shows an improvement relative to the pure SSSB retrofit case, achieving a positive NPV of 817,214 € and an IRR of 4.61%, with a payback year of 2042. While financially viable, this solution remains borderline and appears primarily justified by strategic considerations such as regulatory compliance, operational flexibility, and battery lifetime optimization rather than short-term profitability.

The Container ship retrofit with Supercapacitors (SC) clearly stands out as the most attractive short- to medium-term investment among the assessed scenarios. This configuration achieves a positive NPV of 1,663,201 €, an IRR of 6.22%, and the earliest payback in 2040, confirming that for operational profiles dominated by manoeuvring power demand, the high-power density and long lifetime of supercapacitors can deliver robust financial performance without the need for large-scale energy storage.

## 5.2 Emission assessment

The primary goal of the AENEAS technologies is the decoupling of maritime operations from fossil fuel combustion. By replacing engine-driven auxiliary generators (hotelling) and optimizing main engine transients (maneuvering), the systems significantly lower the carbon intensity of each voyage. This transition directly impacts three key areas:

- $CO_2$ reductions: by shifting from Marine Diesel Oil (MDO) to grid-based or battery-stored energy, carbon dioxide emissions are reduced by nearly 100% during the port stay period, significantly lowering the vessel's annual carbon footprint.
- Local pollutants (NOx, SOx, and PM): the elimination of engine combustion in port areas removes nitrogen oxides, sulfur oxides, and particulate matter, which is critical for compliance with increasingly strict Air Quality Acquis and local port regulations.
- Noise and vibration: beyond chemical emissions, the transition to ESS reduces acoustic pollution, improving the environment for both the crew and the surrounding port communities.

The following table summarizes the projected $CO_2$ emission savings based on the four representative business cases:

**Table 6. Projected $CO_2$ Emission Savings for Representative ESS Business Cases**

| Vessel Segment | Technology | Operational Focus | Estimated Annual CO2 Savings (t/year) | 25-Year Cumulative Savings (t) |
|---|---|---|---|---|
| **Ro-Ro** | SSSB | Port-stay electrification | ~625 | 15,625 |
| **Ferry** | SSSB | Port-stay electrification | ~1,080 | 27,000 |
| **Container** | SC | Maneuvering (Peak Shaving) | ~682 | 17,050 |
| **Ferry** | Hybrid | Combined Port + Maneuver | ~1,480 | 37,000 |

## 5.3 Financial conclusions

The analysis of CAPEX and OPEX across all scenarios highlights that newbuild vessels consistently outperform retrofits in terms of financial performance. By integrating energy storage systems at the design stage, newbuilds achieve lower upfront investments, reduced maintenance costs, and optimized operational efficiency, resulting in stronger NPVs and IRRs. Retrofit solutions, by contrast, face higher cumulative costs due to both elevated CAPEX and ongoing OPEX related to battery maintenance and integration inefficiencies.

Among the technologies considered, SC-based solutions stand out for their low and stable OPEX, minimal maintenance requirements, and predictable long-term cost profile. Hybrid (SSSB-SC) configurations for retrofits can mitigate some of the disadvantages of battery-based retrofits by reducing battery stress and extending lifespan, but they remain CAPEX-intensive.

The financial viability of the AENEAS project is built upon the balance between CAPEX and projected operational savings, which vary depending on the technology type and vessel scenario. The primary operational benefits are threefold:

- Fuel consumption savings: SSSB solutions (Scenarios 1 & 2) generate savings during port-stay electrification, while SC retrofits (Scenario 3) on containerships reduce fuel use by approximately 10% during manoeuvring through peak shaving, enabling engines to operate at optimal efficiency.
- Maintenance cost reductions: By reducing auxiliary engine hours and avoiding high-load transients on main engines, the frequency of overhauls and spare parts consumption is reduced.
- $CO_2$ emission reductions and ETS avoidance: A critical component of savings arises from mitigation of carbon taxes. As EU ETS prices are projected to increase significantly toward 2050, the avoided cost of $CO_2$ becomes the dominant factor in sustaining positive cash flows, particularly for newbuilds, where cumulative $CO_2$ savings can exceed 50,000 tons over the vessel lifetime.

Despite these clear benefits, several operational and regulatory risks must be managed to achieve projected outcomes. For SSSB retrofits, charging infrastructure reliability is essential, and the weight/volume of large batteries may require structural adjustments or reduce cargo capacity. Hybrid configurations (Scenario 4) introduce additional system complexity, requiring sophisticated Power Management Systems to coordinate SSSB and SC operation; failures in control logic could result in inefficient energy use or premature battery degradation. Finally, projections are sensitive to fuel price volatility and carbon market evolution, meaning delayed ETS implementation or low fuel prices could extend payback periods.

A key driver of financial success for AENEAS solutions remains the ability to avoid carbon penalties under the EU ETS. Decarbonization should not be treated solely as a compliance cost; rather, it functions as an asset optimization strategy. Direct fuel savings provide a consistent baseline benefit, but from 2030 onward, the avoided cost of $CO_2$ emissions dominates OPEX and financial returns. By adopting these technologies, shipowners create a financial hedge against carbon price volatility. Conventional vessels are exposed to steep OPEX escalation as the EU ETS phase-in reaches 100%, whereas electrified vessels maintain a lower and more predictable cost structure.

Over the next 25 years, economic value will increasingly be determined not just by fuel prices but also by avoided carbon taxation. The data confirms that AENEAS solutions are financially robust for newbuilds today, and their competitiveness for retrofits is expected to increase alongside the evolution of the European carbon market, particularly as operational benefits, $CO_2$ avoidance, and maintenance optimization are realized.

# 6 Conclusions

The economic and technical feasibility analysis carried out in Chapter 4 demonstrates that the deployment of AENEAS energy storage solutions is highly dependent on vessel type, operational profile, and intended use of the ESS. The screening-level CAPEX and OPEX assessment across a wide range of vessel categories confirms that ESS technologies cannot be applied uniformly across the fleet but can deliver significant benefits when matched to appropriate operational conditions.

Based on the combined CAPEX and OPEX results, Chapter 4 identifies a limited number of promising vessel segments where ESS deployment offers the highest potential impact under current assumptions. These include Ro-Ro vessels and ferries for SSSB-based port-stay electrification, containerships for SC-based manoeuvring optimisation, and large ferries as representative candidates for hybrid configurations.

From a technical and environmental perspective, the analysis shows that ESS technologies can deliver substantial $CO_2$ emission reductions, with the magnitude of the impact strongly linked to the operational phase addressed. The hybrid case study, in which both SSSB and SC are integrated on the same vessel, provides a consistent framework to isolate and quantify the contribution of each technology without overlap.

The results show that SSSB systems deliver the largest absolute emission reduction, as they target energy-intensive port-stay operations by replacing auxiliary engine use. In the analysed hybrid scenario, SSSB integration leads to an estimated reduction of 1,080.87 $tCO_2$ per year, reflecting the high cumulative energy demand during port-stay and the direct substitution of fuel-based electricity generation.

By contrast, SC systems achieve emission reductions through efficiency gains during manoeuvring, where power peaks and load fluctuations are mitigated. Although the duration of manoeuvring phases is shorter, the high-power demand makes this operational phase particularly fuel intensive. In the same hybrid case, SC deployment results in an annual emission reduction of 400.50 $tCO_2$, corresponding to a fuel saving of approximately 10% during manoeuvring.

The financial assessment of AENEAS solutions confirms that newbuild vessels consistently outperform retrofits. By integrating energy storage systems at the design stage, newbuilds achieve lower CAPEX, reduced maintenance costs, and optimized operational efficiency, leading to positive NPV and attractive IRR. For example, the Ferry newbuild with SSSB achieves the strongest performance, with an NPV of €7.9M and an IRR of 5.7%, while the Ro-Ro newbuild with SSSB reaches an NPV of €4.85M and an IRR of 6.5%. These results reflect the benefits of design-in integration, which avoids costly structural modifications and minimizes revenue losses from extended shipyard stays.

Retrofit solutions show more mixed results. The Ro-Ro retrofit with SSSB exhibits a negative NPV of −€3.6M and a negative IRR, indicating it is not financially viable under current assumptions. Similarly, the Ferry retrofit with SSSB remains marginal, with a negative NPV of −€2.33M despite a small positive IRR of 2.0%, and a late payback beyond 2045. Hybrid SSSB–SC retrofits improve financial outcomes relative to pure SSSB retrofits, achieving a modest positive NPV of €0.82M and an IRR of 4.6%, but remain largely justified by strategic factors such as regulatory compliance and battery lifetime optimization rather than short-term profitability. The Container ship retrofit with SC stands out as the most attractive retrofit scenario, achieving an NPV of €1.66M, an IRR of 6.2%, and the earliest payback in 2040, thanks to its low CAPEX and stable OPEX profile.

A key driver across all scenarios is the avoidance of carbon penalties under the EU ETS, which becomes increasingly significant from 2030 onward. Fuel savings provide a consistent benefit, but the avoided cost of $CO_2$ emissions dominates OPEX and financial returns over the vessel lifetime. As a result, AENEAS solutions provide a financially robust option for newbuilds today, while the competitiveness of retrofits is expected to increase as operational efficiencies, maintenance optimization, and carbon market incentives continue to grow over the next 25 years.

When comparing technologies, the results highlight an important trade-off. Although SC solutions are often economically attractive due to their lower CAPEX, their absolute emission reduction potential is significantly lower than that of SSSB in vessels with substantial port-stay energy demand. In the analysed case, the emission savings achieved by SSSB are more than double those provided by SC.

Consequently, the selection and sizing of an ESS cannot be based solely on economic indicators. It must be tailored to the specific vessel, its operational profile, and the primary objective of the intervention—whether the priority is maximising emission reductions, optimising short-term financial performance, or achieving a balanced outcome through hybrid configurations. Proper dimensioning of the ESS on a case-by-case basis is therefore essential to ensure that the selected technology delivers the intended environmental and economic impact over the vessel’s lifetime.

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# 8 Acknowledgements and disclaimer

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| # | Partner | Partner full name |
|---|---|---|
| 1 | FM | FLANDERS MAKE |
| 2 | CEA | COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES |
| 3 | ABEE | AVESTA BATTERY & ENERGY ENGINEERING |
| 4 | SIE | SIEMENS INDUSTRY SOFTWARE SAS |
| 5 | UVA | VAASAN YLIOPISTO |
| 6 | I2M | I2M UNTERNEHMENSENTWICKLUNG GMBH |
| 7 | GRIM | GRIMALDI EUROMED SPA |
| 8 | INLS | INLAND SHIPPING SRL |
| 9 | FV | FUNDACION DE LA COMUNIDAD VALENCIANA PARA LA INVESTIGACION, PROMOCION Y ESTUDIOS COMERCIALES DE VALENCIAPORT |
| 10 | AUTH | ARISTOTELIO PANEPISTIMIO THESSALONIKIS |
| 11 | SOER | FUNDACION CENTRO TECNOLOGICO SOERMAR |
| 12 | FMAR | FORMARE- POLO NAZIONALE PER LO SHIPPING SRL |
| 13 | ISSN | INSTITUTE FOR SUSTAINABLE SOCIETY AND INNOVATION |
| 14 | FS | CONSTRUCCIONES NAVALES P FREIRE SA |

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# Abbreviations and Definitions

| Term | Definition |
|---|---|
| **AENEAS** | innovAtive ENErgy storage systems onboArd vesselS |
| **ESS** | Energy Storage System |
| **SSB** | Solid-State Battery |
| **SSSB** | Semi-Solid-State Battery |
| **SC** | Supercapacitor |
| **CAPEX** | Capital Expenditure |
| **OPEX** | Operational Expenditure |
| **NPV** | Net Present Value |
| **IRR** | Internal Rate of Return |
| **TCO** | Total Cost of Ownership |
| **EU** | European Union |
| **IMO** | International Maritime Organization |
| **EU ETS** | European Union Emissions Trading System |
| **$CO_2$** | Carbon Dioxide |
| **$CO_2eq$** | Carbon Dioxide Equivalent |
| **GHG** | Greenhouse Gas |
| **EEDI** | Energy Efficiency Design Index |
| **EEXI** | Energy Efficiency Existing Ship Index |
| **CII** | Carbon Intensity Indicator |
| **OPS** | Onshore Power Supply |
| **LCC** | Life Cycle Cost |
| **LHV** | Lower Heating Value |
| **GT** | Gross Tonnage |
| **DWT** | Deadweight Tonnage |
| **MCR** | Maximum Continuous Rating |
| **AUX** | Auxiliary (engine or power) |
| **MWh** | Megawatt-hour |
| **kW** | Kilowatt |
| **LNG** | Liquefied Natural Gas |
| **HFO** | Heavy Fuel Oil |
| **MDO** | Marine Diesel Oil |
| **MGO** | Marine Gas Oil |
| **NOx** | Nitrogen Oxides |
| **SOx** | Sulphur Oxides |
| **PM** | Particulate Matter |
| **DP** | Dynamic Positioning |
| **OSV** | Offshore Support Vessel |
| **Ro-Ro** | Roll-on / Roll-off vessel |
| **Ro-Pax** | Roll-on / Roll-off Passenger vessel |

| | |
|---|---|
| **EC** | European Commission |
| **DG REGIO** | Directorate-General for Regional and Urban Policy |
| **MBF** | Maritime Battery Forum |
| **FNPV/VAN** | Financial Net Present Value |
| **FRR/TIR** | Financial Rate of Return |
| **GA** | Grant Agreement |
| **WP** | Work Package |
| **LCA** | Life Cycle Assessment |
| **FFS** | Fire Fighting System |
| **IRR** | Internal Rate of Return |
| **CIMAC** | International Council on Combustion Engines |

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# Annex

## Table 7. Annex 1. Technical and Operational Input Parameters for Fuel Consumption Estimation

| Vessel type | fuel_type_main_engine | Total power (kW) | DWT (TN) | Sailing | Manoeuvring | Hotelling | Sailing | Manoeuvring | Hotelling | Sailing | Manoeuvring | Hotelling |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bulk Carrier | Heavy Fuel Oil | 12.265 | 63.652 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 3.448 | 4.653 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| Chemical Tanker | Heavy Fuel Oil | 9.038 | 29.650 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| | LNG | 7.163 | 18.122 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| | Marine Diesel Oil | 3.775 | 9.094 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| Container | Heavy Fuel Oil | 47.864 | 78.544 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | LNG | 64.734 | 168.505 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| Cruise Ship | Heavy Fuel Oil | 58.911 | 8.060 | 0,370 | 0,082 | 0,548 | 0,8 | 0,2 | 0,0 | 0,3 | 0,5 | 0,4 |
| | LNG | 83.106 | 15.451 | 0,370 | 0,082 | 0,548 | 0,8 | 0,2 | 0,0 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 10.765 | 1.754 | 0,370 | 0,082 | 0,548 | 0,8 | 0,2 | 0,0 | 0,3 | 0,5 | 0,4 |
| Ferry Pax Only | Heavy Fuel Oil | 12.517 | 2.756 | 0,466 | 0,082 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 17.667 | 3.175 | 0,466 | 0,082 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| Ferry Ro Pax | Heavy Fuel Oil | 35.252 | 4.927 | 0,466 | 0,082 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | LNG | 29.317 | 6.732 | 0,466 | 0,082 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 17.711 | 2.096 | 0,466 | 0,082 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| General Cargo | Heavy Fuel Oil | 5.397 | 12.488 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | LNG | 3.443 | 5.890 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 2.777 | 5.097 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| Liquefied Gas Tanker | Heavy Fuel Oil | 14.696 | 35.225 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| | LNG | 40.139 | 84.524 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| | Marine Diesel Oil | 12.272 | 30.864 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| Offshore | Heavy Fuel Oil | 19.005 | 18.752 | 0,274 | 0,274 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | LNG | 31.028 | 71.791 | 0,274 | 0,274 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 7.306 | 7.748 | 0,274 | 0,274 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| Oil Tanker | Heavy Fuel Oil | 17.824 | 111.626 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| | LNG | 20.817 | 144.120 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| | Marine Diesel Oil | 9.244 | 62.897 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| Other Liquid Tanker | Heavy Fuel Oil | 38.301 | 43.067 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| | Marine Diesel Oil | 2.201 | 2.245 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,6 |
| Other Misc | Heavy Fuel Oil | 34.665 | 14.011 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 7.690 | 7.415 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| Other Service | Heavy Fuel Oil | 14.081 | 10.644 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | LNG | 32.019 | 10.133 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 6.059 | 3.773 | 0,671 | 0,082 | 0,247 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| Refrigerated Bulk | Heavy Fuel Oil | 11.252 | 8.970 | 0,466 | 0,082 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 10.197 | 7.882 | 0,466 | 0,082 | 0,452 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| RoRo | Heavy Fuel Oil | 19.626 | 14.572 | 0,411 | 0,041 | 0,548 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LNG | 20.391 | 14.775 | 0,411 | 0,041 | 0,548 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 16.807 | 13.462 | 0,411 | 0,041 | 0,548 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| **Service Tug** | Heavy Fuel Oil | 6.732 | 620 | 0,110 | 0,397 | 0,493 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | Marine Diesel Oil | 7.024 | 816 | 0,110 | 0,397 | 0,493 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| **Vehicle** | Heavy Fuel Oil | 19.080 | 18.453 | 0,411 | 0,041 | 0,548 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |
| | LNG | 14.197 | 15.480 | 0,411 | 0,041 | 0,548 | 0,8 | 0,2 | 0,2 | 0,3 | 0,5 | 0,4 |

**Table 8. Annex 2. Estimated Energy Use by Operational Phase and Vessel Type**

| Vessel type | Total power (kW) | Hoteling | | | Manoeuvring | | | Sailing | | Total Auxiliary MWh/year | Total Main MWh/year |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Energy main MWh/year | Energy auxiliary MWh/year | Total MWh/year | Energy main MWh/year | Energy auxiliary MWh/year | Total MWh/year | Energy main MWh/year | Energy auxiliary MWh/year | | |
| Bulk Carrier | 12.265 | 191 | 2973 | 3164 | 1271 | 1239 | 2.509 | 41.506 | 6.070 | 10.282 | 42.967 |
| | 3.448 | 54 | 836 | 889 | 357 | 348 | 705 | 11.668 | 1.706 | 2.891 | 12.079 |
| Chemical Tanker | 9.038 | 2892 | 3037 | 5929 | 964 | 844 | 1.808 | 31.494 | 4.134 | 8.014 | 35.350 |
| | 7.163 | 2292 | 2407 | 4699 | 764 | 669 | 1.433 | 24.958 | 3.276 | 6.351 | 28.014 |
| | 3.775 | 1208 | 1269 | 2477 | 403 | 352 | 755 | 13.155 | 1.727 | 3.348 | 14.766 |
| Container | 47.864 | 814 | 8792 | 9606 | 5427 | 3663 | 9.090 | 177.286 | 17.950 | 30.405 | 183.527 |
| | 64.734 | 1101 | 11891 | 12992 | 7340 | 4954 | 12.294 | 239.770 | 24.277 | 41.122 | 248.211 |
| Cruise Ship | 58.911 | 0 | 24047 | 24047 | 6680 | 4509 | 11.188 | 120.235 | 12.174 | 40.729 | 126.914 |
| | 83.106 | 0 | 33923 | 33923 | 9423 | 6361 | 15.784 | 169.615 | 17.174 | 57.457 | 179.038 |
| | 10.765 | 0 | 4394 | 4394 | 1221 | 824 | 2.045 | 21.971 | 2.225 | 7.443 | 23.192 |
| Ferry Pax Only | 12.517 | 390 | 4215 | 4606 | 1419 | 958 | 2.377 | 32.170 | 3.257 | 8.430 | 33.980 |
| | 17.667 | 551 | 5950 | 6500 | 2003 | 1352 | 3.355 | 45.406 | 4.597 | 11.899 | 47.960 |
| Ferry Ro Pax | 35.252 | 1004 | 15667 | 16672 | 3652 | 3561 | 7.213 | 82.779 | 12.106 | 31.334 | 87.436 |
| | 29.317 | 835 | 13029 | 13865 | 3037 | 2961 | 5.998 | 68.842 | 10.068 | 26.059 | 72.714 |
| | 17.711 | 505 | 7871 | 8376 | 1835 | 1789 | 3.624 | 41.590 | 6.083 | 15.743 | 43.929 |
| General Cargo | 5.397 | 86 | 1209 | 1295 | 576 | 504 | 1.079 | 18.804 | 2.468 | 4.181 | 19.466 |
| | 3.443 | 55 | 771 | 826 | 367 | 321 | 689 | 11.995 | 1.574 | 2.667 | 12.417 |
| | 2.777 | 44 | 622 | 666 | 296 | 259 | 555 | 9.676 | 1.270 | 2.151 | 10.016 |
| Liquefied Gas Tanker | 14.696 | 235 | 4938 | 5173 | 1568 | 1372 | 2.939 | 51.206 | 6.721 | 13.030 | 53.009 |
| | 40.139 | 642 | 13487 | 14129 | 4281 | 3746 | 8.028 | 139.861 | 18.357 | 35.590 | 144.785 |
| | 12.272 | 196 | 4123 | 4320 | 1309 | 1145 | 2.454 | 42.760 | 5.612 | 10.881 | 44.265 |
| Offshore | 19.005 | 638 | 4592 | 5230 | 7731 | 3479 | 11.210 | 30.924 | 2.087 | 10.159 | 39.293 |
| | 31.028 | 1041 | 7497 | 8539 | 12622 | 5680 | 18.301 | 50.486 | 3.408 | 16.585 | 64.149 |
| | 7.306 | 245 | 1765 | 2010 | 2972 | 1337 | 4.309 | 11.887 | 802 | 3.905 | 15.104 |
| Oil Tanker | 17.824 | 5704 | 5989 | 11693 | 1901 | 1664 | 3.565 | 62.108 | 8.152 | 15.804 | 69.713 |
| | 20.817 | 6662 | 6995 | 13656 | 2221 | 1943 | 4.163 | 72.536 | 9.520 | 18.458 | 81.418 |
| | 9.244 | 2958 | 3106 | 6064 | 986 | 863 | 1.849 | 32.210 | 4.228 | 8.196 | 36.154 |
| Other Liquid Tanker | 38.301 | 12256 | 12869 | 25125 | 4085 | 3575 | 7.660 | 133.457 | 17.516 | 33.960 | 149.799 |
| | 2.201 | 704 | 740 | 1444 | 235 | 205 | 440 | 7.669 | 1.007 | 1.952 | 8.608 |
| Other Misc | 34.665 | 635 | 4569 | 5203 | 4230 | 1904 | 6.134 | 138.191 | 9.328 | 15.800 | 143.056 |
| | 7.690 | 141 | 1014 | 1154 | 938 | 422 | 1.361 | 30.656 | 2.069 | 3.505 | 31.735 |
| Other Service | 14.081 | 258 | 1856 | 2114 | 1718 | 773 | 2.492 | 56.135 | 3.789 | 6.418 | 58.111 |
| | 32.019 | 586 | 4220 | 4806 | 3907 | 1758 | 5.666 | 127.643 | 8.616 | 14.594 | 132.137 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6.059 | 111 | 799 | 909 | 739 | 333 | 1.072 | 24.152 | 1.630 | 2.762 | 25.003 |
| **Refrigerated Bulk** | 11.252 | 321 | 5001 | 5321 | 1166 | 1137 | 2.302 | 26.422 | 3.864 | 10.002 | 27.908 |
| | 10.197 | 291 | 4532 | 4822 | 1056 | 1030 | 2.086 | 23.944 | 3.502 | 9.064 | 25.291 |
| **RoRo** | 19.626 | 678 | 10573 | 11250 | 1017 | 991 | 2.008 | 40.664 | 5.947 | 17.511 | 42.358 |
| | 20.391 | 704 | 10985 | 11689 | 1056 | 1030 | 2.086 | 42.250 | 6.179 | 18.194 | 44.010 |
| | 16.807 | 580 | 9054 | 9634 | 871 | 849 | 1.719 | 34.823 | 5.093 | 14.996 | 36.274 |
| **Service Tug** | 6.732 | 264 | 1058 | 1322 | 4260 | 1065 | 5.324 | 4.700 | 176 | 2.299 | 9.224 |
| | 7.024 | 276 | 1103 | 1379 | 4444 | 1111 | 5.556 | 4.904 | 184 | 2.398 | 9.624 |
| **Vehicle** | 19.080 | 659 | 10279 | 10937 | 988 | 964 | 1.952 | 39.533 | 5.782 | 17.024 | 41.180 |
| | 14.197 | 490 | 7648 | 8138 | 735 | 717 | 1.452 | 29.414 | 4.302 | 12.667 | 42.967 |

**Table 9. Annex 3. Simplified CAPEX Estimated for SSSB by Vessel Type**

| Vessel type | Fuel type main engine | Total power (kW) | DWT (TN) | Battery (kWh) | Battery (tonnes) | Battery (m3 ) | Batteries Cost | Retrofit+Installation + FF System | CAPEX SSSB |
|---|---|---|---|---|---|---|---|---|---|
| Bulk Carrier | Heavy Fuel Oil | 12.265 | 63.652 | 2,05 | 18,32 | 11,73 | 1.231.344,50 € | 1.119.404,09 € | 2.350.748,59 € |
| | Marine Diesel Oil | 3.448 | 4.653 | 0,58 | 5,15 | 3,30 | 346.156,25 € | 314.687,50 € | 660.843,74 € |
| Chemical Tanker | Heavy Fuel Oil | 9.038 | 29.650 | 1,51 | 13,50 | 8,64 | 907.437,71 € | 824.943,38 € | 1.732.381,09 € |
| | LNG | 7.163 | 18.122 | 1,20 | 10,70 | 6,85 | 719.109,36 € | 653.735,78 € | 1.372.845,14 € |
| | Marine Diesel Oil | 3.775 | 9.094 | 0,63 | 5,64 | 3,61 | 379.050,29 € | 344.591,17 € | 723.641,46 € |
| Container | Heavy Fuel Oil | 47.864 | 78.544 | 8,01 | 71,51 | 45,77 | 4.805.446,84 € | 4.368.588,04 € | 9.174.034,88 € |
| | LNG | 64.734 | 168.505 | 10,83 | 96,71 | 61,90 | 6.499.124,69 € | 5.908.295,17 € | 12.407.419,86 € |
| Cruise Ship | Heavy Fuel Oil | 58.911 | 8.060 | 9,86 | 88,01 | 56,33 | 5.914.545,00 € | 5.376.859,09 € | 11.291.404,09 € |
| | LNG | 83.106 | 15.451 | 13,91 | 124,16 | 79,46 | 8.343.670,24 € | 7.585.154,76 € | 15.928.825,00 € |
| | Marine Diesel Oil | 10.765 | 1.754 | 1,80 | 16,08 | 10,29 | 1.080.795,88 € | 982.541,71 € | 2.063.337,59 € |
| Ferry Pax Only | Heavy Fuel Oil | 12.517 | 2.756 | 2,09 | 18,70 | 11,97 | 1.256.688,99 € | 1.142.444,53 € | 2.399.133,52 € |
| | Marine Diesel Oil | 17.667 | 3.175 | 2,96 | 26,40 | 16,89 | 1.773.745,87 € | 1.612.496,24 € | 3.386.242,11 € |
| Ferry Ro Pax | Heavy Fuel Oil | 35.252 | 4.927 | 5,90 | 52,67 | 33,71 | 3.539.240,27 € | 3.217.491,16 € | 6.756.731,43 € |
| | LNG | 29.317 | 6.732 | 4,91 | 43,80 | 28,03 | 2.943.340,54 € | 2.675.764,13 € | 5.619.104,68 € |
| | Marine Diesel Oil | 17.711 | 2.096 | 2,96 | 26,46 | 16,94 | 1.778.176,11 € | 1.616.523,74 € | 3.394.699,85 € |
| General Cargo | Heavy Fuel Oil | 5.397 | 12.488 | 0,90 | 8,06 | 5,16 | 541.798,79 € | 492.544,35 € | 1.034.343,14 € |
| | LNG | 3.443 | 5.890 | 0,58 | 5,14 | 3,29 | 345.618,79 € | 314.198,90 € | 659.817,68 € |
| | Marine Diesel Oil | 2.777 | 5.097 | 0,46 | 4,15 | 2,66 | 278.788,31 € | 253.443,92 € | 532.232,23 € |
| Liquefied Gas Tanker | Heavy Fuel Oil | 14.696 | 35.225 | 2,46 | 21,96 | 14,05 | 1.475.401,88 € | 1.341.274,43 € | 2.816.676,31 € |
| | LNG | 40.139 | 84.524 | 6,72 | 59,97 | 38,38 | 4.029.841,87 € | 3.663.492,61 € | 7.693.334,48 € |
| | Marine Diesel Oil | 12.272 | 30.864 | 2,05 | 18,33 | 11,73 | 1.232.052,37 € | 1.120.047,60 € | 2.352.099,97 € |
| Offshore | Heavy Fuel Oil | 19.005 | 18.752 | 3,18 | 28,39 | 18,17 | 1.908.100,23 € | 1.734.636,58 € | 3.642.736,81 € |
| | LNG | 31.028 | 71.791 | 5,19 | 46,36 | 29,67 | 3.115.147,22 € | 2.831.952,02 € | 5.947.099,23 € |
| | Marine Diesel Oil | 7.306 | 7.748 | 1,22 | 10,91 | 6,99 | 733.459,31 € | 666.781,19 € | 1.400.240,50 € |
| Oil Tanker | Heavy Fuel Oil | 17.824 | 111.626 | 2,98 | 26,63 | 17,04 | 1.789.519,20 € | 1.626.835,64 € | 3.416.354,85 € |
| | LNG | 20.817 | 144.120 | 3,48 | 31,10 | 19,90 | 2.089.997,47 € | 1.899.997,70 € | 3.989.995,17 € |
| | Marine Diesel Oil | 9.244 | 62.897 | 1,55 | 13,81 | 8,84 | 928.063,70 € | 843.694,27 € | 1.771.757,97 € |
| Other Liquid Tanker | Heavy Fuel Oil | 38.301 | 43.067 | 6,41 | 57,22 | 36,62 | 3.845.313,97 € | 3.495.739,97 € | 7.341.053,94 € |
| | Marine Diesel Oil | 2.201 | 2.245 | 0,37 | 3,29 | 2,10 | 220.969,68 € | 200.881,52 € | 421.851,20 € |
| Other Misc | Heavy Fuel Oil | 34.665 | 14.011 | 5,80 | 51,79 | 33,15 | 3.480.308,34 € | 3.163.916,67 € | 6.644.225,01 € |
| | Marine Diesel Oil | 7.690 | 7.415 | 1,29 | 11,49 | 7,35 | 772.068,42 € | 701.880,38 € | 1.473.948,80 € |
| Other Service | Heavy Fuel Oil | 14.081 | 10.644 | 2,36 | 21,04 | 13,46 | 1.413.737,80 € | 1.285.216,18 € | 2.698.953,98 € |
| | LNG | 32.019 | 10.133 | 5,36 | 47,84 | 30,62 | 3.214.661,33 € | 2.922.419,39 € | 6.137.080,72 € |
| | Marine Diesel Oil | 6.059 | 3.773 | 1,01 | 9,05 | 5,79 | 608.274,11 € | 552.976,46 € | 1.161.250,57 € |
| Refrigerated Bulk | Heavy Fuel Oil | 11.252 | 8.970 | 1,88 | 16,81 | 10,76 | 1.129.676,19 € | 1.026.978,35 € | 2.156.654,54 € |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Marine Diesel Oil | 10.197 | 7.882 | 1,71 | 15,23 | 9,75 | 1.023.741,74 € | 930.674,31 € | 1.954.416,05 € |
| RoRo | Heavy Fuel Oil | 19.626 | 14.572 | 3,28 | 29,32 | 18,77 | 1.970.384,81 € | 1.791.258,92 € | 3.761.643,74 € |
| | LNG | 20.391 | 14.775 | 3,41 | 30,46 | 19,50 | 2.047.237,87 € | 1.861.125,34 € | 3.908.363,21 € |
| | Marine Diesel Oil | 16.807 | 13.462 | 2,81 | 25,11 | 16,07 | 1.687.376,16 € | 1.533.978,33 € | 3.221.354,48 € |
| Service Tug | Heavy Fuel Oil | 6.732 | 620 | 1,13 | 10,06 | 6,44 | 675.876,74 € | 614.433,40 € | 1.290.310,14 € |
| | Marine Diesel Oil | 7.024 | 816 | 1,18 | 10,49 | 6,72 | 705.216,64 € | 641.106,03 € | 1.346.322,67 € |
| Vehicle | Heavy Fuel Oil | 19.080 | 18.453 | 3,19 | 28,51 | 18,24 | 1.915.607,59 € | 1.741.461,45 € | 3.657.069,04 € |
| | LNG | 14.197 | 15.480 | 2,38 | 21,21 | 13,57 | 1.425.297,61 € | 1.295.725,10 € | 2.721.022,72 € |

**Table 10. Annex 4. Simplified CAPEX Estimated for SC by Vessel Type**

| Vessel type | Fuel type main engine | Total power (kW) | DWT (TN) | Battery (kWh) | Battery (tonnes) | Battery (m3 ) | Batteries Cost (5M€/MWh) | Retrofit+Installation + FF System) | CAPEX SC |
|---|---|---|---|---|---|---|---|---|---|
| Bulk Carrier | Heavy Fuel Oil | 12.265 | 63.652 | 7 | 2955 | 5 | 36.935,95 € | 377.933,90 € | 414.869,85 € |
| | Marine Diesel Oil | 3.448 | 4.653 | 2 | 831 | 1 | 10.383,45 € | 106.244,99 € | 116.628,44 € |
| Chemical Tanker | Heavy Fuel Oil | 9.038 | 29.650 | 5 | 2178 | 4 | 27.219,90 € | 278.517,89 € | 305.737,79 € |
| | LNG | 7.163 | 18.122 | 4 | 1726 | 3 | 21.570,72 € | 220.714,68 € | 242.285,40 € |
| | Marine Diesel Oil | 3.775 | 9.094 | 2 | 910 | 2 | 11.370,16 € | 116.341,08 € | 127.711,24 € |
| Container | Heavy Fuel Oil | 47.864 | 78.544 | 29 | 11532 | 21 | 144.146,29 € | 1.474.925,39 € | 1.619.071,68 € |
| | LNG | 64.734 | 168.505 | 39 | 15596 | 28 | 194.950,59 € | 1.994.762,27 € | 2.189.712,86 € |
| Cruise Ship | Heavy Fuel Oil | 58.911 | 8.060 | 35 | 14193 | 25 | 177.415,28 € | 1.815.338,49 € | 1.992.753,77 € |
| | LNG | 83.106 | 15.451 | 50 | 20022 | 36 | 250.280,38 € | 2.560.904,64 € | 2.811.185,02 € |
| | Marine Diesel Oil | 10.765 | 1.754 | 6 | 2594 | 5 | 32.420,03 € | 331.726,34 € | 364.146,37 € |
| Ferry Pax Only | Heavy Fuel Oil | 12.517 | 2.756 | 8 | 3016 | 5 | 37.696,19 € | 385.712,83 € | 423.409,02 € |
| | Marine Diesel Oil | 17.667 | 3.175 | 11 | 4256 | 8 | 53.206,06 € | 544.411,98 € | 597.618,04 € |
| Ferry Ro Pax | Heavy Fuel Oil | 35.252 | 4.927 | 21 | 8493 | 15 | 106.164,60 € | 1.086.291,35 € | 1.192.455,95 € |
| | LNG | 29.317 | 6.732 | 18 | 7063 | 13 | 88.289,73 € | 903.393,14 € | 991.682,87 € |
| | Marine Diesel Oil | 17.711 | 2.096 | 11 | 4267 | 8 | 53.338,95 € | 545.771,74 € | 599.110,69 € |
| General Cargo | Heavy Fuel Oil | 5.397 | 12.488 | 3,25 | 1300,16 | 2,32 | 16.252,03 € | 166.293,13 € | 182.545,16 € |
| | LNG | 3.443 | 5.890 | 2,07 | 829,39 | 1,48 | 10.367,33 € | 106.080,03 € | 116.447,36 € |
| | Marine Diesel Oil | 2.777 | 5.097 | 1,67 | 669,01 | 1,19 | 8.362,66 € | 85.567,89 € | 93.930,55 € |
| Liquefied Gas Tanker | Heavy Fuel Oil | 14.696 | 35.225 | 8,85 | 3540,54 | 6,32 | 44.256,80 € | 452.841,90 € | 497.098,70 € |
| | LNG | 40.139 | 84.524 | 24,18 | 9670,47 | 17,27 | 120.880,90 € | 1.236.870,64 € | 1.357.751,54 € |
| | Marine Diesel Oil | 12.272 | 30.864 | 7,39 | 2956,57 | 5,28 | 36.957,18 € | 378.151,16 € | 415.108,35 € |
| Offshore | Heavy Fuel Oil | 19.005 | 18.752 | 11,45 | 4578,90 | 8,18 | 57.236,21 € | 585.649,07 € | 642.885,28 € |
| | LNG | 31.028 | 71.791 | 18,69 | 7475,47 | 13,35 | 93.443,32 € | 956.125,39 € | 1.049.568,71 € |
| | Marine Diesel Oil | 7.306 | 7.748 | 4,40 | 1760,09 | 3,14 | 22.001,17 € | 225.119,08 € | 247.120,24 € |
| Oil Tanker | Heavy Fuel Oil | 17.824 | 111.626 | 10,74 | 4294,34 | 7,67 | 53.679,20 € | 549.253,25 € | 602.932,46 € |
| | LNG | 20.817 | 144.120 | 12,54 | 5015,40 | 8,96 | 62.692,48 € | 641.478,40 € | 704.170,88 € |
| | Marine Diesel Oil | 9.244 | 62.897 | 5,57 | 2227,09 | 3,98 | 27.838,60 € | 284.848,58 € | 312.687,19 € |
| Other Liquid Tanker | Heavy Fuel Oil | 38.301 | 43.067 | 23,07 | 9227,66 | 16,48 | 115.345,72 € | 1.180.233,89 € | 1.295.579,61 € |
| | Marine Diesel Oil | 2.201 | 2.245 | 1,33 | 530,26 | 0,95 | 6.628,30 € | 67.821,74 € | 74.450,05 € |
| Other Misc | Heavy Fuel Oil | 34.665 | 14.011 | 20,88 | 8351,75 | 14,91 | 104.396,85 € | 1.068.203,50 € | 1.172.600,35 € |
| | Marine Diesel Oil | 7.690 | 7.415 | 4,63 | 1852,74 | 3,31 | 23.159,30 € | 236.969,29 € | 260.128,59 € |
| Other Service | Heavy Fuel Oil | 14.081 | 10.644 | 8,48 | 3392,57 | 6,06 | 42.407,10 € | 433.915,48 € | 476.322,58 € |
| | LNG | 32.019 | 10.133 | 19,29 | 7714,27 | 13,78 | 96.428,39 € | 986.669,04 € | 1.083.097,43 € |
| | Marine Diesel Oil | 6.059 | 3.773 | 3,65 | 1459,68 | 2,61 | 18.246,06 € | 186.696,25 € | 204.942,31 € |
| Refrigerated Bulk | Heavy Fuel Oil | 11.252 | 8.970 | 6,78 | 2710,90 | 4,84 | 33.886,26 € | 346.729,07 € | 380.615,33 € |
| | Marine Diesel Oil | 10.197 | 7.882 | 6,14 | 2456,69 | 4,39 | 30.708,61 € | 314.214,84 € | 344.923,44 € |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **RoRo** | Heavy Fuel Oil | 19.626 | 14.572 | 11,82 | 4728,36 | 8,44 | 59.104,53 € | 604.765,94 € | 663.870,47 € |
| | LNG | 20.391 | 14.775 | 12,28 | 4912,79 | 8,77 | 61.409,84 € | 628.354,29 € | 689.764,13 € |
| | Marine Diesel Oil | 16.807 | 13.462 | 10,12 | 4049,22 | 7,23 | 50.615,27 € | 517.902,71 € | 568.517,98 € |
| **Service Tug** | Heavy Fuel Oil | 6.732 | 620 | 4,05 | 1621,91 | 2,90 | 20.273,89 € | 207.445,38 € | 227.719,28 € |
| | Marine Diesel Oil | 7.024 | 816 | 4,23 | 1692,32 | 3,02 | 21.153,99 € | 216.450,62 € | 237.604,60 € |
| **Vehicle** | Heavy Fuel Oil | 19.080 | 18.453 | 11,49 | 4596,91 | 8,21 | 57.461,40 € | 587.953,29 € | 645.414,69 € |
| | LNG | 14.197 | 15.480 | 8,55 | 3420,31 | 6,11 | 42.753,85 € | 437.463,51 € | 480.217,36 € |

**Table 11. Annex 5. Estimated Fuel, Emissions, and Simplified OPEX of SSSB by Vessel Type**

| Vessel type | Fuel type main engine | Total Energy MWh/y | Saved Energy MWh/y | Total Fuel (t) | Saved fuel (t) | Total CO2eq (t) | Saved CO2eq (t) | Maintenance (€) | OPEX Bat (€) | OPEX Trad (€) | Savings (€) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bulk Carrier | Heavy Fuel Oil | 53.249 | 677 | 9.222,56 | 117,30 | 29.567,53 | 376,05 | 30.783,61 | 10.749.902,64 | 10.857.204,30 | 107.301,66 |
| | Marine Diesel Oil | 14.969 | 190 | 2.592,65 | 32,97 | 8.312,04 | 105,72 | 8.653,91 | 3.022.018,56 | 3.052.183,26 | 30.164,70 |
| Chemical Tanker | Heavy Fuel Oil | 43.364 | 499 | 7.510,56 | 86,44 | 24.078,85 | 277,13 | 22.685,94 | 8.762.683,12 | 8.841.758,94 | 79.075,82 |
| | LNG | 34.365 | 396 | 5.951,83 | 68,50 | 19.081,56 | 219,61 | 17.977,73 | 6.944.088,11 | 7.006.752,65 | 62.664,54 |
| | Marine Diesel Oil | 18.114 | 208 | 3.137,27 | 36,11 | 10.058,09 | 115,76 | 9.476,26 | 3.660.303,65 | 3.693.334,80 | 33.031,15 |
| Container | Heavy Fuel Oil | 213.932 | 2.643 | 37.052,30 | 457,76 | 118.789,69 | 1.467,57 | 120.136,17 | 43.200.847,01 | 43.619.602,65 | 418.755,63 |
| | LNG | 289.333 | 3.575 | 50.111,37 | 619,09 | 160.657,07 | 1.984,81 | 162.478,12 | 58.426.968,51 | 58.993.314,40 | 566.345,89 |
| Cruise Ship | Heavy Fuel Oil | 167.644 | 3.253 | 29.035,27 | 563,41 | 93.087,06 | 1.806,28 | 147.863,63 | 33.666.187,95 | 34.181.592,47 | 515.404,52 |
| | LNG | 236.496 | 4.589 | 40.960,16 | 794,80 | 131.318,26 | 2.548,13 | 208.591,76 | 47.493.014,32 | 48.220.097,36 | 727.083,04 |
| | Marine Diesel Oil | 30.634 | 594 | 5.305,77 | 102,95 | 17.010,29 | 330,07 | 27.019,90 | 6.151.999,39 | 6.246.181,96 | 94.182,58 |
| Ferry Pax Only | Heavy Fuel Oil | 42.410 | 691 | 7.345,25 | 119,71 | 23.548,87 | 383,79 | 31.417,22 | 8.537.642,19 | 8.647.152,42 | 109.510,23 |
| | Marine Diesel Oil | 59.859 | 976 | 10.367,41 | 168,96 | 33.237,91 | 541,70 | 44.343,65 | 12.050.402,06 | 12.204.969,59 | 154.567,53 |
| Ferry Ro Pax | Heavy Fuel Oil | 118.770 | 1.947 | 20.571 | 337,14 | 65.949 | 1.080,87 | 88.481,01 | 23.908.132,81 | 24.216.548,83 | 308.416,02 |
| | LNG | 98.773 | 1.619 | 17.107,09 | 280,38 | 54.845,34 | 898,89 | 73.583,51 | 19.882.735,05 | 20.139.223,25 | 256.488,20 |
| | Marine Diesel Oil | 59.672 | 978 | 10.335,00 | 169,39 | 33.134,01 | 543,05 | 44.454,40 | 12.011.863,38 | 12.166.816,98 | 154.953,59 |
| General Cargo | Heavy Fuel Oil | 23.646 | 298 | 4.095,47 | 51,61 | 13.130,07 | 165,46 | 13.544,97 | 4.774.152,57 | 4.821.365,93 | 47.213,36 |
| | LNG | 15.084 | 190 | 2.612,54 | 32,92 | 8.375,80 | 105,55 | 8.640,47 | 3.045.478,99 | 3.075.596,85 | 30.117,87 |
| | Marine Diesel Oil | 12.168 | 153 | 2.107,37 | 26,56 | 6.756,22 | 85,14 | 6.969,71 | 2.456.590,84 | 2.480.884,97 | 24.294,14 |
| Liquefied Gas Tanker | Heavy Fuel Oil | 66.039 | 811 | 11.437,66 | 140,54 | 36.669,14 | 450,58 | 36.885,05 | 13.336.346,49 | 13.464.915,77 | 128.569,28 |
| | LNG | 180.375 | 2.216 | 31.240,27 | 383,87 | 100.156,32 | 1.230,70 | 100.746,05 | 36.426.256,71 | 36.777.424,67 | 351.167,96 |
| | Marine Diesel Oil | 55.146 | 678 | 9.551,16 | 117,36 | 30.621,01 | 376,27 | 30.801,31 | 11.136.679,10 | 11.244.042,45 | 107.363,35 |
| Offshore | Heavy Fuel Oil | 49.451 | 1.049 | 8.564,82 | 181,76 | 27.458,80 | 582,73 | 47.702,51 | 9.916.603,13 | 10.082.878,55 | 166.275,43 |
| | LNG | 80.734 | 1.713 | 13.982,84 | 296,74 | 44.828,99 | 951,36 | 77.878,68 | 16.189.756,76 | 16.461.216,52 | 271.459,76 |
| | Marine Diesel Oil | 19.009 | 403 | 3.292,25 | 69,87 | 10.554,96 | 224,00 | 18.336,48 | 3.811.867,30 | 3.875.782,32 | 63.915,02 |
| Oil Tanker | Heavy Fuel Oil | 85.517 | 984 | 14.811,25 | 170,47 | 47.484,87 | 546,51 | 44.737,98 | 17.280.513,60 | 17.436.455,65 | 155.942,05 |
| | LNG | 99.876 | 1.149 | 17.298,21 | 199,09 | 55.458,06 | 638,28 | 52.249,94 | 20.182.085,54 | 20.364.211,83 | 182.126,29 |
| | Marine Diesel Oil | 44.350 | 510 | 7.681,27 | 88,41 | 24.626,16 | 283,43 | 23.201,59 | 8.961.858,21 | 9.042.731,42 | 80.873,21 |
| Other Liquid Tanker | Heavy Fuel Oil | 183.759 | 2.115 | 31.826,37 | 366,30 | 102.035,36 | 1.174,35 | 96.132,85 | 37.132.320,30 | 37.467.408,15 | 335.087,86 |
| | Marine Diesel Oil | 10.560 | 122 | 1.828,89 | 21,05 | 5.863,43 | 67,48 | 5.524,24 | 2.133.796,33 | 2.153.052,04 | 19.255,71 |
| Other Misc | Heavy Fuel Oil | 158.856 | 1.914 | 27.513,30 | 331,53 | 88.207,63 | 1.062,88 | 87.007,71 | 32.086.584,70 | 32.389.865,28 | 303.280,58 |
| | Marine Diesel Oil | 35.241 | 425 | 6.103,52 | 73,55 | 19.567,90 | 235,79 | 19.301,71 | 7.118.058,58 | 7.185.338,07 | 67.279,49 |
| Other Service | Heavy Fuel Oil | 64.529 | 778 | 11.176,19 | 134,67 | 35.830,87 | 431,75 | 35.343,45 | 13.033.907,71 | 13.157.103,47 | 123.195,76 |
| | LNG | 146.731 | 1.768 | 25.413,25 | 306,22 | 81.474,87 | 981,75 | 80.366,53 | 29.637.461,12 | 29.917.592,73 | 280.131,61 |
| | Marine Diesel Oil | 27.764 | 335 | 4.808,66 | 57,94 | 15.416,57 | 185,77 | 15.206,85 | 5.607.962,49 | 5.660.968,64 | 53.006,14 |
| Refrigerated Bulk | Heavy Fuel Oil | 37.910 | 621 | 6.565,83 | 107,61 | 21.050,05 | 345,00 | 28.241,90 | 7.631.142,89 | 7.729.584,99 | 98.442,10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Marine Diesel Oil | 34.355 | 563 | 5.950,13 | 97,52 | 19.076,10 | 312,65 | 25.593,54 | 6.915.538,83 | 7.004.749,60 | 89.210,77 |
| **RoRo** | Heavy Fuel Oil | 59.869 | 1.084 | 10.369,02 | 187,69 | 33.243,09 | 601,75 | 49.259,62 | 12.035.166,73 | 12.206.869,75 | 171.703,02 |
| | LNG | 62.204 | 1.126 | 10.773,46 | 195,02 | 34.539,70 | 625,22 | 51.180,95 | 12.504.587,41 | 12.682.987,55 | 178.400,14 |
| | Marine Diesel Oil | 51.270 | 928 | 8.879,71 | 160,74 | 28.468,34 | 515,32 | 42.184,40 | 10.306.541,77 | 10.453.582,89 | 147.041,12 |
| **Service Tug** | Heavy Fuel Oil | 11.523 | 372 | 1.995,70 | 64,38 | 6.398,20 | 206,41 | 16.896,92 | 2.290.523,17 | 2.349.420,33 | 58.897,16 |
| | Marine Diesel Oil | 12.022,94 | 387,87 | 2.082,33 | 67,18 | 6.675,95 | 215,37 | 17.630,42 | 2.389.955,08 | 2.451.408,97 | 61.453,90 |
| **Vehicle** | Heavy Fuel Oil | 58.204,25 | 1.053,58 | 10.080,76 | 182,48 | 32.318,92 | 585,02 | 47.890,19 | 11.700.585,91 | 11.867.515,54 | 166.929,63 |
| | LNG | 43.306,56 | 783,91 | 7.500,54 | 135,77 | 24.046,72 | 435,28 | 35.632,44 | 8.705.758,54 | 8.829.961,64 | 124.203,10 |

**Table 12. Annex 6. Estimated Fuel, Emissions, and Simplified OPEX of SC by Vessel Type**

| Vessel type | Fuel type main engine | Total Energy (MWh/y) | Saved Energy (MWh/y) | Total Fuel (t) | Saved fuel (t) | Total CO2eq (t) | Saved CO2eq (t) | Maintenance | OPEX Bat (€) | OPEX Trad (€) | Savings (€) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bulk Carrier | Heavy Fuel Oil | 53.249 | 250,94 | 9.222,56 | 43,46 | 29.567,53 | 139,34 | 73,87 | 10.816.986,01 | 10.857.204,30 | 40.218,29 |
| | Marine Diesel Oil | 14.969 | 70,54 | 2.592,65 | 12,22 | 8.312,04 | 39,17 | 20,77 | 3.040.877,08 | 3.052.183,26 | 11.306,19 |
| Chemical Tanker | Heavy Fuel Oil | 43.364 | 180,77 | 7.510,56 | 31,31 | 24.078,85 | 100,38 | 54,44 | 8.813.153,12 | 8.841.758,94 | 28.605,82 |
| | LNG | 34.365 | 143,25 | 5.951,83 | 24,81 | 19.081,56 | 79,54 | 43,14 | 6.984.083,64 | 7.006.752,65 | 22.669,01 |
| | Marine Diesel Oil | 18.114 | 75,51 | 3.137,27 | 13,08 | 10.058,09 | 41,93 | 22,74 | 3.681.385,72 | 3.693.334,80 | 11.949,08 |
| Container | Heavy Fuel Oil | 213.932 | 909,04 | 37.052,30 | 157,44 | 118.789,69 | 504,76 | 288,29 | 43.480.256,83 | 43.619.602,65 | 139.345,82 |
| | LNG | 289.333 | 1.229,43 | 50.111,37 | 212,93 | 160.657,07 | 682,66 | 389,90 | 58.804.856,20 | 58.993.314,40 | 188.458,19 |
| Cruise Ship | Heavy Fuel Oil | 167.644 | 1.118,85 | 29.035,27 | 193,78 | 93.087,06 | 621,26 | 354,83 | 34.010.085,61 | 34.181.592,47 | 171.506,86 |
| | LNG | 236.496 | 1.578,36 | 40.960,16 | 273,37 | 131.318,26 | 876,41 | 500,56 | 47.978.152,01 | 48.220.097,36 | 241.945,36 |
| | Marine Diesel Oil | 30.634 | 204,45 | 5.305,77 | 35,41 | 17.010,29 | 113,53 | 64,84 | 6.214.841,61 | 6.246.181,96 | 31.340,35 |
| Ferry Pax Only | Heavy Fuel Oil | 42.410 | 237,73 | 7.345,25 | 41,17 | 23.548,87 | 132,00 | 75,39 | 8.610.711,62 | 8.647.152,42 | 36.440,81 |
| | Marine Diesel Oil | 59.859 | 335,54 | 10.367,41 | 58,11 | 33.237,91 | 186,31 | 106,41 | 12.153.535,44 | 12.204.969,59 | 51.434,15 |
| Ferry Ro Pax | Heavy Fuel Oil | 118.770 | 721,28 | 20.570,54 | 124,92 | 65.949,16 | 400,50 | 212,33 | 24.100.949,83 | 24.216.548,83 | 115.599,00 |
| | LNG | 98.773 | 599,84 | 17.107,09 | 103,89 | 54.845,34 | 333,07 | 176,58 | 20.043.087,59 | 20.139.223,25 | 96.135,67 |
| | Marine Diesel Oil | 59.672 | 362,38 | 10.335,00 | 62,76 | 33.134,01 | 201,22 | 106,68 | 12.108.738,02 | 12.166.816,98 | 58.078,96 |
| General Cargo | Heavy Fuel Oil | 23.646 | 107,93 | 4.095,47 | 18,69 | 13.130,07 | 59,93 | 32,50 | 4.804.286,42 | 4.821.365,93 | 17.079,52 |
| | LNG | 15.084 | 68,85 | 2.612,54 | 11,92 | 8.375,80 | 38,23 | 20,73 | 3.064.701,66 | 3.075.596,85 | 10.895,19 |
| | Marine Diesel Oil | 12.168 | 55,54 | 2.107,37 | 9,62 | 6.756,22 | 30,84 | 16,73 | 2.472.096,53 | 2.480.884,97 | 8.788,45 |
| Liquefied Gas Tanker | Heavy Fuel Oil | 66.039 | 293,91 | 11.437,66 | 50,90 | 36.669,14 | 163,20 | 88,51 | 13.418.405,60 | 13.464.915,77 | 46.510,17 |
| | LNG | 180.375 | 802,78 | 31.240,27 | 139,04 | 100.156,32 | 445,76 | 241,76 | 36.650.389,02 | 36.777.424,67 | 127.035,65 |
| | Marine Diesel Oil | 55.146 | 245,43 | 9.551,16 | 42,51 | 30.621,01 | 136,28 | 73,91 | 11.205.203,57 | 11.244.042,45 | 38.838,89 |
| Offshore | Heavy Fuel Oil | 49.451 | 1.121,00 | 8.564,82 | 194,15 | 27.458,80 | 622,45 | 114,47 | 9.860.272,57 | 10.082.878,55 | 222.605,98 |
| | LNG | 80.734 | 1.830,13 | 13.982,84 | 316,97 | 44.828,99 | 1.016,21 | 186,89 | 16.097.792,00 | 16.461.216,52 | 363.424,52 |
| | Marine Diesel Oil | 19.009 | 430,90 | 3.292,25 | 74,63 | 10.554,96 | 239,27 | 44,00 | 3.790.214,26 | 3.875.782,32 | 85.568,06 |
| Oil Tanker | Heavy Fuel Oil | 85.517 | 356,49 | 14.811,25 | 61,74 | 47.484,87 | 197,95 | 107,36 | 17.380.043,33 | 17.436.455,65 | 56.412,32 |
| | LNG | 99.876 | 416,34 | 17.298,21 | 72,11 | 55.458,06 | 231,18 | 125,38 | 20.298.327,31 | 20.364.211,83 | 65.884,52 |
| | Marine Diesel Oil | 44.350 | 184,88 | 7.681,27 | 32,02 | 24.626,16 | 102,66 | 55,68 | 9.013.475,39 | 9.042.731,42 | 29.256,03 |
| Other Liquid Tanker | Heavy Fuel Oil | 183.759 | 766,02 | 31.826,37 | 132,67 | 102.035,36 | 425,34 | 230,69 | 37.346.189,51 | 37.467.408,15 | 121.218,64 |
| | Marine Diesel Oil | 10.560 | 44,02 | 1.828,89 | 7,62 | 5.863,43 | 24,44 | 13,26 | 2.146.086,26 | 2.153.052,04 | 6.965,79 |
| Other Misc | Heavy Fuel Oil | 158.856 | 613,40 | 27.513,30 | 106,24 | 88.207,63 | 340,60 | 208,79 | 32.300.541,04 | 32.389.865,28 | 89.324,24 |
| | Marine Diesel Oil | 35.241 | 136,08 | 6.103,52 | 23,57 | 19.567,90 | 75,56 | 46,32 | 7.165.522,46 | 7.185.338,07 | 19.815,61 |
| Other Service | Heavy Fuel Oil | 64.529 | 249,17 | 11.176,19 | 43,16 | 35.830,87 | 138,36 | 84,81 | 13.120.819,03 | 13.157.103,47 | 36.284,44 |
| | LNG | 146.731 | 566,58 | 25.413,25 | 98,13 | 81.474,87 | 314,60 | 192,86 | 29.835.086,48 | 29.917.592,73 | 82.506,25 |
| | Marine Diesel Oil | 27.764 | 107,21 | 4.808,66 | 18,57 | 15.416,57 | 59,53 | 36,49 | 5.645.356,91 | 5.660.968,64 | 15.611,73 |
| Refrigerated Bulk | Heavy Fuel Oil | 37.910 | 230,22 | 6.565,83 | 39,87 | 21.050,05 | 127,83 | 67,77 | 7.692.687,40 | 7.729.584,99 | 36.897,59 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Marine Diesel Oil | 34.355 | 208,63 | 5.950,13 | 36,13 | 19.076,10 | 115,85 | 61,42 | 6.971.312,05 | 7.004.749,60 | 33.437,55 |
| **RoRo** | Heavy Fuel Oil | 59.869 | 200,78 | 10.369,02 | 34,77 | 33.243,09 | 111,48 | 118,21 | 12.200.849,19 | 12.206.869,75 | 6.020,56 |
| | LNG | 62.204 | 208,61 | 10.773,46 | 36,13 | 34.539,70 | 115,83 | 122,82 | 12.676.732,16 | 12.682.987,55 | 6.255,39 |
| | Marine Diesel Oil | 51.270 | 171,94 | 8.879,71 | 29,78 | 28.468,34 | 95,47 | 101,23 | 10.448.427,07 | 10.453.582,89 | 5.155,82 |
| **Service Tug** | Heavy Fuel Oil | 11.523 | 532,44 | 1.995,70 | 92,22 | 6.398,20 | 295,65 | 40,55 | 2.242.443,34 | 2.349.420,33 | 106.976,99 |
| | Marine Diesel Oil | 12.022,94 | 555,55 | 2.082,33 | 96,22 | 6.675,95 | 308,48 | 42,31 | 2.339.788,10 | 2.451.408,97 | 111.620,87 |
| **Vehicle** | Heavy Fuel Oil | 58.204,25 | 195,19 | 10.080,76 | 33,81 | 32.318,92 | 108,39 | 114,92 | 11.861.662,36 | 11.867.515,54 | 5.853,19 |
| | LNG | 43.306,56 | 145,23 | 7.500,54 | 25,15 | 24.046,72 | 80,64 | 85,51 | 8.825.606,61 | 8.829.961,64 | 4.355,03 |

Table 13. Annex 7. Study 1. RORO Investment details

| RORO - Study 1 (INVESTMENT) | | | | |
|---|---|---|---|---|
| Year | BATTERY | SHIPYARD | OTHER | TOTAL |
| 2025 | 2.047.237,87 € | 468.000,00 € | 1.393.125,34 € | 3.908.363,21 € |
| 2026 | | | | 0,00 € |
| 2027 | | | | 0,00 € |
| 2028 | | | | 0,00 € |
| 2029 | | | | 0,00 € |
| 2030 | | | | 0,00 € |
| 2031 | | | | 0,00 € |
| 2032 | | | | 0,00 € |
| 2033 | | | | 0,00 € |
| 2034 | | | | 0,00 € |
| 2035 | 1.225.756,94 € | 117.000,00 € | | 1.342.756,94 € |
| 2036 | | | | 0,00 € |
| 2037 | | | | 0,00 € |
| 2038 | | | | 0,00 € |
| 2039 | | | | 0,00 € |
| 2040 | | | | 0,00 € |
| 2041 | | | | 0,00 € |
| 2042 | | | | 0,00 € |
| 2043 | | | | 0,00 € |
| 2044 | | | | 0,00 € |
| 2045 | 1.225.756,94 € | 117.000,00 € | | 1.342.756,94 € |
| 2046 | | | | 0,00 € |
| 2047 | | | | 0,00 € |
| 2048 | | | | 0,00 € |
| 2049 | | | | 0,00 € |
| 2050 | | | | 0,00 € |

**Table 14. Annex 8. Study 2. RORO Investment details**

| RORO - Study 2 (INVESTMENT) | | | |
|---|---|---|---|
| Year | BATTERY | OTHER | TOTAL |
| **2025** | 2.047.237,87 € | 1.393.125,34 € | 3.440.363,21 € |
| **2026** | | | 0,00 € |
| **2027** | | | 0,00 € |
| **2028** | | | 0,00 € |
| **2029** | | | 0,00 € |
| **2030** | | | 0,00 € |
| **2031** | | | 0,00 € |
| **2032** | | | 0,00 € |
| **2033** | | | 0,00 € |
| **2034** | | | 0,00 € |
| **2035** | 1.225.756,94 € | | 1.225.756,94 € |
| **2036** | | | 0,00 € |
| **2037** | | | 0,00 € |
| **2038** | | | 0,00 € |
| **2039** | | | 0,00 € |
| **2040** | | | 0,00 € |
| **2041** | | | 0,00 € |
| **2042** | | | 0,00 € |
| **2043** | | | 0,00 € |
| **2044** | | | 0,00 € |
| **2045** | 1.225.756,94 € | | 1.225.756,94 € |
| **2046** | | | 0,00 € |
| **2047** | | | 0,00 € |
| **2048** | | | 0,00 € |
| **2049** | | | 0,00 € |
| **2050** | | | 0,00 € |

**Table 15. Annex 9. Study 1. Ferry Investment details**

| FERRY - Study 1 (INVESTMENT) | | | | |
|---|---|---|---|---|
| Year | BATTERY | SHIPYARD | OTHER | TOTAL |
| 2025 | 3.539.240,27 € | 572.000,00 € | 3.217.491,16 € | 7.328.731,43 € |
| 2026 | | | | 0,00 € |
| 2027 | | | | 0,00 € |
| 2028 | | | | 0,00 € |
| 2029 | | | | 0,00 € |
| 2030 | | | | 0,00 € |
| 2031 | | | | 0,00 € |
| 2032 | | | | 0,00 € |
| 2033 | | | | 0,00 € |
| 2034 | | | | 0,00 € |
| 2035 | 2.119.073,89 € | 143.000,00 € | | 2.262.073,89 € |
| 2036 | | | | 0,00 € |
| 2037 | | | | 0,00 € |
| 2038 | | | | 0,00 € |
| 2039 | | | | 0,00 € |
| 2040 | | | | 0,00 € |
| 2041 | | | | 0,00 € |
| 2042 | | | | 0,00 € |
| 2043 | | | | 0,00 € |
| 2044 | | | | 0,00 € |
| 2045 | 2.119.073,89 € | 143.000,00 € | | 2.262.073,89 € |
| 2046 | | | | 0,00 € |
| 2047 | | | | 0,00 € |
| 2048 | | | | 0,00 € |
| 2049 | | | | 0,00 € |
| 2050 | | | | 0,00 € |

**Table 16 Annex 10. Study 2. Ferry Investment details**

| FERRY - Study 2 (INVESTMENT) | | | |
|---|---|---|---|
| Year | BATTERY | OTHER | TOTAL |
| **2025** | 3.539.240,27 € | 3.217.491,16 € | 6.756.731,43 € |
| **2026** | | | 0,00 € |
| **2027** | | | 0,00 € |
| **2028** | | | 0,00 € |
| **2029** | | | 0,00 € |
| **2030** | | | 0,00 € |
| **2031** | | | 0,00 € |
| **2032** | | | 0,00 € |
| **2033** | | | 0,00 € |
| **2034** | | | 0,00 € |
| **2035** | 2.119.073,89 € | | 2.119.073,89 € |
| **2036** | | | 0,00 € |
| **2037** | | | 0,00 € |
| **2038** | | | 0,00 € |
| **2039** | | | 0,00 € |
| **2040** | | | 0,00 € |
| **2041** | | | 0,00 € |
| **2042** | | | 0,00 € |
| **2043** | | | 0,00 € |
| **2044** | | | 0,00 € |
| **2045** | 2.119.073,89 € | | 2.119.073,89 € |
| **2046** | | | 0,00 € |
| **2047** | | | 0,00 € |
| **2048** | | | 0,00 € |
| **2049** | | | 0,00 € |
| **2050** | | | 0,00 € |

**Table 17. Annex 11. Study 3 Containership Investment details**

| CONTAINER - Study 3 (INVESTMENT) | | | | |
|---|---|---|---|---|
| Year | BATTERY | SHIPYARD | OTHER | TOTAL |
| 2025 | 194.950,59 € | 728.000,00 € | 1.994.762,27 € | 2.917.712,86 € |
| 2026 | | | | 0,00 € |
| 2027 | | | | 0,00 € |
| 2028 | | | | 0,00 € |
| 2029 | | | | 0,00 € |
| 2030 | | | | 0,00 € |
| 2031 | | | | 0,00 € |
| 2032 | | | | 0,00 € |
| 2033 | | | | 0,00 € |
| 2034 | | | | 0,00 € |
| 2035 | | | | 0,00 € |
| 2036 | | | | 0,00 € |
| 2037 | | | | 0,00 € |
| 2038 | | | | 0,00 € |
| 2039 | | | | 0,00 € |
| 2040 | | | | 0,00 € |
| 2041 | | | | 0,00 € |
| 2042 | | | | 0,00 € |
| 2043 | | | | 0,00 € |
| 2044 | | | | 0,00 € |
| 2045 | | | | 0,00 € |
| 2046 | | | | 0,00 € |
| 2047 | | | | 0,00 € |
| 2048 | | | | 0,00 € |
| 2049 | | | | 0,00 € |
| 2050 | | | | 0,00 € |

**Table 18. Annex 12. Study 4 Containership Investment details**

| FERRY HYBRID - Study 4 (INVESTMENT) | | | | | |
|---|---|---|---|---|---|
| Year | BATTERY SSSB | BATTERY SC | SHIPYARD | RESTO | TOTAL |
| 2025 | 3.539.240,27 € | 106.164,60 € | 572.000,00 € | 3.516.593,39 € | 7.733.998,26 € |
| 2026 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2027 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2028 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2029 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2030 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2031 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2032 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2033 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2034 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2035 | 2.119.073,89 € | | 143.000,00 € | 0,00 € | 2.262.073,89 € |
| 2036 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2037 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2038 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2039 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2040 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2041 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2042 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2043 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2044 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2045 | 2.119.073,89 € | | 143.000,00 € | 0,00 € | 2.262.073,89 € |
| 2046 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2047 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2048 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2049 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |
| 2050 | 0,00 € | | 0,00 € | 0,00 € | 0,00 € |

**Table 19. Annex 13 Study 1 RORO Financial assessment results**

| RORO Study 1 (retrofit - SSSB) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | CAPEX | OPEX AENEAS | OPEX TRAD | OPEX DIF | RESIDUAL VALUE | DIFFERENTIAL CASH FLOW | CUMULATIVE BALANCE |
| 2025 | 3.908.363,21 € | 13.114.915,70 € | 10.127.049,53 € | - 2.987.866,17 € | | -6.896.229,38 € | -6.896.229,38 |
| 2026 | 0,00 € | 10.883.504,76 € | 11.032.019,91 € | 148.515,15 € | | 148.515,15 € | -6.747.714,23 |
| 2027 | 0,00 € | 11.867.299,80 € | 12.033.951,41 € | 166.651,61 € | | 166.651,61 € | -6.581.062,62 |
| 2028 | 0,00 € | 11.962.505,77 € | 12.130.912,52 € | 168.406,75 € | | 168.406,75 € | -6.412.655,86 |
| 2029 | 0,00 € | 12.089.447,06 € | 12.260.194,00 € | 170.746,94 € | | 170.746,94 € | -6.241.908,92 |
| 2030 | 0,00 € | 16.561.354,03 € | 16.814.541,49 € | 253.187,46 € | | 253.187,46 € | -5.988.721,46 |
| 2031 | 0,00 € | 16.817.509,51 € | 17.075.419,24 € | 257.909,74 € | | 257.909,74 € | -5.730.811,72 |
| 2032 | 0,00 € | 17.091.026,32 € | 17.353.978,39 € | 262.952,08 € | | 262.952,08 € | -5.467.859,65 |
| 2033 | 0,00 € | 17.388.687,36 € | 17.657.126,88 € | 268.439,52 € | | 268.439,52 € | -5.199.420,13 |
| 2034 | 0,00 € | 17.675.156,63 € | 17.948.877,27 € | 273.720,64 € | | 273.720,64 € | -4.925.699,49 |
| 2035 | 1.342.756,94 € | 21.041.152,43 € | 20.582.546,42 € | -458.606,00 € | | -1.801.362,94 € | -6.727.062,43 |
| 2036 | 0,00 € | 20.589.127,26 € | 20.916.567,54 € | 327.440,28 € | | 327.440,28 € | -6.399.622,15 |
| 2037 | 0,00 € | 20.923.885,00 € | 21.257.496,61 € | 333.611,61 € | | 333.611,61 € | -6.066.010,55 |
| 2038 | 0,00 € | 21.264.747,34 € | 21.604.642,81 € | 339.895,47 € | | 339.895,47 € | -5.726.115,07 |
| 2039 | 0,00 € | 21.623.310,16 € | 21.969.815,82 € | 346.505,65 € | | 346.505,65 € | -5.379.609,42 |
| 2040 | 0,00 € | 26.431.940,34 € | 26.867.094,07 € | 435.153,73 € | | 435.153,73 € | -4.944.455,69 |
| 2041 | 0,00 € | 26.826.243,28 € | 27.268.666,06 € | 442.422,79 € | | 442.422,79 € | -4.502.032,90 |
| 2042 | 0,00 € | 27.228.346,54 € | 27.678.182,18 € | 449.835,64 € | | 449.835,64 € | -4.052.197,26 |
| 2043 | 0,00 € | 27.648.828,58 € | 28.106.415,89 € | 457.587,31 € | | 457.587,31 € | -3.594.609,95 |
| 2044 | 0,00 € | 28.088.367,68 € | 28.554.057,98 € | 465.690,31 € | | 465.690,31 € | -3.128.919,64 |
| 2045 | 1.342.756,94 € | 37.663.114,67 € | 37.510.937,93 € | -152.176,74 € | | -1.494.933,68 € | -4.623.853,32 |
| 2046 | 0,00 € | 37.361.446,18 € | 37.998.087,58 € | 636.641,40 € | | 636.641,40 € | -3.987.211,92 |
| 2047 | 0,00 € | 37.849.612,89 € | 38.495.253,75 € | 645.640,85 € | | 645.640,85 € | -3.341.571,07 |
| 2048 | 0,00 € | 38.357.854,10 € | 39.012.864,48 € | 655.010,38 € | | 655.010,38 € | -2.686.560,69 |
| 2049 | 0,00 € | 38.886.848,10 € | 39.551.610,59 € | 664.762,49 € | | 664.762,49 € | -2.021.798,20 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2050** | 0,00 € | 44.292.438,55 € | 45.056.854,20 € | 764.415,66 € | 671.378,47 € | 1.435.794,12 € | -586.004,07 |
| | | 628.122.547,12 € | 626.865.164,58 € | | | - 1.257.382,54 € | - 1.257.382,54 € |

| | |
|---|---|
| **VAN** | **-3.606.187,89 €** |
| **TIR** | **-0,49%** |
| **Payback** | **0** |

**Table 20. Annex 14 Study 1 Ferry Financial assessment results**

| Ferry Study 1 (retrofit - SSSB) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | CAPEX | OPEX AENEAS | OPEX TRAD | OPEX DIF | RESIDUAL VALUE | DIFFERENTIAL CASH FLOW | CUMULATIVE BALANCE |
| 2025 | 7.328.731,43 € | 21.057.879,44 € | 19.336.310,82 € | -1.721.568,62 € | | -9.050.300,05 € | -9.050.300,05 |
| 2026 | 0,00 € | 20.807.485,26 € | 21.064.236,47 € | 256.751,21 € | | 256.751,21 € | -8.793.548,84 |
| 2027 | 0,00 € | 22.689.191,70 € | 22.977.297,01 € | 288.105,31 € | | 288.105,31 € | -8.505.443,53 |
| 2028 | 0,00 € | 22.871.292,33 € | 23.162.431,90 € | 291.139,58 € | | 291.139,58 € | -8.214.303,95 |
| 2029 | 0,00 € | 23.114.093,16 € | 23.409.278,42 € | 295.185,27 € | | 295.185,27 € | -7.919.118,69 |
| 2030 | 0,00 € | 31.667.517,26 € | 32.105.224,70 € | 437.707,44 € | | 437.707,44 € | -7.481.411,24 |
| 2031 | 0,00 € | 32.157.466,27 € | 32.603.337,53 € | 445.871,26 € | | 445.871,26 € | -7.035.539,98 |
| 2032 | 0,00 € | 32.680.622,34 € | 33.135.210,73 € | 454.588,39 € | | 454.588,39 € | -6.580.951,59 |
| 2033 | 0,00 € | 33.249.959,13 € | 33.714.034,15 € | 464.075,02 € | | 464.075,02 € | -6.116.876,57 |
| 2034 | 0,00 € | 33.797.889,38 € | 34.271.094,34 € | 473.204,95 € | | 473.204,95 € | -5.643.671,62 |
| 2035 | 2.262.073,89 € | 39.231.627,96 € | 39.299.750,05 € | 68.122,09 € | | -2.193.951,80 € | -7.837.623,42 |
| 2036 | 0,00 € | 39.371.445,99 € | 39.937.520,82 € | 566.074,83 € | | 566.074,83 € | -7.271.548,59 |
| 2037 | 0,00 € | 40.011.737,68 € | 40.588.481,43 € | 576.743,74 € | | 576.743,74 € | -6.694.804,85 |
| 2038 | 0,00 € | 40.663.705,67 € | 41.251.312,88 € | 587.607,22 € | | 587.607,22 € | -6.107.197,63 |
| 2039 | 0,00 € | 41.349.529,39 € | 41.948.564,21 € | 599.034,82 € | | 599.034,82 € | -5.508.162,82 |
| 2040 | 0,00 € | 50.547.004,55 € | 51.299.293,09 € | 752.288,55 € | | 752.288,55 € | -4.755.874,27 |
| 2041 | 0,00 € | 51.301.188,44 € | 52.066.043,64 € | 764.855,20 € | | 764.855,20 € | -3.991.019,06 |
| 2042 | 0,00 € | 52.070.292,04 € | 52.847.962,50 € | 777.670,46 € | | 777.670,46 € | -3.213.348,60 |
| 2043 | 0,00 € | 52.874.548,75 € | 53.665.620,21 € | 791.071,46 € | | 791.071,46 € | -2.422.277,15 |
| 2044 | 0,00 € | 53.715.255,94 € | 54.520.335,75 € | 805.079,81 € | | 805.079,81 € | -1.617.197,33 |
| 2045 | 2.262.073,89 € | 71.024.483,52 € | 71.622.356,84 € | 597.873,32 € | | -1.664.200,57 € | -3.281.397,90 |
| 2046 | 0,00 € | 71.451.889,02 € | 72.552.507,04 € | 1.100.618,01 € | | 1.100.618,01 € | -2.180.779,89 |
| 2047 | 0,00 € | 72.385.606,33 € | 73.501.782,49 € | 1.116.176,16 € | | 1.116.176,16 € | -1.064.603,74 |
| 2048 | 0,00 € | 73.357.720,16 € | 74.490.094,24 € | 1.132.374,09 € | | 1.132.374,09 € | 67.770,35 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2049** | 0,00 € | 74.369.527,87 € | 75.518.761,30 € | 1.149.233,42 € | | 1.149.233,42 € | 1.217.003,78 |
| **2050** | 0,00 € | 84.708.809,95 € | 86.030.322,57 € | 1.321.512,61 € | 1.131.036,94 € | 2.452.549,56 € | 3.669.553,34 |
| | | **1.194.380.648,74 €** | **1.196.919.165,13 €** | | | **2.538.516,39 €** | **2.538.516,39 €** |

| | |
|---|---|
| **VAN** | -2.331.984,77 € |
| **TIR** | 2,04% |
| **Payback** | 2048 |

**Table 21. Annex 15 Study 2 RORO Financial assessment results**

| Ro-Ro Study 2 (newbuild - SSSB) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **CAPEX** | **OPEX AENEAS** | **OPEX TRAD** | **OPEX DIF** | **RESIDUAL VALUE** | **DIFFERENTIAL CASH FLOW** | **CUMULATIVE BALANCE** |
| **2025** | 3.092.081,88 € | 9.994.915,70 € | 10.127.049,53 € | 132.133,83 € | | -2.959.948,05 € | -2.959.948,05 € |
| **2026** | | 10.883.504,76 € | 11.032.019,91 € | 148.515,15 € | | 148.515,15 € | -2.811.432,90 € |
| **2027** | | 11.867.299,80 € | 12.033.951,41 € | 166.651,61 € | | 166.651,61 € | -2.644.781,28 € |
| **2028** | | 11.962.505,77 € | 12.130.912,52 € | 168.406,75 € | | 168.406,75 € | -2.476.374,53 € |
| **2029** | | 12.089.447,06 € | 12.260.194,00 € | 170.746,94 € | | 170.746,94 € | -2.305.627,59 € |
| **2030** | | 16.561.354,03 € | 16.814.541,49 € | 253.187,46 € | | 253.187,46 € | -2.052.440,13 € |
| **2031** | | 16.817.509,51 € | 17.075.419,24 € | 257.909,74 € | | 257.909,74 € | -1.794.530,39 € |
| **2032** | | 17.091.026,32 € | 17.353.978,39 € | 262.952,08 € | | 262.952,08 € | -1.531.578,31 € |
| **2033** | | 17.388.687,36 € | 17.657.126,88 € | 268.439,52 € | | 268.439,52 € | -1.263.138,79 € |
| **2034** | | 17.675.156,63 € | 17.948.877,27 € | 273.720,64 € | | 273.720,64 € | -989.418,16 € |
| **2035** | 1.342.756,94 € | 20.261.152,43 € | 20.582.546,42 € | 321.394,00 € | | -1.021.362,94 € | -2.010.781,10 € |
| **2036** | | 20.589.127,26 € | 20.916.567,54 € | 327.440,28 € | | 327.440,28 € | -1.683.340,82 € |
| **2037** | | 20.923.885,00 € | 21.257.496,61 € | 333.611,61 € | | 333.611,61 € | -1.349.729,21 € |
| **2038** | | 21.264.747,34 € | 21.604.642,81 € | 339.895,47 € | | 339.895,47 € | -1.009.833,74 € |
| **2039** | | 21.623.310,16 € | 21.969.815,82 € | 346.505,65 € | | 346.505,65 € | -663.328,08 € |
| **2040** | | 26.431.940,34 € | 26.867.094,07 € | 435.153,73 € | | 435.153,73 € | -228.174,35 € |
| **2041** | | 26.826.243,28 € | 27.268.666,06 € | 442.422,79 € | | 442.422,79 € | 214.248,43 € |
| **2042** | | 27.228.346,54 € | 27.678.182,18 € | 449.835,64 € | | 449.835,64 € | 664.084,07 € |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2043** | | 27.648.828,58 € | 28.106.415,89 € | 457.587,31 € | | 457.587,31 € | 1.121.671,39 € |
| **2044** | | 28.088.367,68 € | 28.554.057,98 € | 465.690,31 € | | 465.690,31 € | 1.587.361,69 € |
| **2045** | 1.342.756,94 € | 36.883.114,67 € | 37.510.937,93 € | 627.823,26 € | | -714.933,68 € | 872.428,01 € |
| **2046** | | 37.361.446,18 € | 37.998.087,58 € | 636.641,40 € | | 636.641,40 € | 1.509.069,41 € |
| **2047** | | 37.849.612,89 € | 38.495.253,75 € | 645.640,85 € | | 645.640,85 € | 2.154.710,26 € |
| **2048** | | 38.357.854,10 € | 39.012.864,48 € | 655.010,38 € | | 655.010,38 € | 2.809.720,64 € |
| **2049** | | 38.886.848,10 € | 39.551.610,59 € | 664.762,49 € | | 664.762,49 € | 3.474.483,14 € |
| **2050** | | 44.292.438,55 € | 45.056.854,20 € | 764.415,66 € | 612.878,47 € | 1.377.294,12 € | 4.851.777,26 € |
| | | **622.626.265,79 €** | **626.865.164,58 €** | | | **4.238.898,79 €** | **4.238.898,79 €** |

| | |
|---|---|
| **VAN** | 4.851.777,26 € |
| **TIR** | 6,51% |
| **Payback** | 2041 |

**Table 22. Annex 16 Study 2 Ferry Financial assessment results**

| Ferry Study 2 (newbuild - SSSB) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | CAPEX | OPEX AENEAS | OPEX TRAD | OPEX DIF | RESIDUAL VALUE | DIFFERENTIAL CASH FLOW | CUMULATIVE BALANCE |
| **2025** | 5.952.358,64 € | 19.107.879,44 € | 19.336.310,82 € | 228.431,38 € | | -5.723.927,26 € | -5.723.927,26 € |
| **2026** | | 20.807.485,26 € | 21.064.236,47 € | 256.751,21 € | | 256.751,21 € | -5.467.176,05 € |
| **2027** | | 22.689.191,70 € | 22.977.297,01 € | 288.105,31 € | | 288.105,31 € | -5.179.070,74 € |
| **2028** | | 22.871.292,33 € | 23.162.431,90 € | 291.139,58 € | | 291.139,58 € | -4.887.931,16 € |
| **2029** | | 23.114.093,16 € | 23.409.278,42 € | 295.185,27 € | | 295.185,27 € | -4.592.745,90 € |
| **2030** | | 31.667.517,26 € | 32.105.224,70 € | 437.707,44 € | | 437.707,44 € | -4.155.038,46 € |
| **2031** | | 32.157.466,27 € | 32.603.337,53 € | 445.871,26 € | | 445.871,26 € | -3.709.167,19 € |
| **2032** | | 32.680.622,34 € | 33.135.210,73 € | 454.588,39 € | | 454.588,39 € | -3.254.578,80 € |
| **2033** | | 33.249.959,13 € | 33.714.034,15 € | 464.075,02 € | | 464.075,02 € | -2.790.503,78 € |
| **2034** | | 33.797.889,38 € | 34.271.094,34 € | 473.204,95 € | | 473.204,95 € | -2.317.298,83 € |
| **2035** | 2.262.073,89 € | 38.744.127,96 € | 39.299.750,05 € | 555.622,09 € | | -1.706.451,80 € | -4.023.750,63 € |
| **2036** | | 39.371.445,99 € | 39.937.520,82 € | 566.074,83 € | | 566.074,83 € | -3.457.675,80 € |
| **2037** | | 40.011.737,68 € | 40.588.481,43 € | 576.743,74 € | | 576.743,74 € | -2.880.932,06 € |
| **2038** | | 40.663.705,67 € | 41.251.312,88 € | 587.607,22 € | | 587.607,22 € | -2.293.324,84 € |
| **2039** | | 41.349.529,39 € | 41.948.564,21 € | 599.034,82 € | | 599.034,82 € | -1.694.290,03 € |
| **2040** | | 50.547.004,55 € | 51.299.293,09 € | 752.288,55 € | | 752.288,55 € | -942.001,48 € |
| **2041** | | 51.301.188,44 € | 52.066.043,64 € | 764.855,20 € | | 764.855,20 € | -177.146,27 € |
| **2042** | | 52.070.292,04 € | 52.847.962,50 € | 777.670,46 € | | 777.670,46 € | 600.524,18 € |
| **2043** | | 52.874.548,75 € | 53.665.620,21 € | 791.071,46 € | | 791.071,46 € | 1.391.595,64 € |
| **2044** | | 53.715.255,94 € | 54.520.335,75 € | 805.079,81 € | | 805.079,81 € | 2.196.675,45 € |
| **2045** | 2.262.073,89 € | 70.536.983,52 € | 71.622.356,84 € | 1.085.373,32 € | | -1.176.700,57 € | 1.019.974,89 € |
| **2046** | | 71.451.889,02 € | 72.552.507,04 € | 1.100.618,01 € | | 1.100.618,01 € | 2.120.592,90 € |
| **2047** | | 72.385.606,33 € | 73.501.782,49 € | 1.116.176,16 € | | 1.116.176,16 € | 3.236.769,05 € |
| **2048** | | 73.357.720,16 € | 74.490.094,24 € | 1.132.374,09 € | | 1.132.374,09 € | 4.369.143,14 € |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2049** | 74.369.527,87 € | 75.518.761,30 € | 1.149.233,42 € | | 1.149.233,42 € | 5.518.376,57 € |
| **2050** | 84.708.809,95 € | 86.030.322,57 € | 1.321.512,61 € | 1.059.536,94 € | 2.381.049,56 € | 7.899.426,12 € |
| **TCO** | **1.190.079.275,95 €** | **1.196.919.165,13 €** | | | | **6.839.889,18 €** |

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|---|---|
| **VAN** | 7.899.426,12 € |
| **TIR** | 5,71% |
| **Payback** | 2042 |

**Table 23. Annex 17 Study 3 Containership Financial assessment results**

| CONTAINER - Study 3 (retrofit - SC) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **CAPEX** | **OPEX AENEAS** | **OPEX TRAD** | **OPEX DIF** | **RESIDUAL VALUE** | **DIFFERENTIAL CASH FLOW** | **CUMULATIVE BALANCE** |
| **2025** | 2.917.712,86 € | 49.306.750,55 € | 47.104.691,58 € | -2.202.058,96 € | | -5.119.771,82 € | -5.119.771,82 € |
| **2026** | 0,00 € | 51.097.988,06 € | 51.314.047,00 € | 216.058,94 € | | 216.058,94 € | -4.903.712,88 € |
| **2027** | 0,00 € | 55.738.543,05 € | 55.974.404,78 € | 235.861,74 € | | 235.861,74 € | -4.667.851,15 € |
| **2028** | 0,00 € | 56.187.629,01 € | 56.425.407,15 € | 237.778,14 € | | 237.778,14 € | -4.430.073,01 € |
| **2029** | 0,00 € | 56.786.410,30 € | 57.026.743,64 € | 240.333,34 € | | 240.333,34 € | -4.189.739,67 € |
| **2030** | 0,00 € | 77.880.367,33 € | 78.210.715,65 € | 330.348,31 € | | 330.348,31 € | -3.859.391,36 € |
| **2031** | 0,00 € | 79.088.651,09 € | 79.424.155,55 € | 335.504,46 € | | 335.504,46 € | -3.523.886,90 € |
| **2032** | 0,00 € | 80.378.828,17 € | 80.719.838,25 € | 341.010,08 € | | 341.010,08 € | -3.182.876,82 € |
| **2033** | 0,00 € | 81.782.893,44 € | 82.129.895,14 € | 347.001,70 € | | 347.001,70 € | -2.835.875,12 € |
| **2034** | 0,00 € | 83.134.167,17 € | 83.486.935,20 € | 352.768,03 € | | 352.768,03 € | -2.483.107,09 € |
| **2035** | 0,00 € | 95.332.293,07 € | 95.737.114,59 € | 404.821,52 € | | 404.821,52 € | -2.078.285,56 € |
| **2036** | 0,00 € | 96.879.348,32 € | 97.290.771,64 € | 411.423,32 € | | 411.423,32 € | -1.666.862,24 € |
| **2037** | 0,00 € | 98.458.398,44 € | 98.876.560,10 € | 418.161,66 € | | 418.161,66 € | -1.248.700,58 € |
| **2038** | 0,00 € | 100.066.243,96 € | 100.491.266,84 € | 425.022,87 € | | 425.022,87 € | -823.677,71 € |
| **2039** | 0,00 € | 101.757.582,55 € | 102.189.822,93 € | 432.240,38 € | | 432.240,38 € | -391.437,33 € |
| **2040** | 0,00 € | 124.439.860,84 € | 124.968.894,09 € | 529.033,26 € | | 529.033,26 € | 137.595,93 € |
| **2041** | 0,00 € | 126.299.785,29 € | 126.836.755,47 € | 536.970,18 € | | 536.970,18 € | 674.566,10 € |
| **2042** | 0,00 € | 128.196.503,86 € | 128.741.567,97 € | 545.064,11 € | | 545.064,11 € | 1.219.630,21 € |
| **2043** | 0,00 € | 130.179.914,99 € | 130.733.442,97 € | 553.527,99 € | | 553.527,99 € | 1.773.158,20 € |
| **2044** | 0,00 € | 132.253.218,15 € | 132.815.593,61 € | 562.375,47 € | | 562.375,47 € | 2.335.533,67 € |
| **2045** | 0,00 € | 173.737.984,35 € | 174.477.389,20 € | 739.404,85 € | | 739.404,85 € | 3.074.938,52 € |
| **2046** | 0,00 € | 175.994.271,08 € | 176.743.304,26 € | 749.033,18 € | | 749.033,18 € | 3.823.971,70 € |
| **2047** | 0,00 € | 178.296.950,39 € | 179.055.809,87 € | 758.859,48 € | | 758.859,48 € | 4.582.831,18 € |
| **2048** | 0,00 € | 180.694.320,97 € | 181.463.410,84 € | 769.089,87 € | | 769.089,87 € | 5.351.921,05 € |

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|---|---|---|---|---|---|---|---|
| **2049** | 0,00 € | 183.189.582,32 € | 183.969.320,30 € | 779.737,98 € | | 779.737,98 € | 6.131.659,03 € |
| **2050** | 0,00 € | 208.687.718,43 € | 209.576.265,50 € | 888.547,06 € | | 888.547,06 € | 7.020.206,09 € |
| | | **2.908.763.918,02 €** | **2.915.784.124,11 €** | | | **2.908.763.918,02 €** | **7.020.206,09 €** |

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|---|---|
| **VAN** | 1.663.200,90 € |
| **TIR** | 6% |
| **Payback** | 2040 |

**Table 24. Annex 18 Study 4 Hybrid ESS Ferry Financial assessment results**

| Ferry - Study 4 (retrofit - hybrid) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | CAPEX | OPEX AENEAS | OPEX TRAD | OPEX DIF | RESIDUAL VALUE | DIFFERENTIAL CASH FLOW | CUMULATIVE BALANCE |
| 2025 | 7.733.998,26 € | 20.940.664,78 € | 19.336.310,82 € | -1.604.353,96 € | | -9.338.352,22 € | -9.338.352,22 € |
| 2026 | 0,00 € | 20.679.777,13 € | 21.064.236,47 € | 384.459,35 € | | 384.459,35 € | -8.953.892,87 € |
| 2027 | 0,00 € | 22.573.359,76 € | 22.977.297,01 € | 403.937,25 € | | 403.937,25 € | -8.549.955,62 € |
| 2028 | 0,00 € | 22.800.833,34 € | 23.162.431,90 € | 361.598,56 € | | 361.598,56 € | -8.188.357,06 € |
| 2029 | 0,00 € | 23.008.979,79 € | 23.409.278,42 € | 400.298,63 € | | 400.298,63 € | -7.788.058,42 € |
| 2030 | 0,00 € | 31.513.284,56 € | 32.105.224,70 € | 591.940,13 € | | 591.940,13 € | -7.196.118,29 € |
| 2031 | 0,00 € | 31.882.522,02 € | 32.603.337,53 € | 720.815,51 € | | 720.815,51 € | -6.475.302,78 € |
| 2032 | 0,00 € | 32.587.374,31 € | 33.135.210,73 € | 547.836,42 € | | 547.836,42 € | -5.927.466,36 € |
| 2033 | 0,00 € | 33.154.377,43 € | 33.714.034,15 € | 559.656,71 € | | 559.656,71 € | -5.367.809,65 € |
| 2034 | 0,00 € | 33.728.606,69 € | 34.271.094,34 € | 542.487,64 € | | 542.487,64 € | -4.825.322,00 € |
| 2035 | 2.262.073,89 € | 38.679.129,41 € | 39.299.750,05 € | 620.620,64 € | | -1.641.453,25 € | -6.466.775,25 € |
| 2036 | 0,00 € | 39.307.958,58 € | 39.937.520,82 € | 629.562,24 € | | 629.562,24 € | -5.837.213,01 € |
| 2037 | 0,00 € | 39.881.447,31 € | 40.588.481,43 € | 707.034,12 € | | 707.034,12 € | -5.130.178,89 € |
| 2038 | 0,00 € | 40.391.058,98 € | 41.251.312,88 € | 860.253,90 € | | 860.253,90 € | -4.269.924,99 € |
| 2039 | 0,00 € | 41.226.855,70 € | 41.948.564,21 € | 721.708,51 € | | 721.708,51 € | -3.548.216,48 € |
| 2040 | 0,00 € | 50.094.660,25 € | 51.299.293,09 € | 1.204.632,85 € | | 1.204.632,85 € | -2.343.583,63 € |
| 2041 | 0,00 € | 50.590.355,89 € | 52.066.043,64 € | 1.475.687,76 € | | 1.475.687,76 € | -867.895,88 € |
| 2042 | 0,00 € | 51.853.920,11 € | 52.847.962,50 € | 994.042,39 € | | 994.042,39 € | 126.146,51 € |
| 2043 | 0,00 € | 52.681.219,03 € | 53.665.620,21 € | 984.401,18 € | | 984.401,18 € | 1.110.547,70 € |
| 2044 | 0,00 € | 53.496.125,58 € | 54.520.335,75 € | 1.024.210,17 € | | 1.024.210,17 € | 2.134.757,87 € |
| 2045 | 2.262.073,89 € | 70.374.074,12 € | 71.622.356,84 € | 1.248.282,72 € | | -1.013.791,16 € | 1.120.966,70 € |
| 2046 | 0,00 € | 70.988.647,32 € | 72.552.507,04 € | 1.563.859,71 € | | 1.563.859,71 € | 2.684.826,41 € |
| 2047 | 0,00 € | 72.288.062,45 € | 73.501.782,49 € | 1.213.720,04 € | | 1.213.720,04 € | 3.898.546,45 € |
| 2048 | 0,00 € | 72.961.540,60 € | 74.490.094,24 € | 1.528.553,64 € | | 1.528.553,64 € | 5.427.100,09 € |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2049** | 0,00 € | 74.217.316,20 € | 75.518.761,30 € | 1.301.445,10 € | | 1.301.445,10 € | 6.728.545,19 € |
| **2050** | 0,00 € | 84.473.246,67 € | 86.030.322,57 € | 1.557.075,89 € | 1.131.036,94 € | 2.688.112,84 € | 9.416.658,03 € |
| | | **1.188.633.544,04 €** | **1.196.919.165,13 €** | | | **1.188.633.544,04 €** | **8.285.621,09 €** |

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|---|---|
| **VAN** | 817.213,55 € |
| **TIR** | 5% |
| **Payback** | 2042 |

**Table 25. Annex 19 Summary of AENEAS ESS**

| Technology | Key Characteristics | Operational Parameters / Ideal Conditions | Main Advantages | Limitations | Most Suitable Applications |
|---|---|---|---|---|---|
| **SSSB (Semi-Solid-State Batteries)** | High energy density; moderate power output; long-duration discharge capability; improved safety compared to conventional Li-ion | Long-duration, predictable energy demand; low to moderate power peaks; one full discharge per port call; charged during navigation | Enables zero-emission port-stay; significant fuel and $CO_2$ reduction; suitable for regular routes; stable operation | Limited peak power capability; volume and weight constraints; high CAPEX; limited cycle life (~4,000 cycles) | Port-stay electrification on ferries, Ro-Ro, Ro-Pax; auxiliary loads on medium vessels; selected containerships (auxiliary use) |
| **SC (Supercapacitors)** | Very high-power density; very low energy density; extremely high cycle life (~1,000,000 cycles); fast charge/discharge | Short-duration, high-power demand; frequent load fluctuations; continuous charge/discharge during manoeuvring | Effective peak shaving; reduced engine load variability; extended engine lifetime; no degradation concerns | Not suitable for energy-intensive or long-duration phases; very high €/MWh cost; negligible standalone energy storage | Manoeuvring support; peak shaving on large ferries, cruise ships, containerships; dynamic positioning support |
| **Hybrid (SSSB + SC)** | Combination of high energy density (SSSB) and high-power density (SC); integrated power management | Vessels with both high cumulative energy demand and significant power peaks; phase-specific or concurrent operation | Maximises fuel and emission savings; protects battery from high C-rates; increased system efficiency and lifetime | Higher system complexity; higher integration cost; requires advanced energy management | Ferries and Ro-Pax with intensive cycles; vessels combining port-stay electrification and manoeuvring optimisation; advanced hybrid retrofits |