project eWAVE

Efficient HV-electric modular battery and distribution systems for sustainable WAterborne VEssels

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PROJECT ABSTRACT

The maritime sector faces challenges in transitioning to sustainable, all-electric vessels. Key obstacles include low energy density in current battery systems, safety concerns, and the need for durable, sustainable materials. Economic viability also remains a significant barrier for widespread adoption. To address these issues, the EU-funded eWAVE project brings together 18 experts from research, technology, and shipbuilding to advance high-voltage (HV) technology for electric vessels. By developing high-energy-density batteries, scalable modular systems, and an integrated safety concept, eWAVE aims to enhance the sustainability, safety, and efficiency of maritime transport. The project will also explore circularity through bio-based materials and recycling, supporting the EU’s goal of reducing the environmental footprint of shipping.

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Public Summary

Large battery systems have been installed as a primary energy onboard of ships since the early 2000s, and the maritime battery market has been analysed in previous (European) research projects. As part of WP2 in eWAVE, an update of these market analyses has been made, including an overview of market trends, a forecast for the years 2028 and 2033, an overview of regulations concerning decarbonisation and circular batteries, and a stakeholder overview. Based on experiences gained in previous projects, the ship register of the Maritime Battery Forum (MBF) was used as the primary source of information for the market analysis, as it is the most comprehensive one on maritime batteries and their implementations. This was supplemented by other market studies to make forecasts and comparisons with other battery markets.

The maritime battery market can be characterized by its diversity and a relatively low number of installations, although the battery systems installed per ship are large. Diversity is present in many aspects, including variations in ship types, ship sizes and battery applications. Next to fully or partially electric sailing, batteries are mostly used in hybrid configurations, where they support other on-board power sources. Ferries, offshore vessel and cargo ships are still the main ship categories using battery systems. However, the tugboat segment has seen significant growth in annual installed energy capacity over the last years. More than 60% of battery-equipped ships operate in the European region, with Norway alone accounting for about 30%. Other noteworthy markets are North America and Asia. Ships suited for battery operation generally have a limited operational range, power demand and operation close to the shore (inland, harbour and coastal). Only a few deep-sea ships are currently equipped with batteries, all in a hybrid configuration.

Due to the diversity of applications and demands a large range of battery types are used, from high-power LTO up to higher-energy NMC and LFP. Where NMC is still the dominant chemistry, the share of LFP has been increased in the past years. Compared to other sectors, maritime battery prices are still very high. As of 2024, the average price is about €550/kWh (and due to the diversity of battery chemistries, there is a wide range of prices). In contrast, battery prices for the EV market average around €110/kWh. Most maritime battery systems are produced by specialized manufacturers who mainly purchase their cells from Asia. Only one European battery manufacturer produces its own cells.

Besides market needs and figures, D2.1 also covers important regulations. It includes an update on decarbonization regulations, which are enablers for battery applications. For realizing the IMO and EU targets for GHG emission reduction targets, regulations are made, some are already in force, others expected soon. For now, most of these regulations apply to larger ship types, where batteries are typically not yet in use.

An upcoming important regulatory development, the EU Battery Passport, is also addressed alongside the analysis of a 9R framework to support the transition to a circular economy for batteries. Requirements for monitoring the state of batteries throughout their life cycles and related indicators such State-of-Health (SoH) and State of Safety (SoS) are analysed.

The report finalizes with a comprehensive stakeholder analysis. On top of the initial list of stakeholder groups identified in the eWAVE proposal two more groups have been recognized: port electric power suppliers and stakeholders supporting alternative powertrain technologies. The eWAVE stakeholder/target groups have been mapped to key exploitable results (KERs) and innovations by using the PESTLE method. Furthermore, the stakeholders have been mapped to the eWAVE consortium partners. The remaining unmapped stakeholders are listed and shall be addressed further in the project.

1 Introduction

Ships equipped with large battery systems as their primary source of energy have been around for over fifteen years. Previous European research projects [1], [2] have performed market studies, which include market numbers for many aspects and forecasts for future market expectations. However, these studies were carried out a few years ago and are now somewhat outdated. In order to develop high-voltage modular battery systems ready for the circular economy, an update of market needs and regulations has been made for the eWAVE project. The market analysis is the first non-organizational work to be carried out in eWAVE and is performed as part of WP2 - Market needs & regulations, Requirements, and Monitoring. WP2 will determine, set and monitor the information base for the developments in the eWAVE project. The market and regulations analysis is performed in the first WP task (T2.1) and will be used as input for the requirements in the next task of WP2 (task 2.2). The results of this analysis are reported in this deliverable.

The following objectives form the basis for the market and regulations analysis:

- market analysis of current applications, ship types and the global market size;
- market forecast for 2028 and 2033;
- create an overview of regulatory constraints related to the full life cycle;
- create a list of key stakeholder/target groups by analysing all stakeholders.

Applications of batteries on board ships is not limited to fully electric sailing; they are also used for many other purposes. First, the market overview provides a concise explanation of all battery applications. Next, an extensive overview of the current maritime battery market is presented using a large number of graphs and tables. This includes, among other things, battery market developments over time in terms of number of ships and installed energy capacity (kWh's), the most relevant ship categories, and battery manufacturers. A forecast of the future market has been made, focusing on 2028 and 2033, five and ten years after the eWAVE proposal was started. Both the market analysis and the market forecast are included in Chapter 2.

Figure 1. EU battery passport enabling circular battery economy (thebatterypass.eu).

The market analysis is not limited to the numbers relating to batteries used on ships; a stakeholder analysis has also been performed to create an overview of all relevant groups related to battery applications onboard ships. This includes not only the design, production, integration and operation of batteries themselves, but also a stakeholder analysis referring to policy makers, energy suppliers, second-life reuse and recycling. The method used, the results and an analysis are included in Chapter 4.

Decarbonization regulations are one of the key drivers for the market of battery powered ships. Due to the importance of this issue, an overview of regulations concerning decarbonization is included in Chapter 0. Also, a concise overview of the ship battery regulations is part of this chapter. Another important aspect of battery regulations relates to the ambition of, amongst others, the European Commission to create a circular economy for batteries. This involves producing batteries based on recycled materials and, after their initial use (first life application), using them for a second life or recycling them to close the circle/loop (see Figure 1). Chapter 0 also provides an overview of the relevant regulations, the EU Battery Passport, and the necessary battery status monitoring. The final Chapter 5 includes conclusions derived from the market and regulations analysis.

Attainment of the objectives and explanation of deviations

The objectives of this deliverable are achieved without any deviations.

2 Global market analysis

To determine the market and its applications for the eWAVE high-voltage modular battery solution, a market analysis was performed. It starts with an analysis of current applications and ship types, as well as the global market size for primary battery systems on board ships (as well as related distribution networks), and it concludes with a market forecast for 2028 and 2033.

2.1 Maritime battery applications

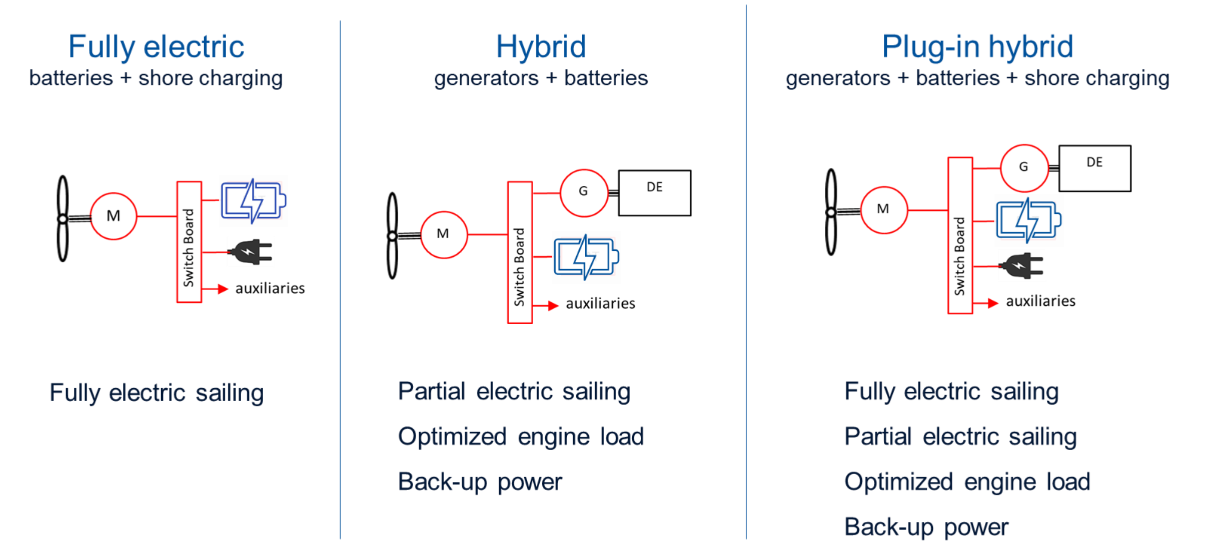


Figure 2. Basic topologies and their possible applications for batteries used for primary energy storage on board ships.

Generally large battery systems onboard of ships can be divided in two main categories: Firstly, batteries are used as the sole source of power for fully or partial electric sailing. Secondly, they can support other primary power sources like combustion engines for optimization, stabilization or backup power. As shown in Figure 2, batteries are applied in different topologies that are similar to automotive battery applications. The applications are explained in detail in [3] and [4]; here, only a summary is given.

2.1.1 Fully and partial electric sailing

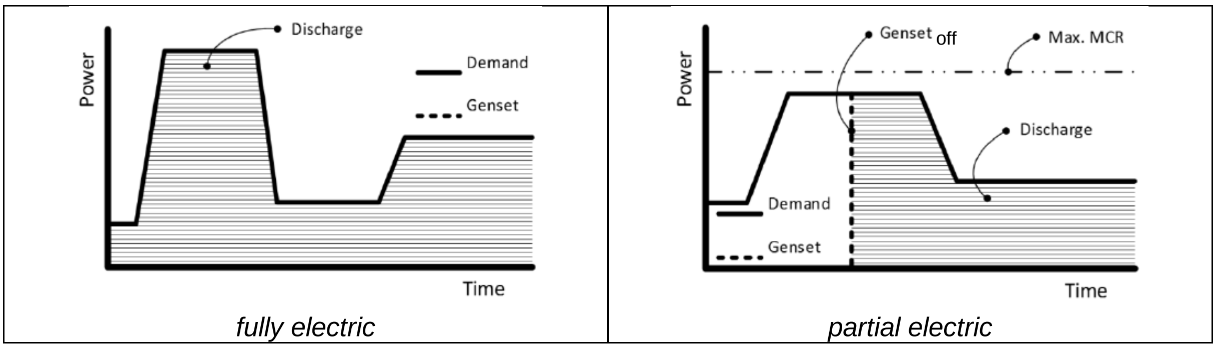


Figure 3. Ship operating partially or fully on batteries.

For sailing partially or fully on batteries, the energy is mostly obtained from onshore sources, where the batteries are charged using a high-power onshore power supply. Consequently, this kind of operation requires a fully electric or plug-in hybrid configuration. For partial electric sailing, however, the batteries can be charged by other onboard power generation. This can be beneficial for ship operation in areas with emission limitations or for silent operation - for example for a super yacht.

2.1.2 Hybrid battery applications

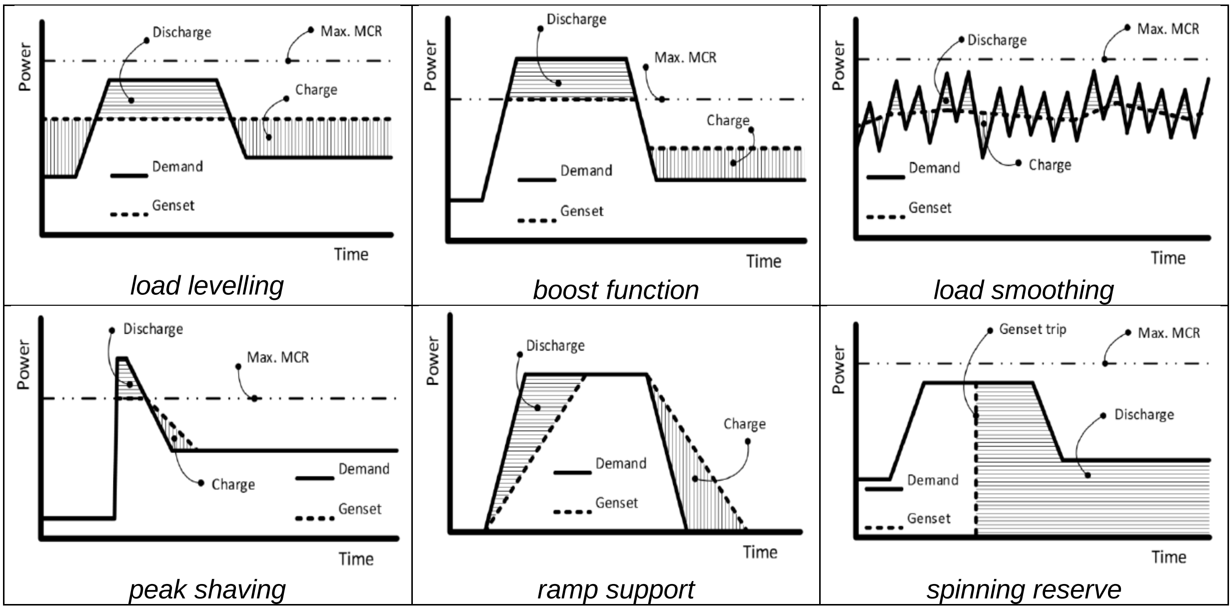


Figure 4. Overview battery applications for support.

- **Load levelling** is a battery application that keeps the load on the diesel engine or generator stable at a stable level by discharging the batteries when demand exceeds the set load, and charging them when the demand is lower than the set load. This application makes the diesel engine or generator run more efficiently and reduces the required maintenance, which can be increased by large load fluctuations.
- **Boost** function is somewhat similar to load levelling, but is used with a more fluctuating engine load. The batteries increase ('boost') the performance of the propulsion system by providing additional power to cover peaks in demand. The batteries are then charged again when demand is below a certain level.
- **Load smoothing** is comparable to load levelling. However, this application involves much higher load fluctuations.
- **Peak shaving** uses the battery to take care of sudden peaks and fluctuations in power demand. This reduces the peaks in load demand on the diesel engine or generator, reducing the required maintenance. It can also be used as a bridging function to avoid the start of an additional generator.
- **Ramp support** uses the battery system to increase the response time of the power system. Compared to combustion engines or fuel cells, batteries can almost instantaneously deliver power.
- **Spinning reserve** function acts as a large UPS, specifically on offshore vessels where high-power availability is required (see par. 2.2.5.2).

2.2 Global market of battery ships

Based on the experiences from previous European research projects (in particular, SEABAT, HYPOBATT and FLEXSHIP) the Maritime Battery Forum battery ship register database [5] is currently the most complete register for battery-powered ships. All other, more general ship databases are limited in their registration of battery information and mostly focus on larger sea going cargo vessel, with numbers presented in ship weights. Although by far most ships are cargo vessels, batteries are mainly applied on other ship types that are much smaller. This makes battery-powered ships marginal in matter of weight. The MBF register has its gaps and is incomplete as well, especially with regard to the Chinese market. However, for this analysis, the MBF ship register is the most useful source of information to perform a comprehensive market analysis. Hence the market study in this report is mainly based on this database.

2.2.1 Total numbers

First ships equipped with battery systems entered service around the end of the previous millennium. For the first decade the numbers were low, with only about 6 ships in service in 2010. As shown in Figure 5 and Figure 6, a more significant increase can be noticed between 2010 and around 2018. Since then, an acceleration can been observed. The total number of ships reported is 1506, of which 1045 are already in service and 461 are still under construction.

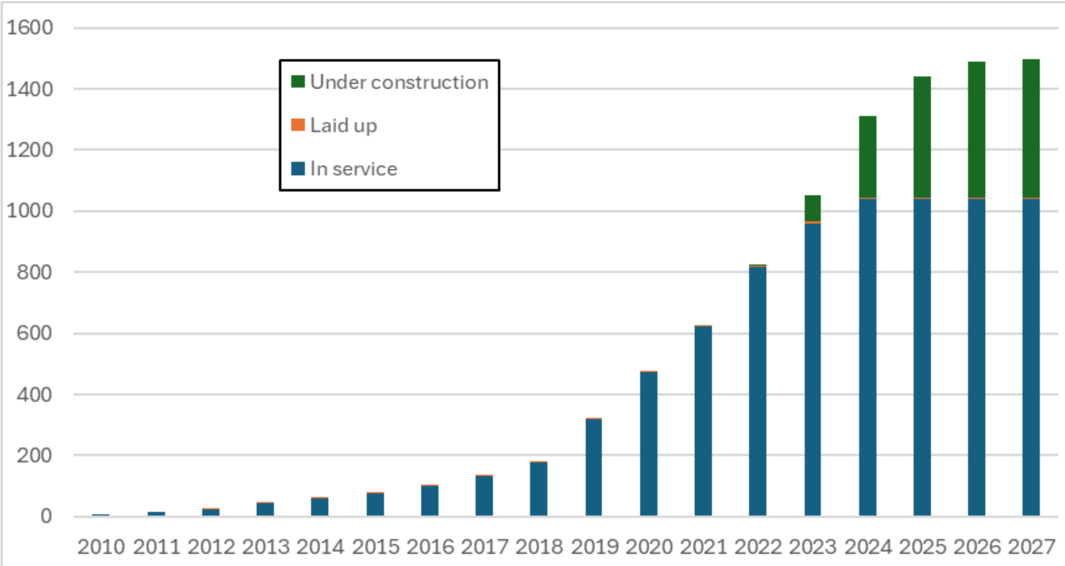


Figure 5. Increase of ships equipped with battery systems, both ships in service and under construction. [5]

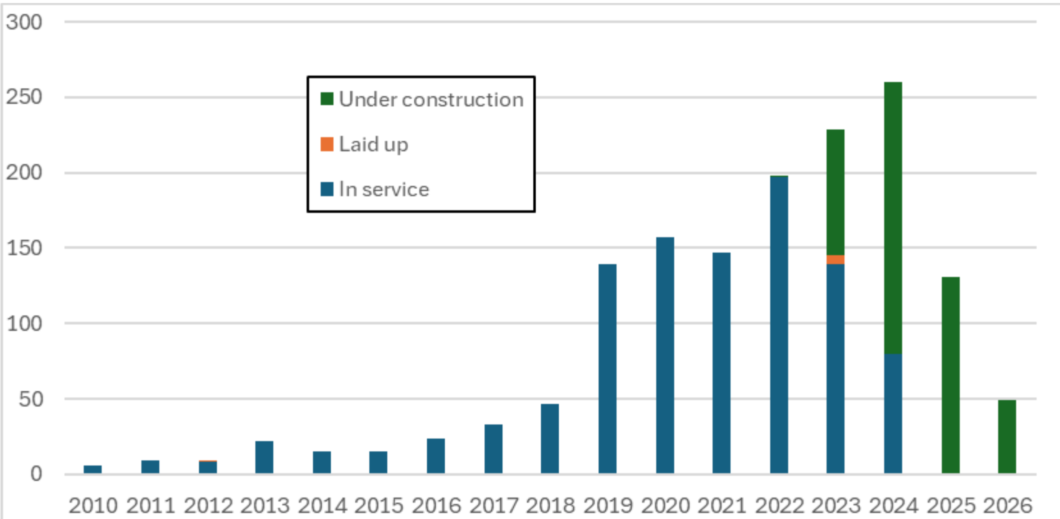


Figure 6. Number of battery ships that enter service per year. [5]

Last year (2024), about 260 battery-powered ships entered service (see Figure 6). Compared with the approximate number of ships entering service globally, which varies depending on the source from 1700 (*Sea Europe* [6]) to 3200 [7], the market share of battery ship has increased significantly.

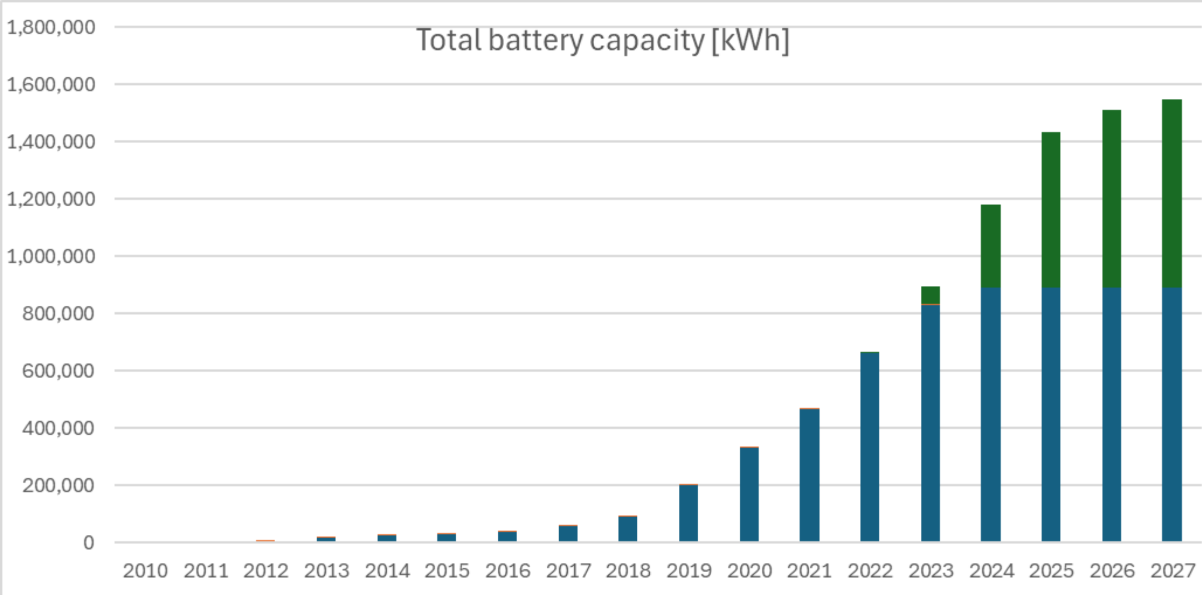


Figure 7. Total battery capacity for all ships reported to be in service per year. [5]

As shown in Figure 8 the average installed battery capacity per ship has been increasing as well. It is now above 1MWh, while 10 years ago it was still below 500kWh. Combined with the growth in the number of ships, implies that the growth in battery system capacity shows an even clearer acceleration (see Figure 7).

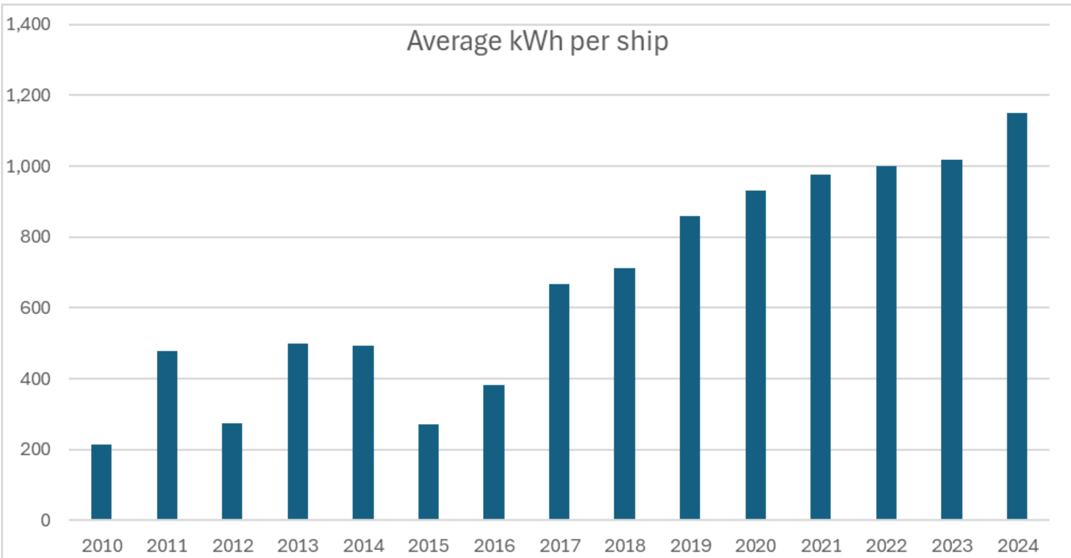


Figure 8. Average battery capacity per ship for all ships in service per year. [5]

2.2.2 Regions of operation analysis

Similar to the development of other battery electric vehicles, Europe is home to the largest number of battery-powered ships (i.e., almost 70% of all battery-powered ships worldwide), half of which operate in Norway (see Figure 9 and Figure 10). Other significant markets are North America, but also Asia, where the first battery ship entered operation in 2016[1].

Figure 9. Aera of operation for the 2024 fleet (right); comparison of the 2019 and 2024 fleets (left). [5]

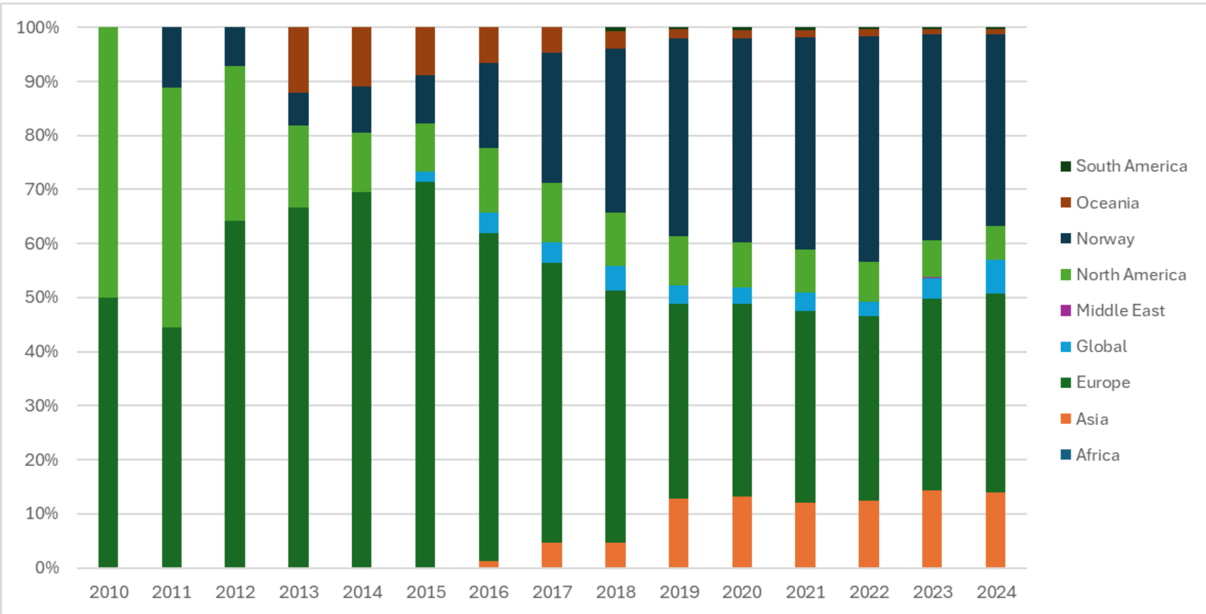


Figure 10. Share of total number of battery ships per region. [5]

The area in which battery ships operate is shown in Figure 11. Most of the ships operate close to the shore; only 3% are categorized as operating deep-sea. This distribution can easily be explained by the limited range of battery-powered ships and the high demand for low-emission sailing. All battery-powered ships operating in the deep-sea have a hybrid or plug-in hybrid topology (see Figure 14). Fully electric sailing over long distances is not feasible. However, with the availability of more compact and cheaper batteries, together with offshore charging possibilities, the range can be increased. By this, fully electric deep-sea sailing becomes possible for an increased number of ships.

About 20% of all battery-powered ships operate inland. The limited range, the possibility to develop a charging infrastructure and the demand for low emissions make inland ships suitable for electric operation.

[1] According to the compiler of the MBF ship register [5] this database is not complete for the Chinese market, so the numbers for the Asia region will be higher

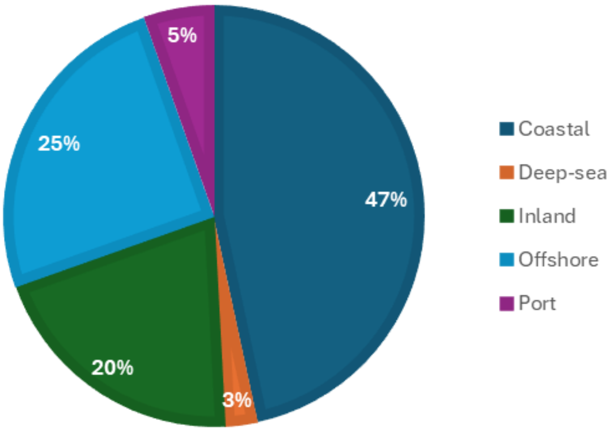


Figure 11. Operation area of all battery ships in operation. [5]

2.2.3 Power system topology

As described in the introduction to this chapter, three main power system topologies are used, similar to those used for electric (road) vehicles. In a hybrid topology the battery is mostly used to support other types of primary energy sources: e.g. to increase system efficiency, availability or comfort. In a pure electric (or fully electric) topology, the batteries are the only source of energy during sailing. A plug-in hybrid combines these two topologies.

As shown in Figure 12, the hybrid topology is still used in 60% of ships. Although this percentage has somewhat decreased in the last 4 years, the number of plug-in hybrid and pure-electric ships is still relatively low. The same also applies to the installed capacity (see Figure 13).

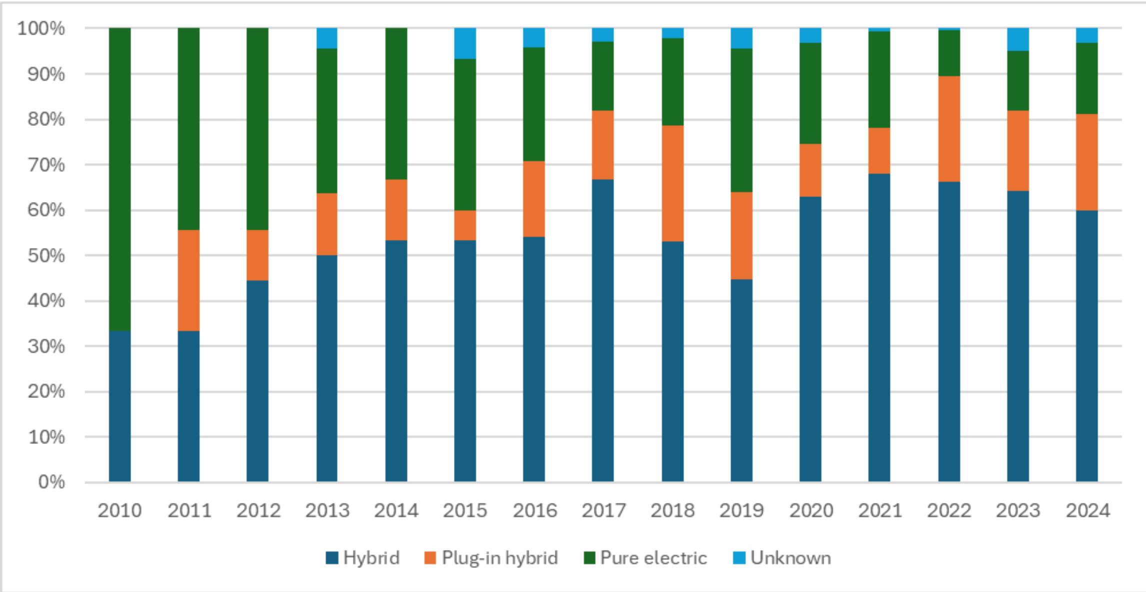
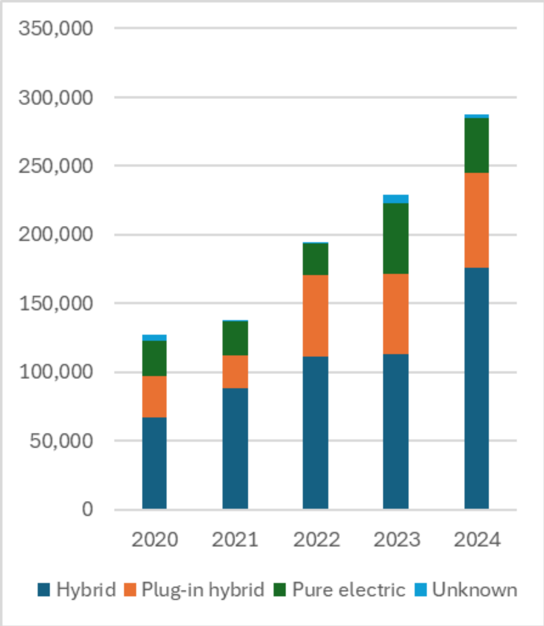
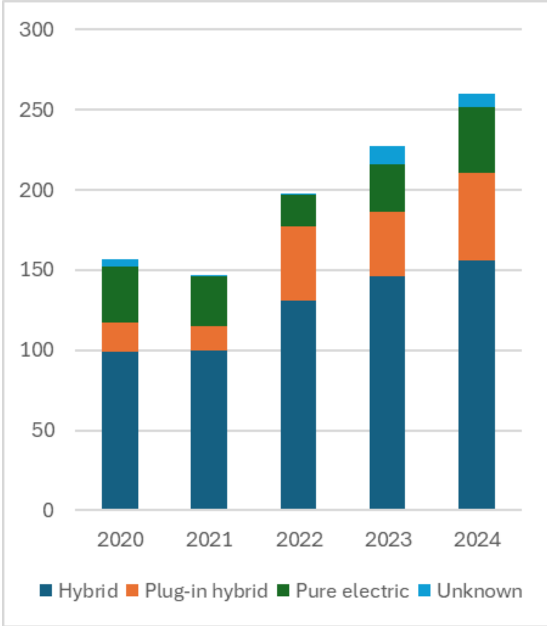


Figure 12. Share of different topologies in the number of ships put into service per year. [5]

Because of the limited range, a pure electric topology is mainly applicable to relatively small ships with a low autonomy. Some plug-in hybrid ships are operated fully electric, using a Diesel-generator as a backup or range extender, for example.





Installed capacity [kWh] annually *Number of ships per year*

Figure 13. Installed capacity and number of ships entering service in the last 5 years, by topology. [5]

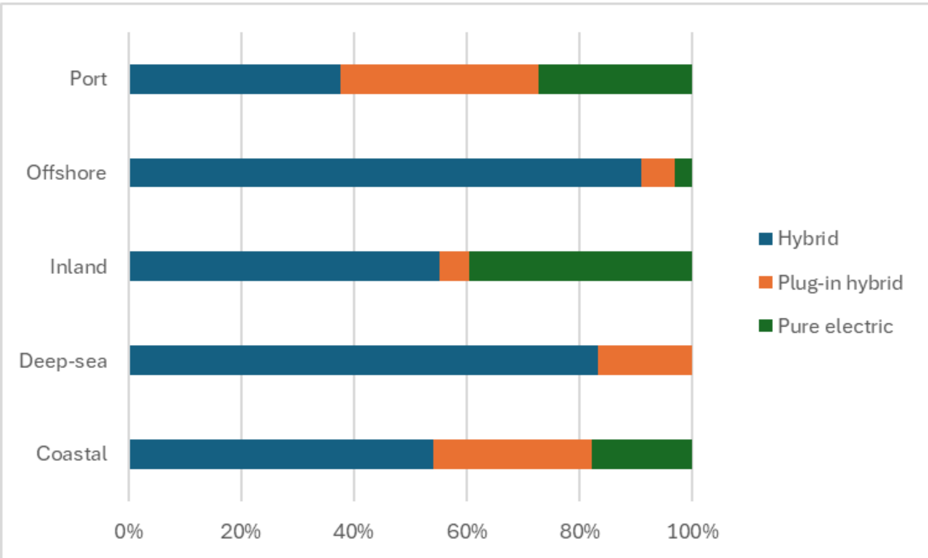


Figure 14. Topology distribution per operational area.

2.2.4 Ship category analysis

The battery ship distribution by category shows a different distribution between the number of ships (Figure 15) and the installed battery capacity (Figure 16). Passenger vessels (i.e. ferries) have always been largest for both, followed by offshore vessels. For the other categories the sequences are different for the number of ships and installed battery capacity.

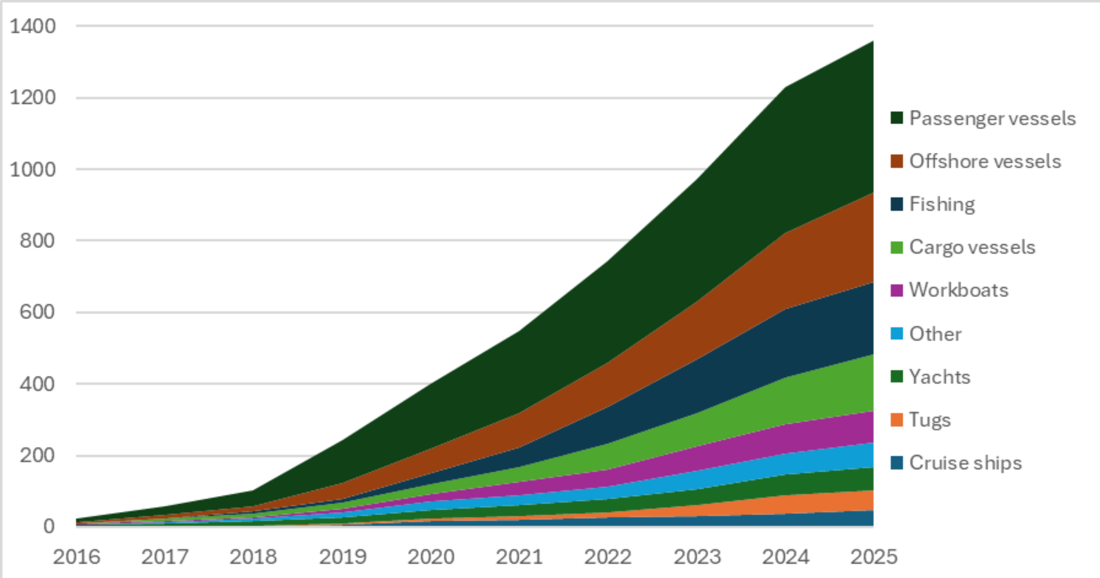


Figure 15. Total number of ships with batteries per ship category. [5]

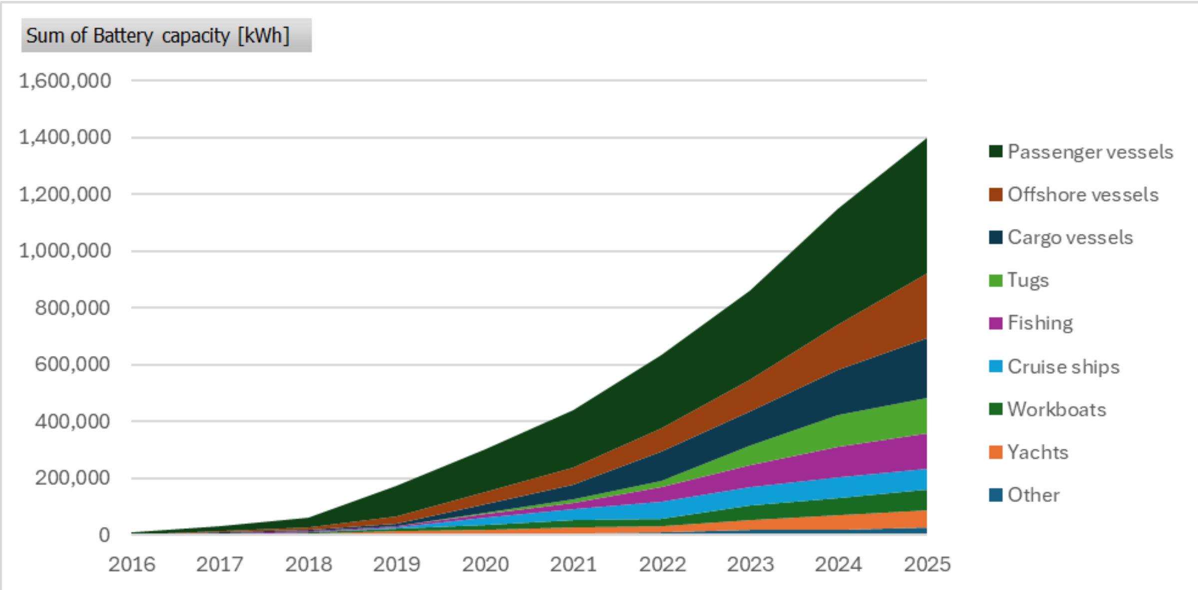


Figure 16. Total installed battery capacity per ship category. [5]

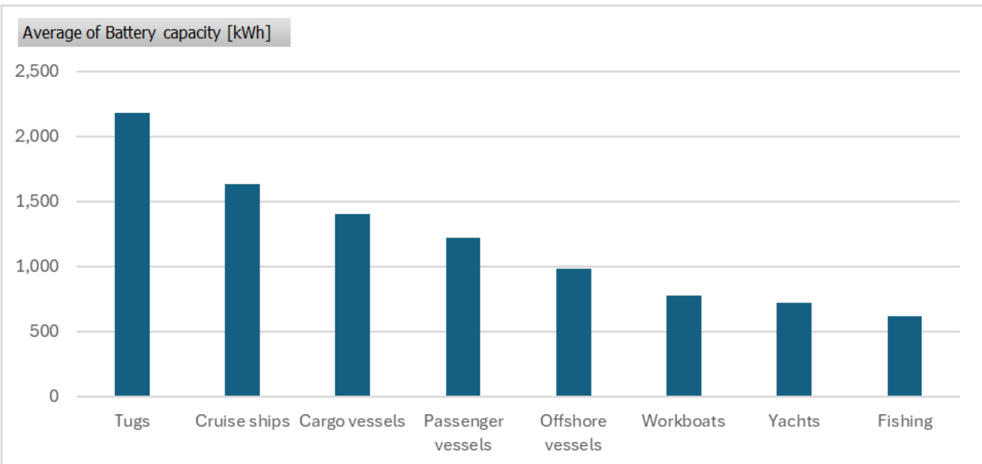


Figure 17. Average installed capacity [kWh] per ship category. [5]

The average installed battery capacity per ship gives a completely different sequence (see Figure 17). Tugs with an average capacity above 2MWh come first, followed by cruise ships and cargo vessels. Passenger and offshore vessels are ranked four and five. This can probably be explained by the fact that offshore vessels mainly use the battery in a hybrid topology for backup applications (see Figure 19), and have been electrified for many years while battery capacities were low in the early days and many ferries are sailing short distances (see Figure 18).

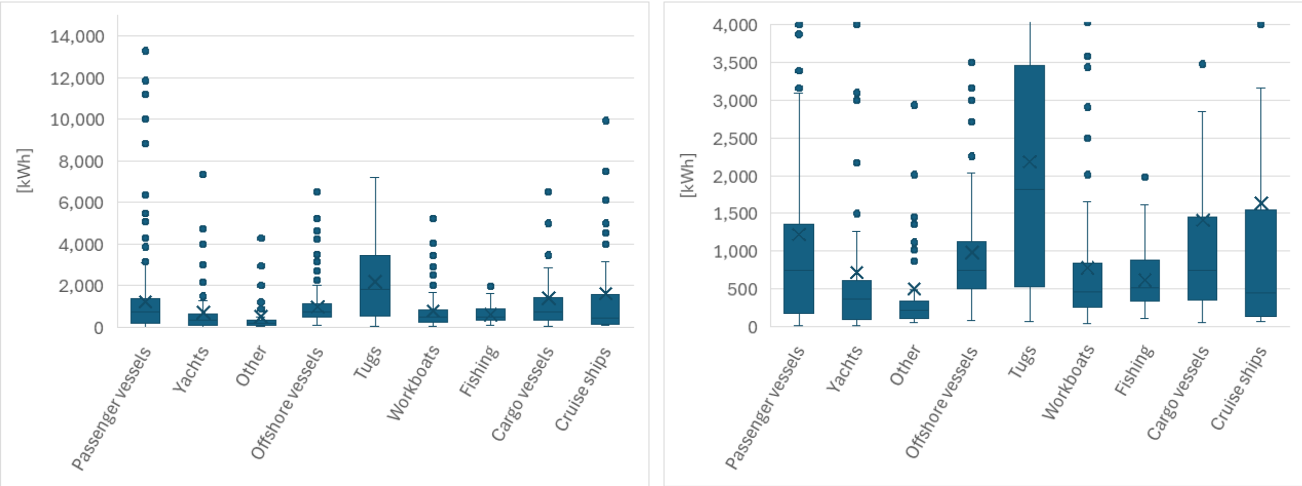


Figure 18. Box & whisker plot with statistics of installed capacity [kWh] per ship category (right: full scale, left: 0-4MWh scale) [5]

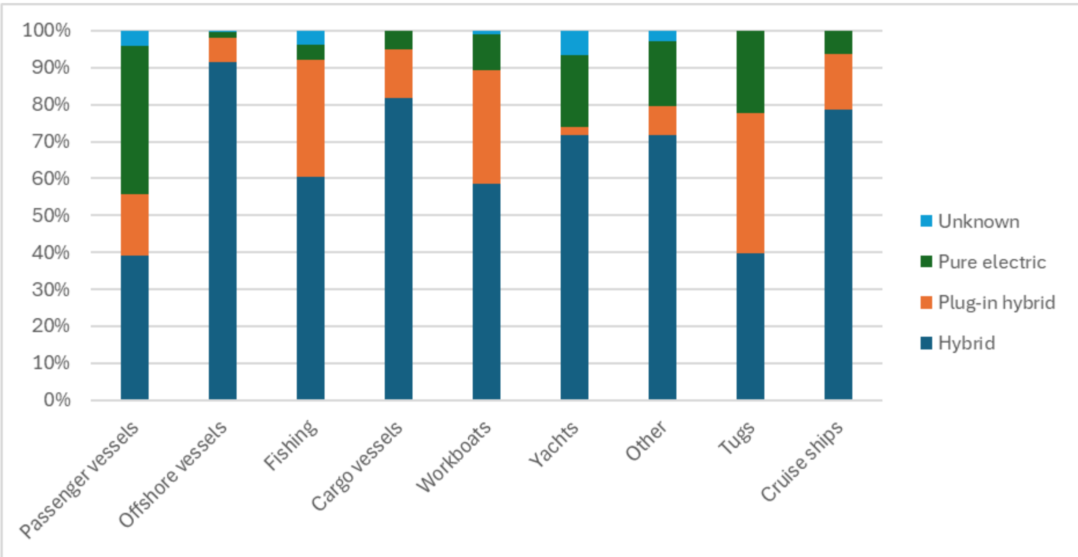


Figure 19. Topology share per ship category. [5]

Battery ships are still relatively small (see Figure 20) compared to ships with conventional propulsion systems [6]. This is easily explained by the limited range and power of batteries as main energy source.

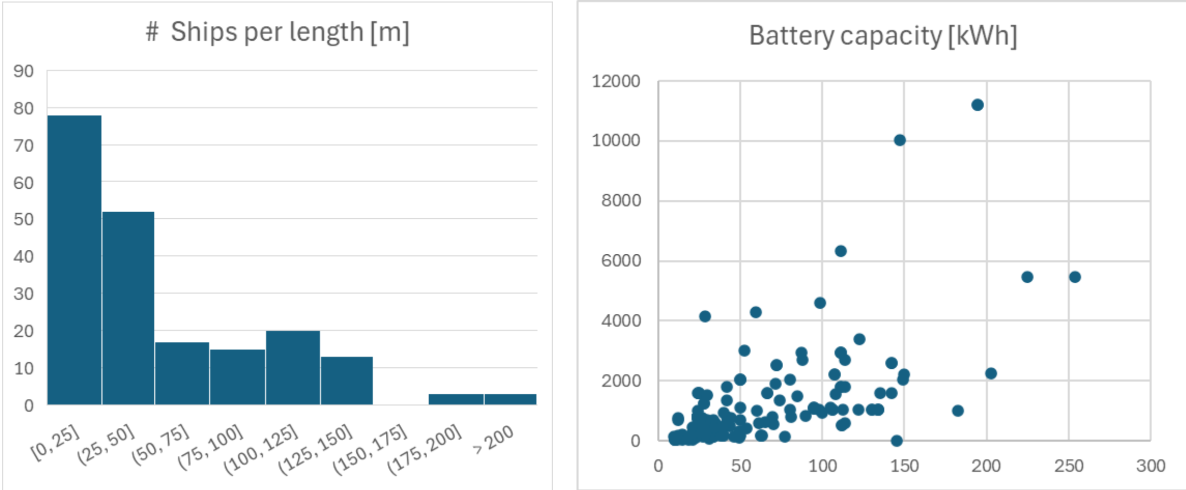


Figure 20. Number of ships (left) and ship battery capacity (right) as function of ship length. Note: Length is only available for 30% of ships [5]

2.2.5 Main ship categories explained

This section briefly explains the ship categories with the largest installed battery capacity.

2.2.5.1 Passenger vessels

The use of batteries in ships started in the ferry market, with Norway being an early growth market. Several aspects make this ship category very attractive. Firstly, the load profile of a ferry is mild and highly predictable, meaning that ferries sail according to a timetable. which gives regular charging opportunities Secondly, as they dock at dedicated and fixed locations, charging infrastructure can easily be implemented. Thirdly, and maybe the main driver, ferry routes are introduced by governments that can set requirements for zero-emission operation.

Road ferry (Lake Ontario) *Passenger ferry (Copenhagen)*

Figure 21. Fully electric ferries in diverse sizes and types.

2.2.5.2 Offshore vessels

The ship category offshore includes many different ship types (see Figure 39 in the Appendix). However, most of these types are ships with a so-called DP (Dynamic Positioning) notation. This kind of vessel is equipped with a manoeuvring system that can automatically maintain position based on local and global positioning. sensors High redundancy ensures that this capability is highly reliable, enabling the vessel to maintain its position in the event of a failure. In the past, an additional diesel generator was running as a backup to ensure power in case of trips. Nowadays large battery systems can replace this additional diesel generator, acting as a kind of large UPS system. The battery has several benefits: firstly, remaining diesel generators can be utilized at a much more efficient point of operation, increasing fuel efficiency and reducing engine fouling. Secondly, the number of hours that the diesel generator are sis reduced significantly, which reduces maintenance costs.

Figure 22. Offshore service operation vessel equipped with batteries for backup power.

2.2.5.3 Tug boats

As can been seen in Figure 15 and Figure 16, tugs have only been equipped with batteries in recent years. Nevertheless, Figure 17 shows that the installed capacity is high, implying that the batteries are used for fully or partial electric operation. This makes sense because the operational load profiles of tugs are ideal for electric operation ([3]). It is expected that the number of electric tugs will grow significantly. This is also supported by the Clarksons market data (see Figure 23), which shows that batteries represent the largest alternative fuel for both ships already in operation and those in production (orderbook).

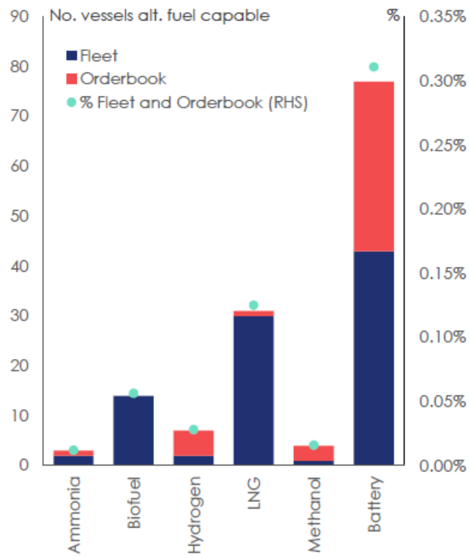


Figure 23. Alternative fuel types and their distribution for tugs [7][2]

[2] LNG is general recognized as a transition fuel and not a final fuel for net zero emission GHG operation

Figure 24. First fully electric tug in New Zeeland, Middle East and Europe, built by DAMEN.

2.2.5.4 Cargo Vessel

Similar to the category offshore, there are many different types of cargo vessels (see Figure 38 in the Appendix). Batteries can be used for low-range fully electric operation, partly electric operation, or peak shaving.

2.2.6 Battery system supplier market

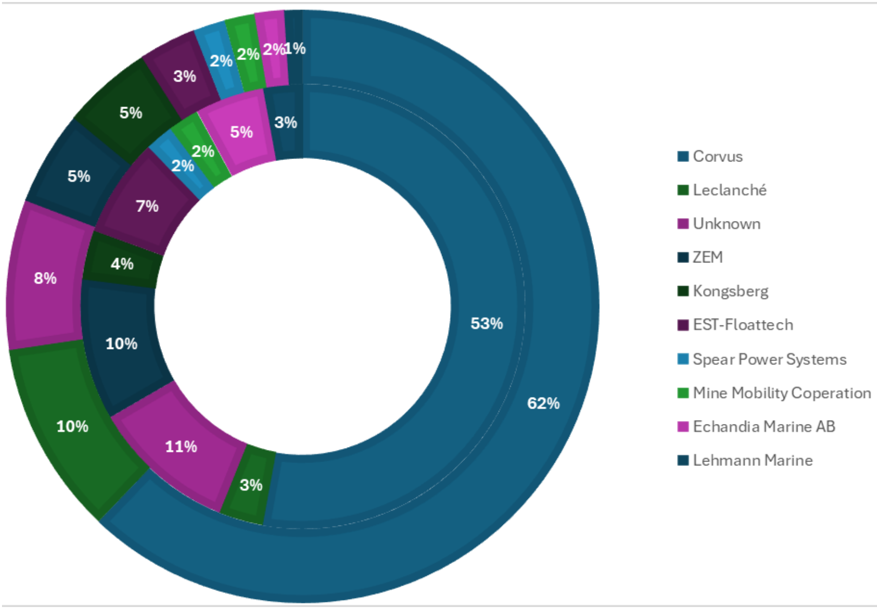


Figure 25. Battery suppliers market, inner circle: share of ships, outer circle: installed energy capacity [kWh] [5]

Although the maritime battery market is relatively small in terms of the number of ships and capacity, there are and have been many maritime specific battery suppliers on the market. Figure 25 shows the market share of the top 9 suppliers, broken down by the share of ships and installed capacity. The figure shows that Corvus Energy is by far the largest supplier, with a market share of over 50%. The other suppliers all have a market share of 10% or less in terms of installed capacity

All of the listed maritime battery suppliers, except for Leclanché, manufacture their systems based on cells or even modules sourced from other manufacturers. Leclanché is the only supplier that that uses its own cells. Figure 26 shows the distribution of battery cell manufacturers.

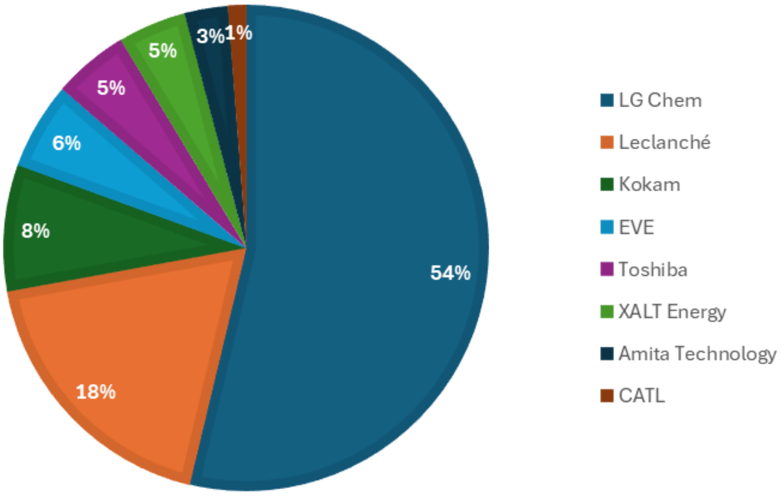


Figure 26. Battery cell suppliers share by capacity of the eight largest suppliers (note: manufacturer data is only available for 50% of capacity). [5]

The number of certified battery systems provides another perspective ([8], [9]). Here, China and the Chinese classification society (CCS) is leading in terms of the number of type-approved BESSs (Figure 27 and Figure 28).

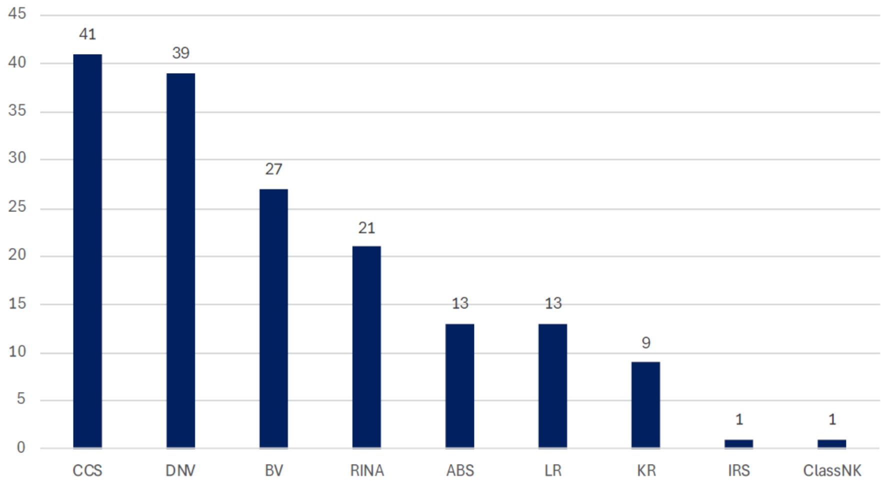


Figure 27. Number of type-approved battery systems per classification society. [9]

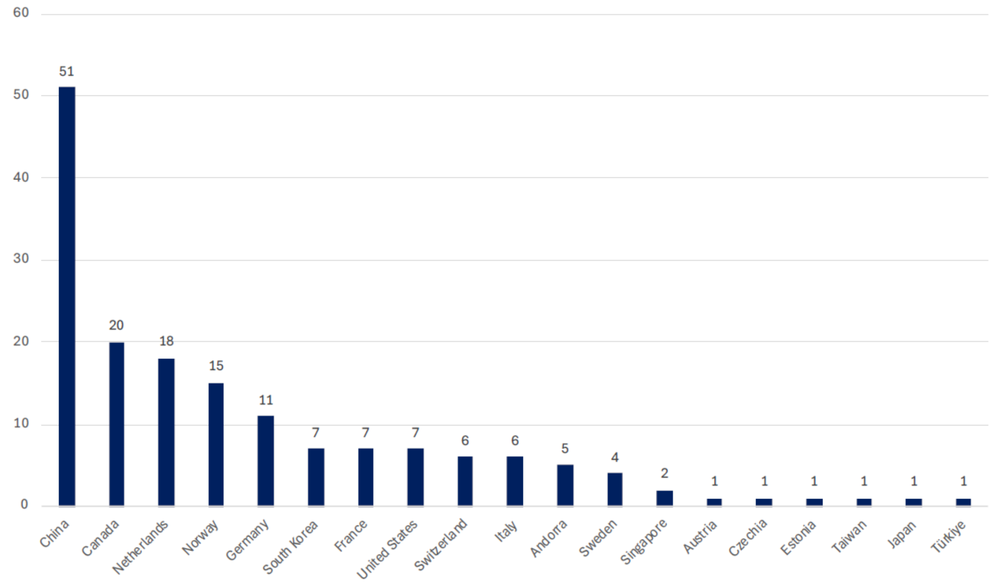


Figure 28. Number of type-approved battery systems per manufacturer's country of origin. [9]

2.2.7 Battery chemistries

Currently NMC is still the dominant cell technology (see Figure 29), but with improved LFP cell technology, this chemistry type is increasing now. The comeback of LFP is also clearly visible in the number of type-approved systems as shown in Figure 30.

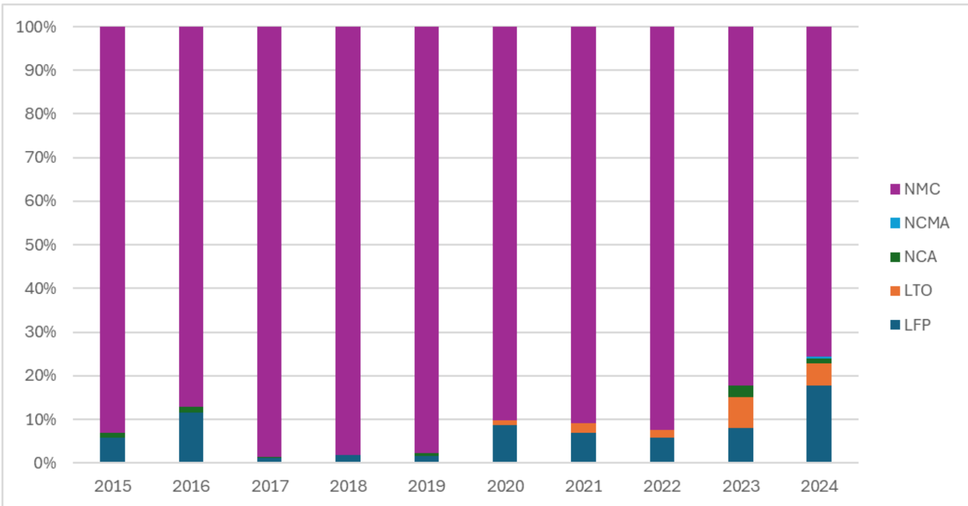


Figure 29. Distribution of battery cell chemistry types as percentage of capacity. [5]

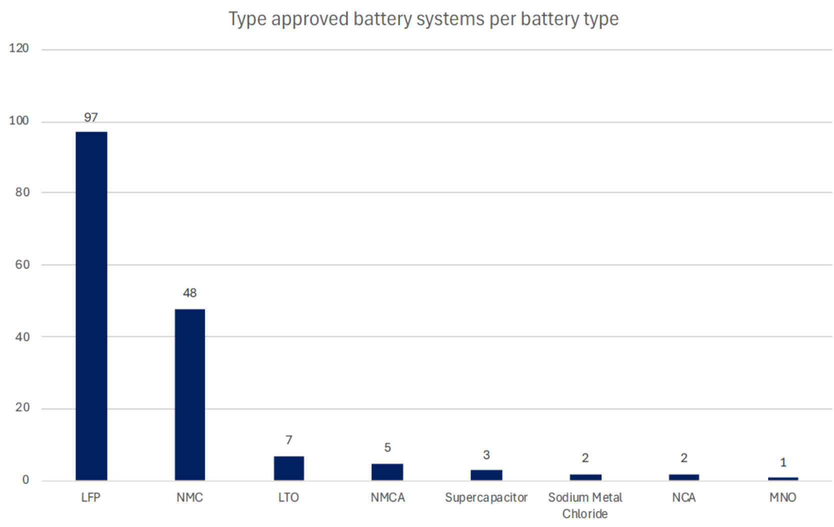


Figure 30. Number of type-approved battery systems per battery (chemistries) type. [9]

2.3 Battery Market Forecast

Market forecasting is naturally very sensitive to future changes. This is particularly true for the maritime battery market, which is characterized by low unit volumes and sensitivity to fluctuations and international developments. The forecasts performed are based on several market studies and own projections based on trendline extrapolation:

1. Annual capacity growth forecast
2. Battery price per unit capacity forecast
3. Maritime electrification market forecast
4. Ship tonnage newbuild forecast

The forecast will focus on the years 2028 and 2033. For these two years, the capacity and market growth are determined.

2.3.1 Battery system cost development

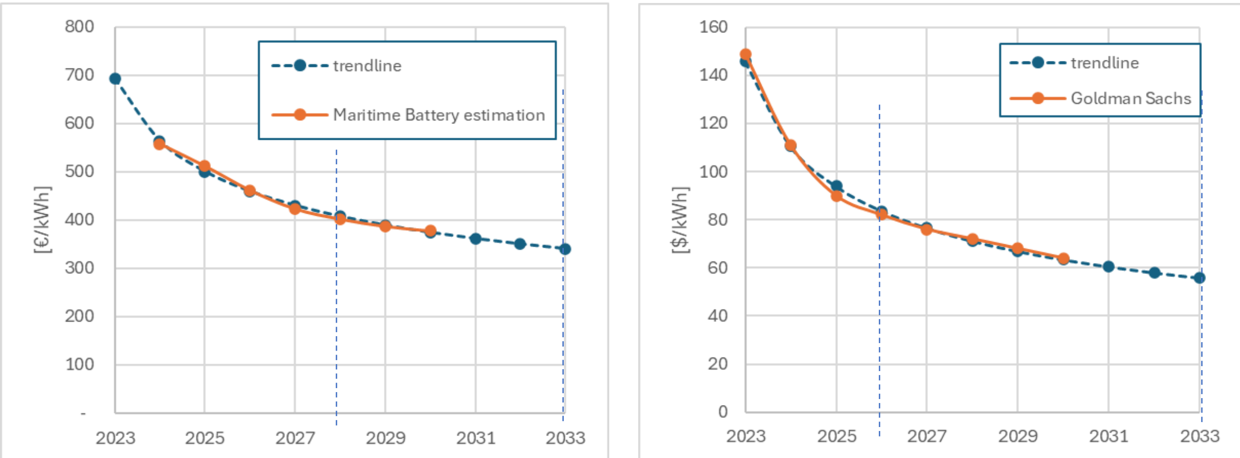


Figure 31. Maritime battery system average cost forecast (left); EV battery pack price forecast (right) by Goldman Sachs [10]

Unlike other applications, where general cost numbers are available, it is difficult to obtain market price information for maritime battery systems. This is mainly due to the fact that these battery systems are project-based and offered per (series of) ship. Based on experiences within the eWAVE consortium and a price development survey by the MBF, in Figure 31 the estimated average price development for maritime batteries is shown. Where the average price of maritime battery systems in 2024 is €550/kWh.

However, as described above, a range of chemistries are used, from the relatively cheap LFP to the expensive LTO. This means that there is a large variation in battery prices, which can be up to ±€300.Compared to other battery applications, the average maritime battery system cost is still relatively high (€550/kWh in 2024), whereas the pack price for automotive applications is about $115/kWh (~€109/kWh) in 2024 [10], [11]. It can be expected that maritime batteries will always be more expensive due to low volumes and high cost of certification.

2.3.2 Capacity and financial forecast

The annual installed battery capacity on board of ships is forecast by fitting a quadratic trendline to the numbers from the last 10 years and extrapolating this line up to 2033. Figure 32 shows the results of this trendline and extrapolation. The expected annual installed battery capacity is 600kWh for 2028 and 1100kWh for 2033, compared to 300kWh installed in 2024.

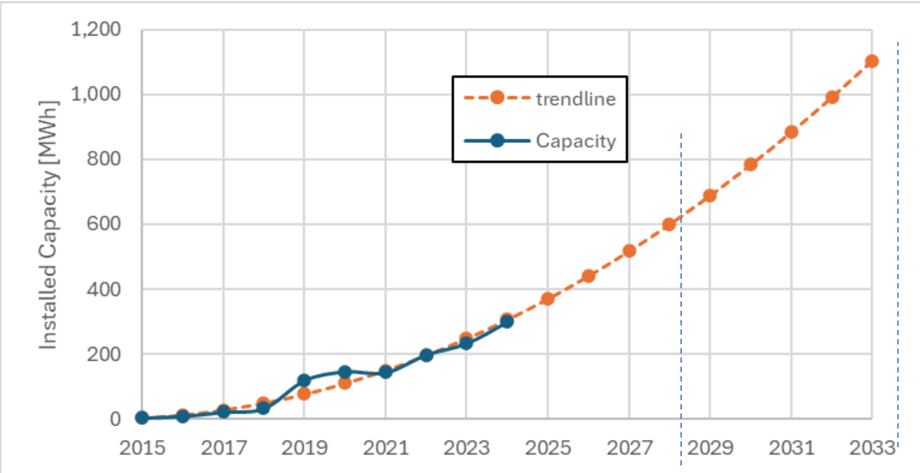


Figure 32. Forecast of installed battery capacity on board ships (quadratic trendline based on the last 10 years) [5]

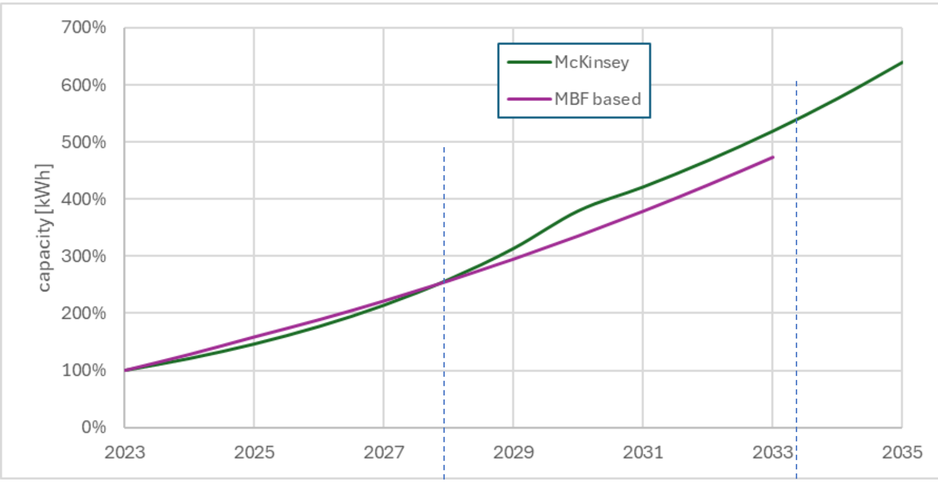


Figure 33. Annual forecasted battery installed capacity relative to 2023 (maritime=MBF and EVs=McKinsey)

In Figure 33 shows a comparison of the maritime annual installed battery capacity with the forecast numbers for the EV market. Both forecasts show similar growth numbers. The market is expected to grow to about 300% by 2028 and 500% by 2033, compared to 2023 (=100%).

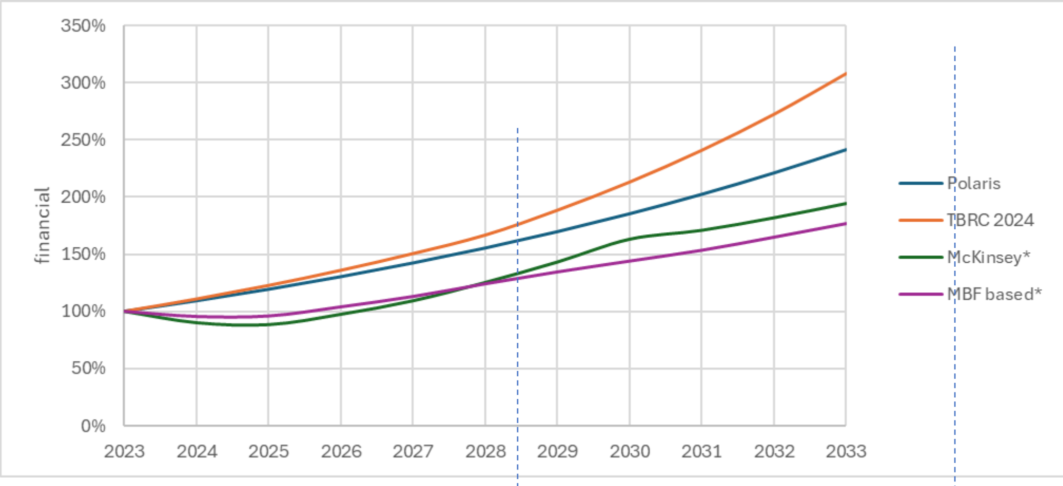


Figure 34. Market financial forecasts, relative to 2023 (=100%). [12], [13]. (MBF based* = maritime battery market, McKinsey* = EV battery market, Polaris and TBRC2024 = full maritime electrical market)

As discussed in the previous section, battery prices will decrease over time. This means that, financially, the growth of the battery market will be lower than its capacity growth. To produce a financial forecast, the forecasted annual installed capacity (Figure 33) is combined with the Goldman Sachs battery price development forecast [10] (Figure 31). The results of this calculation are presented in Figure 34. In this graph two market forecasts for the ship electric market are included. Theis market considered includes all electrical systems such as electric drives, distribution systems, and installations. The forecast shows a larger growth for the full electric ship systems market compared to the battery market.

In Table 1, the size of the maritime battery markets for the years 2024, 2028 and 2033 are estimated based on the market forecast for the maritime battery market as shown in Figure 34 and the 2024 maritime battery price of €550/kWh as described the previous section.

Table 1. Estimated and forecasted market size for maritime battery systems.

Year	2024	2028	2033
Market size	M€ 167	M€ 207	M€ 295

3 Existing battery life cycle regulations

3.1 Decarbonization regulation overview

The maritime industry is highly regulated by a variety of regulations, such as those from the International Maritime Organization (IMO) and the European Union (EU). Maritime companies (e.g., ship builders, operators, and system suppliers) typically operate within a stringent regulatory framework aimed at ensuring safety and security (e.g., battery safety in the context of the eWAVE project). This section aims at outlining and summarizing a set of existing regulations and guidelines relevant to the scope of the eWAVE project. The purpose is twofold: 1) to utilize the existing regulations/guidelines to guide the design and development of technical work packages (i.e. WPs 3-6), and 2) to identify potential regulatory gaps between the existing ones and emerging trends in the maritime market/industry (e.g., electric vessels for decarbonization).

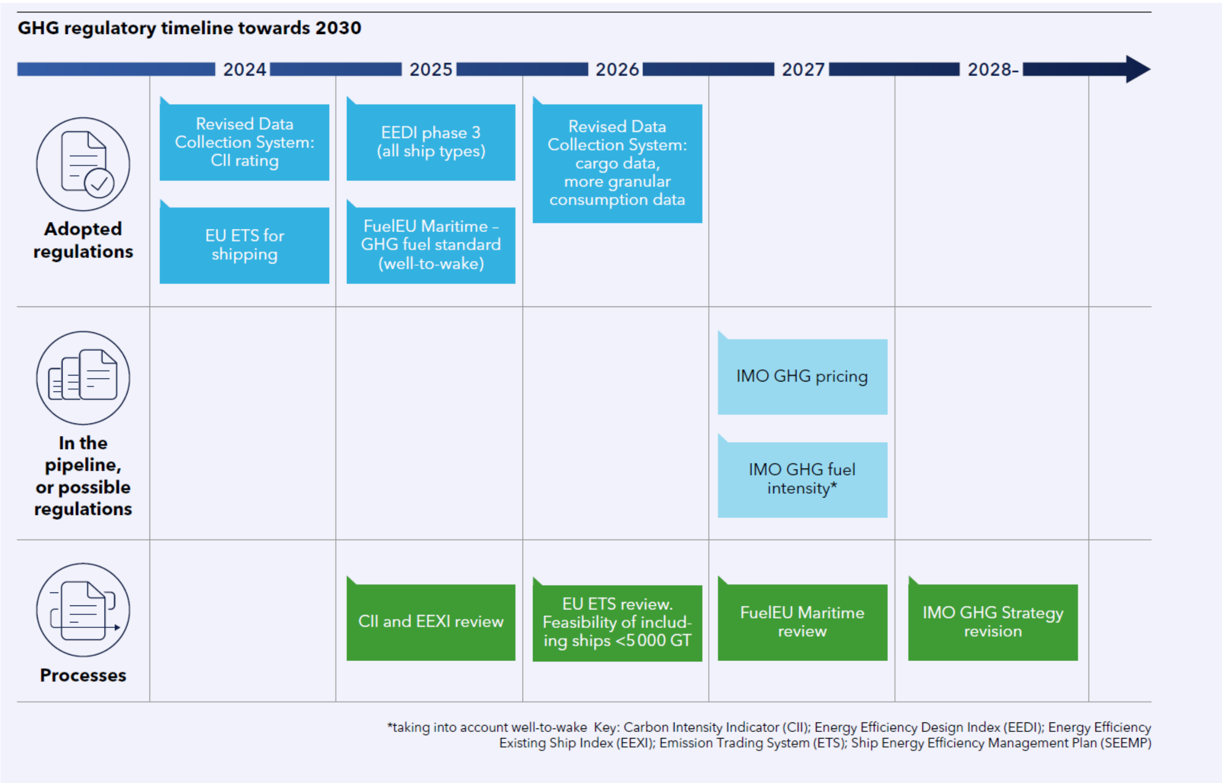


Figure 35. Decarbonization regulatory timeline towards 2030 [14]

It is known that IMO has set a clear decarbonization/environmental ambition for the maritime industries: a 20% emission reduction by 2030, a 70% reduction by 2040, and a full-scale decarbonization by around 2050. These ambitions are driven by various regulations and target all the maritime stakeholders, from ship builders and ship operators to cargo owners. Figure 35 shows various regulations along the decarbonization regulatory timeline towards 2030; measures and indices based on these regulations are discussed below.

The ***Carbon Intensity Indicator (CII)*** is a mandatory regulatory measure from IMO to assess the operational energy efficiency of ships. Currently, the CII index applies to all cargo, RoPax, and cruise vessels above 5,000 gross tonnages (GT) engaged in international voyages. It calculates a ship's annual carbon emissions relative to the amount of cargo carried and the distance travelled, resulting in a performance rating ranging from A to E. Ships rated D or E for three consecutive years are required to implement corrective action plans. CII is part of the IMO's broader strategy to reduce greenhouse gas emissions from international shipping and drive the transition toward low-carbon maritime operations.

The ***EU Emissions Trading System (ETS)*** was adapted in 2024 for ships trading in the EU by 1) setting a cap on the total amount of emissions allowed, based on the regulatory responsibilities and contracts; and 2) enabling companies throughout the supply chain to take responsibility for their approximate allowances. The first deadline for surrendering emissions allowances under the EU ETS is set for September 2025, covering emissions generated in 2024. From 2025 onwards, general cargo vessels between 400 and 5,000 GT, as well as offshore vessels of 400 GT or more, will be required to report their GHG emissions. Offshore ships exceeding 5,000 GT will fall under the scope of the EU ETS from 2027. Following a review scheduled for 2026, the potential inclusion of general cargo and offshore vessels between 400 and 5,000 GT will be re-evaluated. From 2024, reporting methane and nitrous oxide emissions is mandatory, with these gases becoming fully incorporated into the EU ETS by 2026. The system also accounts for the permanent storage of carbon as part of its emissions reduction framework.

The ***Energy Efficiency Design Index (EEDI)*** is a key regulatory measure from IMO to promote the design of more energy-efficient and environmentally friendly ships. EEDI sets mandatory energy efficiency standards for new ship designs requiring a minimum level of carbon emissions per unit of transport work (measured in grams of CO_2 per tonne-nautical mile). The regulation applies to most ship types and becomes progressively stricter over time through phased reduction targets. By encouraging the adoption of cleaner technologies and optimized hull and engine designs, the EEDI supports the IMO's long-term strategy to reduce greenhouse gas emissions from international shipping. Compared with CII that focuses on measures operational cabin intensity of a ship per year, the focus of EEDI lies on the estimation of energy efficiency of new ships. EEDI is usually only measured once at the deign phase while CII is measured at a yearly basis.

FuelEU Maritime is a key regulatory initiative under the *European Union's Fit for 55 package*, aimed at accelerating the decarbonisation of the maritime sector. Adopted in 2023 and entering into force from 2025, the regulation will set increasingly stringent limits on the GHG intensity of the energy used on board ships calling at EU ports, regardless of their flag. It promotes the uptake of renewable and low-carbon fuels by requiring ship operators to gradually reduce the GHG intensity of their fuels. FuelEU Maritime applies to ships above 5,000 gross tonnage and complements other EU measures, such as the EU ETS and the Alternative Fuels Infrastructure Regulation (AFIR), forming a comprehensive policy framework to support the maritime industry's transition to climate neutrality.

The ***Energy Efficiency Existing Ship Index (EEXI***) is a technical index for the energy efficiency of the global fleet. Effective from January 2023 onwards, EEXI applies to existing ships above 400 GT that are engaged in international trade and sets minimum energy efficiency requirements based on a vessel's type and size. It is modelled on EEDI, but adapted for ships already in service. Shipowners are required to calculate their vessels' EEXI values and implement technical or operational measures—such as engine power limitation, hull modifications, or energy-saving technologies—if necessary to meet compliance. EEXI is part of the IMO's broader strategy to reduce greenhouse gas emissions from shipping and support the transition towards more sustainable maritime operations.

The ***Ship Energy Efficiency Management Plan (SEEMP)*** is an operational measure designed to enhance the energy efficiency of ships and reduce greenhouse gas emissions. Applicable to all ships over 400 GT, SEEMP provides a structured framework for monitoring and improving a vessel's fuel consumption and environmental performance throughout its lifecycle. The regulation has evolved over time: *SEEMP Part I* focuses on ship-specific efficiency measures; *Part II* introduces mandatory fuel oil consumption data collection; and *Part III*, effective from 2023, requires ships to include a plan for achieving annual operational carbon intensity targets under the CII regime. SEEMP is a key component of the IMO's strategy to drive continuous improvement in ship energy efficiency and support global climate goals.

3.2 Battery integration regulations

In addition to the above-mentioned measures/indices, the ***European Maritime Safety Agency (EMSA) Guidance on the Safety of Battery Energy Storage Systems (BESS) on board ships*** [15] can be used as a comprehensive guidance on the safe installation and operation of BESSs on board ships, recognizing their growing role in supporting maritime decarbonization. The guidance aims to help ship designers, operators, and national administrations identify and mitigate the unique risks associated with lithium-ion battery technologies, such as thermal runaway, fire propagation, and toxic gas emissions. It provides a structured, risk-based approach to the design, integration, and lifecycle management of BESSs in line with existing international regulations (e.g., IMO international code for fire safety systems) and class society standards (battery power design safety rules from DNV). Key topics covered include hazard identification, fire detection and suppression systems, ventilation requirements, battery room design, monitoring and control systems, and emergency response procedures. The guidance also emphasizes the importance of system-level safety assessments, crew training, and maintenance protocols to ensure safe and reliable operation. By offering best practices and harmonized safety principles, the EMSA guidance supports the broader adoption of BESSs in maritime applications while ensuring a high level of safety and environmental protection.

Moreover, the regulation EU 2023/1542 [16] specifies mandatory sustainability requirements for all types of batteries placed on the EU market, including portable, industrial, automotive, electric vehicle (EV), and light means of transport (LMT) batteries. This regulation covers various topics such as carbon footprint rules and recycled content requirements. In the next paragraph a more extensive battery passport explanation is included.

In addition, there exist a set of international standards that can be used to support regulatory compliance of battery systems, such as

- IEC 62619 that specifies safety requirements for the operation of secondary lithium cells and batteries used in industrial applications,
- IEC 62620 that specifies requirements for testing secondary lithium cells and batteries applied in the industrial sector,
- IEC 60092 that consists of a set of international standards for electrical installations in ships and offshore units,
- IEC 60038 that specifies nominal voltage values for AC and DC electricity systems for compatibility and consistency across electrical installations and equipment.

The IEC 600038 defines limits for low-voltage at 1000 VAC and 1500 VDC. Voltage levels above are considered as high-voltage, where more stringent safety regulations are applicable. This limit has created a kind of two separate electrical components and systems markets, one for low-voltage distribution and another for high-voltage. High-voltage AC systems have been applied on larger ships with large electrical power systems (tenths of MW) for decades. However, high-voltage DC is still in development and not used onboard of ships.

Battery systems that will be connected directly to a high-voltage distribution system have to comply to high-voltage regulations. To the knowledge of the partners involved in the regulations analysis, there are no active regulations or standards available for applying/restricting high-voltage battery systems on board of ship in the maritime domain.

In summary, the above regulations/measures/guidelines could be employed in the eWAVE project to guide the following technical design and development. On the other hand, the eWAVE outcome will also be taken as input to regulatory bodies (e.g., IMO) for the improvement of the existing regulatory framework.

3.3 EU Battery Passport

The battery passport comprises a digital record that ensures traceability of battery materials, usage, and performance over the product lifecycle. In the maritime sector, it aims to optimize battery usage, promote second-life applications and support regulatory compliance while enhancing environmental accountability.

The purpose of the Battery Passport in maritime applications includes:

- Monitoring lifecycle performance of batteries used in ships, ferries, and other waterborne vessels.
- Ensuring compliance with international maritime regulations and sustainability goals.
- Facilitating second-life applications and end-of-life recycling.
- Enhancing safety and operational efficiency through real-time monitoring.

The Battery Passport would collect and store:

- Manufacturing Details: origin of raw materials, cell manufacturing data, and assembly specifications.
- Operational Data: charge/discharge cycles, State of Charge (SoC), State of Health (SoH), temperature logs, and degradation metrics.
- Maintenance Records: servicing history, and any incidents of overheating or failure.
- Lifecycle Analysis: environmental impact metrics, carbon footprint during production, and emissions saved during operations.
- End-of-Life Data: pathways for recycling, repurposing, or safe disposal.

From traceability and monitoring perspective:

- Real-time monitoring of battery health and performance through onboard BMS as outlined in the SEABAT documentation [17].
- Integration with Maritime Fleet Management Systems for remote diagnostics and predictive maintenance [18].
- Modular design to enable individual module replacement without full system overhaul, enhancing lifecycle extension [18].

A full LCA, as demonstrated in the Maritime Battery Forum's study, evaluates the environmental payback period of maritime batteries. The LCA would form part of the Passport, reflecting real-time emissions saved compared to diesel alternatives, supporting environmental reporting and compliance [19].

Finally, it should be noted that ship batteries are classified as industrial batteries under the EU Battery Regulation [16][not as electric vehicle batteries, but regardless of this, they must also have an electronic record ('battery passport') when placed on the European market or put into service from 18 February 2027.

3.4 Circularity with focus on Reuse and Second-life applications

3.4.1 SoH estimation for Reuse and Second-life applications

This section sets out regulatory requirements for the assessment of the State of X (SoX), e.g., State of Charge (SoC), State of Health (SoH), and State of Safety (SoS), for maritime batteries intended for reuse, repurposing or second-life applications. The regulations support the battery passport initiative by ensuring accurate life-cycle tracking, safety and alignment with circular economy.

These requirements apply to:

1. Battery packs from EVs, maritime vessels, or industrial energy storage systems.
2. Battery modules or cells intended for second-life use, repurposing, or recycling

Batteries to be considered for second-life use must meet minimum SoH requirements and must have at least 70–80% of their original rated capacity (SoC). Where appropriate, an identification of degradation 'knee points' must be considered to avoid underestimating the risk of failure [20].

There are several approved methods for estimating SoH:

1. Direct Measurements:
    a. Full charge/discharging cycling
    b. Internal resistance and impedance spectroscopy (EIS)
    c. Open Circuit Voltage (OCV) profiling
2. Indirect and data-driven methods [21]:
    a. Coulomb counting and thermal modelling
    b. Machine learning
        i. Kalman Filters
        ii. Support Vector Machines
        iii. Neural Networks

All of these methods must be validated and traceable via the battery passport system. Each battery undergoing SoX evaluation must have a history of usage parameters including depth of discharge, average temperature, and total charge cycles [20]. Each battery must also report SoX values upon transfer, repurposing or reuse.

SoX, mainly SoH data, must inform whether batteries should be

1. reused in less demanding applications (e.g., residential storage, grid peak shaving)
    a. if SoH > 70% and the risk metrics are acceptable.
2. recycled if below the reuse threshold or if refurbishment is economically not viable.

An Environmental Life Cycle Assessment (LCA) must be considered here: reuse generally results in lower emissions than direct recycling [21]. Recycling processes must meet EU targets [17]. SoH evaluations must align with IEC 62660, UL1974, and similar international safety standards. Second-life battery systems must use an adaptive Battery Management System (BMS) that is capable of operating with diverse SoC profiles [20]. Non-uniform or high-risk cells must be segregated or replaced prior to reuse.

Circularity also promotes smarter product use and manufacturing, as well as the useful application of materials, for example., recycling that recovers critical raw materials. The concept of circularity is not limited to LCA, promotion of smarter product use, and reusability; it is quite broad, focusing on extending the lifespan of battery products through effective refuse, rethink, reduce, reuse, refurbishment, repurposing recycling, and recover. The 9R Framework: provides a structured model for achieving circularity goals, as illustrated in [17] and depicted in Figure 36.

Circular Economy ↑	Smarter Product Use and Manufacture	R0 Refuse	Make products redundant by choosing circular products that possess some or all of the qualities of the 9R's
		R1 Rethink	Make product use more intensive (e.g. by sharing product)
		R2 Reduce	Increase efficiency in product manufacturing or use by consuming fewer natural resources and materials
	Extend Lifespan of product and its parts	R3 Reuse	Reuse by another consumer a discarded product which is still in good condition and fulfils its original function
		R4 Repair	Repair and maintenance of defective products so it can be used with its original function. Generally has not been tested and may not include a warranty
		R5 Refurbish	Restore a product and bring it up-to-date or restore functionality. Includes testing for defects prior to resell and usually includes a warranty
		R6 Remanufacture	Rebuilding of a product to original specifications by exchanging worn parts with repaired, used or new parts. The product or machine should perform as a new one and includes a warranty
		R7 Repurpose	Use discarded products or its parts in a new product with a different function
	Useful application of materials	R8 Recyclable Resource Recovery	Process materials to obtain the same (high grade) or lower grade quality
Linear Economy		R9 Recover	(1) Recover or 'cannibalise' from damaged products for the reuse of parts in order to facilitate remanufacturing or refurbising activities. (2) Incineration of material for energy recovery

Figure 36. Circular Economy Pathways for Battery Lifecycle according to the 9R framework

While the full 9R framework includes stages from R0 to R9, this document focuses specifically on R3 to R8 because these stages are the most relevant to battery lifetime extension. Thus, batteries must be evaluated across these different stages of their lifecycle:

- R3(Reuse): This involves reusing discarded products with minimal processing. For batteries, this could mean simple checks and reinstallation in less demanding applications.
- R4(Repair): Damaged or underperforming batteries undergo repairs to restore their original capacity and function.
- R5(Refurbish): This step extends battery life by replacing or upgrading degraded components, allowing continued use with improved reliability.
- R6(Remanufacture): A complete overhaul of batteries to 'like new' conditions, ensuring safe and efficient operation.
- R7(Repurpose): Batteries that no longer meet EV and maritime standards can be repurposed for stationary energy storage applications, such as grid support or renewable energy storage. Such batteries are categorized as industrial batteries [16]
- R8(Recycle): When batteries reach the end of their useful life, material recovery is prioritized.

On the other hand, R0-R2 (refuse, rethink, reduce) focus on design choices and consumption reduction strategies, which occur before a battery is manufactured and do not involve extension of battery lifetime with respect SOH. Meanwhile, R9 (recover) typically refers to energy recovery that involves reclaiming of damaged materials for reusing and bypasses performance evaluation and is not directly relevant to battery lifetime extension.

The SOH of batteries plays a critical role in determining their suitability for the different strategies of the 9R model. As shown in Table 2, key components influencing SOH evaluation include Cells, Sensors, and the Battery Management system (BMS). These are particularly essential for advanced circularities such as R5, R6 and R7, where performance, reliability and safety are paramount.

For R6 and R7, all three components must be thoroughly assessed to ensure safe reintegration intro secondary applications. In contrast, Mechanical fixations and Other Electronics are marked “Maybe” (M), indicating that their relevance is context-dependent and varies by application.

This mapping highlights that SOH interventions are most critical from R4 to R7, where decisions regarding repair, upgrade or reconfiguration rely heavily on accurate SOH estimation. Effective SOH estimation not only supports the decision-making process but also contributes to the success of the EU Battery Passport initiative, enabling traceability and performance monitoring throughout the battery’s extended lifecycle.

Table 2. Mapping SOH scope relevant to 9R framework to components for second-life: Y = Yes, N = No, M = Maybe

SOH-relevant Components	Cells	Sensors	BMS	Mechanical Fixations	Other Electrics and Electronics
R2 Reduce	N	N	N	N	N
R3 Reuse	N	N	N	M	M
R4 Repair	N	N	M	M	M
R5 Refurbish	M	M	Y	M	M
R6 Remanufacture	Y	Y	Y	M	M
R7 Repurpose	Y	Y	Y	Y	Y

These mappings also indicate that, if SOH estimation reveals sufficient capacity and reliability of these components, the battery can be considered for these high-value circularity applications. Conversely, if SOH estimation reveals significant degradation, the pathway/focus shifts towards recycling (R8).

Table 3. Dependency analysis for defective and affected components illustrating the relationship component requirements, and circularity strategies

	The defective component					
The affected component	Dependencies	Cells	Sensors	BMS	Mechanical Fixations	Other Electrics and Electronics
	Cells	-	N	N	N	N
	Sensors	Y	-	Y	Y	N
	BMS	Y	Y	-	N	Y
	Mechanical Fixations	Y	Y	Y	-	Y
	Other Electrics and Electronics	N	N	Y	N	-

Table 3 dives deeper into the interdependencies showing how failure of one component can impact others, highlighting critical interrelationships within battery systems:

- For example, if Sensors fail, it affects the BMS and Mechanical Fixations, but not necessarily the Cells directly.
- The BMS is critically dependent on both the Cells and Sensors for effective SoH monitoring and management.
- This analysis emphasizes the importance of ensuring that interdependent components are functioning correctly during second-life assessments. While Table 3does not directly focus on evaluation of SOH and its value in circularity, understanding these dependencies is essential to ensure accurate SOH estimation and safe reuse, as the effectiveness of SOH estimation relies on health and functionality of these supporting components.

In conclusion, Table 2 and Table 3 illustrate the critical dependencies in assessing SoH for making effective decisions across the 9R framework. Understanding the degradation and remaining performance capabilities of batteries enables stakeholders to make informed decisions, such as extending the battery's lifecycle through reuse and repurposing, or initiating material recovery through recycling. These steps are essential for supporting the circular economy goals set out in the EU's Battery Passport initiative, thereby ensuring traceability, sustainability, and optimized resource use.

Once a battery has degraded to the point where it no longer meets the operational profile of a vessel, it will (in most cases) still have sufficient capacity and can be repurposed for a second-life application. Although the industry is still in its infancy when it comes to the availability of maritime batteries for second-life applications, the batteries that are suitable for this purpose often still have substantial storage capacity.

The concept of ‘second life’ for automotive and maritime batteries has received significant interest from major car manufacturers. However, these batteries are small, and many thousands of them would need to be integrated and controlled for grid applications. By contrast, maritime battery systems, generally on the megawatt scale, require fewer systems to be integrated [8].

One of the primary challenges for second-life batteries is controlling the individual modules when different battery systems are combined. Because each module may have experienced different usage patterns, their states of health can vary significantly. This variability can create challenges across second-life pathways such as reuse, repurposing and refurbishment, as manufacturers and adopters may hesitate due to uncertainties around battery degradation and health assessment.

The end-of-life phase of batteries is a critical point in their lifecycle. While batteries used on ships that are too degraded for classification and safety standards may be deemed unsuitable for further use on board, they may still possess enough capacity for stationary applications. However, grid stabilization, while technically promising, still requires enhanced safety procedures and better infrastructure to support second-life use. A major barrier is the reluctance of battery manufacturers to allow used batteries in grid services due to liability concerns. Furthermore, the non-standardized shapes and control interfaces of old batteries make repurposing them for terrestrial applications technically challenging and costly [8]. Members of the MBF indicate that infrastructures enabling the safe return of used batteries to certified recycling facilities are not currently in place. Establishing these infrastructures would be crucial in preventing unauthorized handling of degraded batteries, ensuring both safety and circularity, in line with EU battery passport regulations.

3.4.2 SoS estimation for Reuse and Second-life applications

The eWAVE project aims to pioneer real-time capable, adaptive, and dynamic models that can accurately predict battery SoC and SoH under dynamic maritime conditions. Furthermore, it aims to identify State of Safety (SoS) parameters and to define appropriate metrics applicable to maritime use-cases, along with the development of effective monitoring and testing procedures. SoS plays a crucial role in evaluating not only the functional status of battery components but also their safety margins during reuse, repurposing, and second-life applications.

The challenge within the scope of circularity is to measure and quantify SoS effectively under varying maritime conditions where temperature fluctuations, environmental exposure and mechanical stresses differ significantly from those in typical terrestrial applications. This requires enhanced diagnostic techniques, adaptive Battery Management Systems (BMS), and the integration of real-time safety monitoring to detect early indicators of thermal runaway, gas leakage and other critical safety risks.

To achieve this, the project will explore strategies to suppress thermal runaway, adapt automotive gas sensor technology for maritime use and develop a framework for assessing the thermal propagation status of individual modules. These measures aim ensure that second-life applications in maritime settings maintain not only efficiency but also the highest standards of safety, in alignment with EU sustainability and safety targets.

4 Stakeholder analysis

4.1 Introduction

This sub-chapter identifies key stakeholder groups based on the target groups already identified in the proposal, but also additional ones, from the following areas: battery manufacturers and suppliers, manufacturers of electrical and electronic components (including distribution grids, converters, and chargers), potential users of second-life batteries (stationary or mobile), engineering service providers, shipbuilders and suppliers, public authorities, and regulatory and certification bodies.

These expanded key stakeholder/target groups (TGs) are then mapped to the key exploitable results (KERs) and innovations (INNs) of ***eWAVE*** and categorized using the PESTLE methodology [22] to identify missing links and use them to identify possible external stakeholders of the project who need to be contacted and with whom information exchange has to be established.

4.2 Methodology

The methodology for identifying key stakeholder/target groups is based on the following approach:

- Analysis, review and supplementation of the KERs identified in the proposal phase
- Analysis, review and supplementation of the INNs identified in the proposal phase
- Analysis, review and supplementation of the target groups identified in the proposal phase
- Assignment of the expanded target/stakeholder groups (TGs) to the relevant categories of the PESTLE methodology
- Assignment of the expanded TGs to the extended KERs
- Assignment of the expanded TGs to the supplemented INNs
- Analysis of the assignments for completeness and gaps

4.3 KERs of the proposal

The following table gives an overview about the KERs identified during the proposal phase:

Table 4. KERs identified during the proposal phase

Identifier	Title	Description
KER01	Battery Passport (BP) for batteries in shipping	BP for ship batteries, incl. 2nd-life use and enhanced circular economy (CE); Evaluation & planning efficiency in terms of safety/reliability metrics through probabilistic BP method
KER02	2nd-Life applications for BSs from shipping	2nd-life applications for Battery Systems (BSs) from shipping, including smart battery design (concepts, components) to reduce the time required for reuse
KER03	Enhanced System Simulation Software	Modular, scalable batteries that enable large BSs connected directly to primary DC power systems and ensure safe operation of high nickel content batteries under all conditions
KER04	Fast charging algorithms for enabling 4C charging	Fast-charging algorithms leveraging the modular converter concept

Identifier	Title	Description
KER05	Algorithms for direct integration of batteries in MV AC grids	Direct battery integration in AC grids without conventional converters
KER06	Safety requirements for handling HV batteries in ships	Enhanced battery safety with advanced real-time capable SoX (SoC/SoS/SoH) estimation algorithms surpassing current BS safety standards
KER07	Innovative Battery Module Design for Maritime use	Modular, scalable batteries that enable large BSs connected directly to primary DC power systems using advanced condition monitoring (CM) for classifying higher-voltage BSs
KER08	Lightweight composite module housing	Reduced battery module weight
KER09	New Simcenter Amesim vessel demonstrator	Vessel demonstrator with modular, scalable batteries that enable large BSs to be connected directly to primary DC power systems including battery performance models that can operate in real time, validated in 4 different vessel types.
KER10	Tool-based assessment methodology	Assessment methodology focussing on economic & ecological analysis of BS from shipping (1st and 2nd life) and increased CE; Evaluation & planning efficiency in terms of safety/reliability metrics through probabilistic BP method
KER11	Improved method for barrier identification	Reduced barriers to commercial deployment; Target: Definition of detailed countermeasures for the top 3-5 barriers that could limit the commercialization of ***eWAVE*** innovations and solutions
KER12	Identified gaps in current class rules	Updated class rules & standards
KER13	Utilization of condition monitoring in class services for electric ships	Advanced CM for classifying higher-voltage BSs with onboard real-time condition monitoring transferred to updated class rules & standards
KER14	Advanced SOC and SOH algorithms for batteries	Showcasing of a fully modular BS operating at elevated voltage in a DC grid, also compatible with medium voltage AC grids and BS efficiency improvement including battery performance models that can operate in real time using advanced real-time capable SoX (SoC/SoS/SoH) estimation algorithms
KER15	Battery condition monitoring tool	Comprehensive CM platform for marine batteries with onboard real-time CM
KER16	Comparative design tool for DC bipolar distribution systems	Design tool for DC bipolar distribution systems
KER17	Integrated BMS – Converter control for increased efficient overall system control	BS with controlled output power enabling enhanced control for DC grid voltage stability and reliability and considering battery integration concept with modular converter systems
KER18	Wireless BMS for increased battery safety	Surpassed current BS safety standards
KER19	MMC Power Electronic Modules for HV & currents	Modular, scalable batteries enabling large BSs connected directly to primary DC power systems including battery integration concept with modular converter systems
KER20	DC output of a MMC based battery storage system	Modular, scalable batteries enabling large BSs connected directly to primary DC power systems including battery integration concept with modular converter systems
KER21	MMC based Battery Storage >1000V	Modular, scalable batteries enabling large BSs connected directly to primary DC power systems including battery integration concept with modular converter systems

4.4 Innovations of the proposal

The following table gives an overview about the planned innovations of ***eWAVE*** (INN), identified in the proposal phase:

Table 5. Planned eWAVE innovations from the proposal phase

Identifier	Title	Description
INN_01	High energy-density battery	New battery chemistry, light-weight housing design and wireless BMS to enable high energy-density battery system
INN_02	High voltage battery systems	High voltage BSs using scalable modular power electronic converters and insulation
INN_03	Applicability of battery systems	Applicability of modular BS to other grid types (bipolar DC, AC, shore-side grids)
INN_04	Battery safety	Methods to improve Battery State Estimation and Safety
INN_05	Sustainable and more circular battery systems	Investigation of concepts to improve sustainability and circularity of BSs considering battery passport, 2nd-life applications and sustainable battery housing
INN_06	Electric system topologies and controls	Novel electric system topologies and control for different ship types with Digital Twins

4.5 Identified key stakeholder/target groups

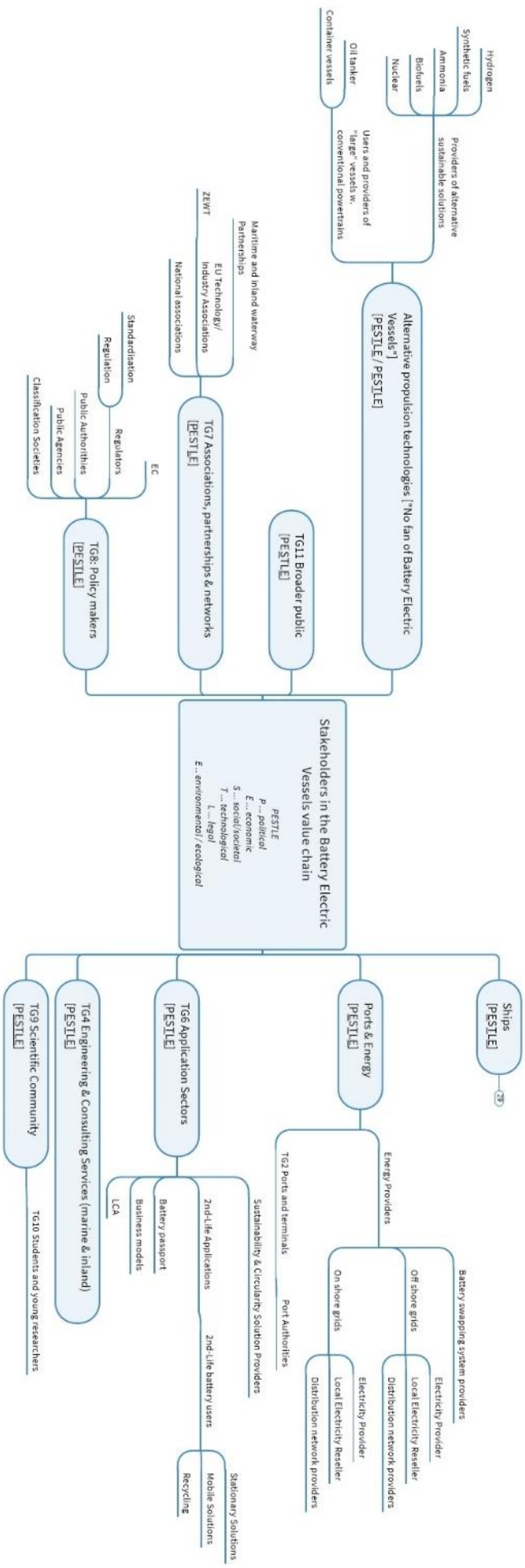


Figure 37. Stakeholder/target groups (TGs) identified and extended upon from the proposal, drawn from the electric shipping value chain (see Appendix for an enlarged version)

Figure 37 not only shows the TGs identified but also assigns them to the relevant categories of the PESTLE methodology to illustrate a comprehensive coverage of all relevant aspects of the electric shipping value chain/'eco-system'. The following table provides an overview of the categories represented by TGs.

Table 6. TG categories

TG Identifier	TG Name	PESTLE areas
TG_01	Ship operators (maritime & inland)	P**E**S**T**L**E**
TG_02	Ports & terminals (charging infrastructure	P**E**S**T**L**E**
TG_03	Technology providers and integrators (Electric storage system and converter providers, Software developers for ship systems, Simulation & Digital Twin experts)	P**E**S**T**L**E**
TG_04	Engineering & Consulting Services (maritime & inland)	P**E**S**T**L**E**
TG_05	Shipyards (maritime & inland)	P**E**S**T**L**E**
TG_06	Application Sectors (Sustainability & Circularity solutions: 2nd-life applications, life-cycle management (LCM)…)	P**E**S**T**L**E**
TG_07	Associations, partnerships & networks (Maritime and inland waterway partnerships, EU technology/ industry associations, National associations)	**P**EST**L**E
TG_08	Policy makers (European Commission, regulators [standardization & certification bodies], public agencies, classification societies)	**P**E**STLE**
TG_09	Scientific community	P**ESTLE**
TG_10	Students and young researcher	PESTLE
TG_11	Broader public	PESTLE
_TG_12_	_Energy providers related to TG_02_	_P**E**S**T**L**E**_
_TG_13_	_Providers and users in favour of other propulsion technologies ("contra")_	_PESTLE_

The following table provides an overview about the identified TGs within the electric shipping value chain, as shown in Figure 37, and the project consortium partners that can cover these TGs either directly or through their existing networks.

Table 7. Overview of identified TGs mapped to the eWAVE consortium partners.

TG Identifier	TG Name	Consortium partner
TG_01	Ship operators (maritime & inland)	DLR
TG_02	Ports & terminals (charging infrastructure)	-
TG_03	Technology providers and integrators (Electric storage system and converter providers, Software developers for ship systems, Simulation & Digital Twin experts)	SIRO, STABL, IFAG, FARPLAS, SIE, I2M, SINTEF, ME, DAMEN, FREIRE
TG_04	Engineering & Consulting Services (maritime & inland)	ME, SIE, I2M
TG_05	Shipyards (maritime & inland)	DAMEN, FREIRE
TG_06	Application Sectors (Sustainability & Circularity solutions: 2nd-life applications, LCM…)	LBF, SYRION
TG_07	Associations, partnerships & networks (Maritime and inland waterway Partnerships, EU technology/ industry associations, National associations)	DNV

TG Identifier	TG Name	Consortium partner
TG_08	Policy makers (European Commission, regulators [standardization & certification bodies], public agencies, classification societies)	DNV
TG_09	Scientific Community	FM, SINTEF, LBF, VIF, DLR
TG_10	Students and young researchers	SYRION, ViF, FM
TG_11	Broader public	All partners
TG_12	*Energy Providers related to TG_02*	-
TG_13	*Providers and users in favour of other propulsion technologies (“contra”)*	-

The rows in italics represent gaps identified within the key stakeholder groups of the value chain.

Table 9 and Table 10 shows the mapping of the TG to the KER (table 9) and the innovations (Table 10).

Table 8. Matching of TGs and KERs

TG Identifier	TG Name	KER
TG_01	Ship operators (maritime & inland)	1,2,4,6,13
TG_02	Ports & terminals (charging infrastructure	4,6
TG_03	Technology providers and integrators (Electric storage system and converter providers, Software developers for ship systems, Simulation & Digital Twin experts)	1-21
TG_04	Engineering & Consulting Services (maritime & inland)	1-21
TG_05	Shipyards (maritime & inland)	3,4,5,13,15,17
TG_06	Application Sectors (Sustainability & Circularity solutions: 2nd-life applications, LCM…)	1,2,10
TG_07	Associations, partnerships & networks (Maritime and inland waterway Partnerships, EU technology/ industry associations, National associations)	1,2,4,10,11
TG_08	Policy makers (European Commission, regulators [standardization & certification bodies], public agencies, classification societies)	1,2,4,6,11,12,13
TG_09	Scientific Community	1-21
TG_10	Students and young researchers	1-21
TG_11	Broader public	1,2,6
TG_12	*Energy providers related TG_02*	*4,6*
TG_13	*Providers and users in favour of other propulsion technologies (“contra”)*	*1-21*

Table 9. Matching of TGs and INNs

TG Identifier	TG Name	Innovation (INN)
TG_01	Ship operators (maritime & inland)	3,4,5
TG_02	Ports & terminals (charging infrastructure	3,4
TG_03	Technology providers and integrators (Electric storage system and converter providers, Software developer for ship systems, Simulation & Digital Twin experts)	1-6
TG_04	Engineering & Consulting Services (maritime & inland)	1-6
TG_05	Shipyards (maritime & inland)	1-6
TG_06	Application Sectors (Sustainability & Circularity solutions: 2nd-life applications, LCM…)	1,5
TG_07	Associations, partnerships & networks (Maritime and inland waterway Partnerships, EU Technology/ Industry Associations, National associations)	4,5,6
TG_08	Policy makers (European Commission, regulators [Standardization, Certification bodies], public agencies, classification societies)	4,5,6
TG_09	Scientific Community	1-6
TG_10	Students and young researcher	1-6
TG_11	Broader public	4,5
TG_12	*Energy Providers related to TG_02*	*3,4*
TG_13	*Providers and users in favour of other propulsion technologies ("contra")*	*1-6*

4.6 Stakeholder analysis results

Through the detailed analysis of key stakeholder/target groups in the value chain for battery electric ships, 2 additional groups were identified compared to the proposal:

- Electric Power Suppliers (for the ports)
- Stakeholders who support other powertrain technologies

Electric Power Suppliers

The increased market penetration of battery-electric ships and the corresponding charging infrastructure must go hand in hand. Potential operators of such ships must therefore work closely with the relevant energy suppliers, not least at a strategic level, to ensure that the necessary infrastructure is put in place in good time. The ever-increasing energy and performance requirements for charging will pose additional challenges for the supply of energy in the future.

Last but not least, different charging concepts such as direct charging, battery swapping, etc. require fundamental investment decisions with corresponding long-term financial and operational consequences, which must be well coordinated between shipbuilders, ship operators and infrastructure operators (ports, energy suppliers) in order to avoid stranded costs and achieve the most efficient and effective market penetration of fully electric ships.

Stakeholders in favour of other propulsion technologies

The volume of goods and passengers transported by ship will continue to rise in the future. This brings with it the challenge of handling higher transport volumes while reducing CO_2 emissions.

In particular, rising CO_2 taxes on marine diesel will increase the attractiveness of alternative solutions such as hydrogen, synthetic fuels, ammonia, biofuels or nuclear power. However, users of large conventional ships are likely to remain reluctant to switch for as long as possible, due to the high investment costs and long service life of such conventional ships, and the shortcomings of alternative propulsion systems, such as lower technological maturity, insufficient range, lack of infrastructure and low fuel availability.

On the other hand, hybrid solutions (such as diesel-battery-electric) can bring improvements/synergies to both conventional propulsion systems (higher efficiency, lower emissions) and alternative solutions, thereby accelerating the market uptake of future purely alternative solutions (such as battery-electric), especially for smaller classes of ships.

The next step for ***eWAVE*** is to establish contact with the following TGs, which are not well covered either directly or through the relevant networks of the ***eWAVE*** project partners (see above):

Table 10. Potential stakeholders to contact further on the project

Target Group	Objective	Activities
TG_02 Ports (Authorities) & Terminals	Establish information exchange on fast charging and safety (KER4, KER6, INN3, INN4)	Workshops, Interviews, Invitation to project presentations
TG_12 Electric Suppliers (for ports)	Establish information exchange on fast charging and safety (KER4, KER6, INN3, INN4)	Workshops, Interviews, Invitation to project presentations
TG_08 Policy Makers	Establish information exchange on innovations (INN4-INN6), key exploitable results (KER1,2,4,6,11,12,13) as well as support for communication to TG_13	Workshops, Interviews, Invitation to project presentations
TG_13 Providers and users of other propulsion technologies (contra)	Establish information exchange on innovations (INN1-INN6)	Workshops, presentations, round tables

5 Conclusions

The market and regulations analysis performed and reported in this document has resulted in a full update of: the current maritime battery market, a market forecast for the years 2028 and 2033, an up-to-date overview of relevant decarbonization and integration regulations, and a structured stakeholder overview mapped against other indicators. The conclusions derived from each topic are further elaborated below.

The maritime battery market analysis has primarily been based on the ship register provided by the Maritime Battery Forum. As with previous studies, this analysis shows that the battery applications are very diverse in many aspects. Of course, there is a lot of diversity among ships themselves in terms of type, size, power levels and operational profiles. However, in addition to fully or partial electric applications, most batteries are part of a hybrid topology. Hybrid topologies have many applications, ranging from heavy-duty load levelling to low-demand backup power. Diversity has also been observed in the types of batteries used. Both heavy-duty batteries, such as LTO, and higher-energy types, such as NMC and LFP, are used. The share of LFP batteries has increased in recent years.

Europe remains the region with the largest share of battery-powered ships in operation, accounting for more than 60% of the total. North-America and Asia are two other regions with noticeable share. The largest ship categories are still ferries, offshore vessels, cargo ships, and tugs, which have shown significant growth especially in installed energy capacity in recent years. Tugs often operate fully electric, which requires large batteries. These ship categories operate close to shore, having limited range and power and the possibilities of charging currently available on the key side.

The analysis shows that the maritime battery market is still growing. This applies to both the number of ships installed with batteries each year and the energy capacity installed per ship. This means that the annual delivered energy capacity shows an even larger growth curve. A forecast has been made based on the trendline of the installed energy capacity over the last 10 years. This shows a similar trend to that predicted for the EV market. It is expected that the annual installed capacity will be 3 times higher in 2028 than in 2023, and 5 times higher in 2033.

Although prices of maritime batteries are still relatively high compared to other applications, like EVs, they are decreasing. Despite decreasing prices, it is expected that the market will grow financially as well, albeit more slowly than the annual energy capacity.

Decarbonization targets and regulations, which are a key driver for battery applications, are available from the IMO and the EU, with new regulations coming into force. Some of these regulations apply to larger ship types where batteries alone cannot provide a zero-emission solution due to greater range and high power demands resulting a very high energy demand.

The EU battery passport regulation, which will enable a circular economy for batteries, requires a state monitoring of the battery. State of Health (SoH) is the most important parameter to monitor, but State of Safety (SoS) should also become available in the future. For the implementation of circular batteries, a 9R framework has been proposed.

Two stakeholder target groups have been added to the list already identified and included in the proposal of eWAVE. All the target groups have been mapped to key exploitable results (KERs) and innovations, and organised by using the PESTLE method. Furthermore, the stakeholders have been mapped to the eWAVE consortium partners. Any remaining unmapped stakeholders will be covered further into the project.

6 References

[1] SEABAT (Horizon 2020), "D1.2 - Market evolution and potential within 5, 10, 15 years for different marine applications," 2021.

[2] P. Rampen, "HYPOBATT - Marine Hyper Charging Application Overview, KPI's and Specifications," EU-Horizon project HYPOBATT, 2022.

[3] SEABAT (Horizon 2020), "D2.1 - Appilcation matrix," 2021.

[4] EMSA, "Study on electrical energy storage for ships," 2020.

[5] Maritime Battery Forum, "Ship register database," February 2025.

[6] SEA Europe, "2023 Shipbuilding Market Analysis," 2024.

[7] Clarksons Research, "Shipping & Shipbuilding Forecast Forum," 2025.

[8] Maritime Battery Forum, "Maritime type approved battery systems," 2024.

[9] Maritime Battery Forum, "Maritime Battery Technology Update - Q1-2025," 2025.

[10] "Electric vehicle battery prices are expected to fall almost 50% by 2026," Goldman Sachs, October 2024. [Online]. Available: https://www.goldmansachs.com/insights/articles/electric-vehicle-battery-prices-are-expected-to-fall-almost-50-percent-by-2025. [Accessed May 2025].

[11] "Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour," BloombergNEF, December 2024. [Online]. Available: https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/. [Accessed May 2025].

[12] Polaris Market Research, "Electric Ship Market," 2021.

[13] The Business Research Company, "Electric Ships Global Market Oppertunities and Strategies to 2033," 2024.

[14] DNV, "Maritime Forecast to 2050," *Energy Transition Outlook 2024,* 2024.

[15] EMSA, "Guidance on the Safety of BESS on board ships," EMSA, 2023.

[16] E. P. a. Council, "Regulation (EU) 2023/1542 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020, and repealing Directive 2006/66/EC," European Union, Brussels, 2023.

[17] SEABAT, "Battery Circular Economy in Europe," European Commission H2020 Project Deliverable, 2021.

[18] F. Mandrile, M. Pastorelli, S. Musumeci, I. A. Urkiri and A. Remirez, "Second life management from battery storage system of electric waterborne transport applications: Perspectives and solutions," in *IEEE Access*, 2023.

[19] M. B. Forum, "Life cycle analysis of batteries in maritime sector," 2016.

[20] M. Gharebaghi, O. Rezaei, L. Changyao and W. Zhanle, “A Survey on Using Second-Life Batteries in Stationary Energy Storage Applications.,” *Energies,* vol. 18, no. 1, 2024.

[21] K. Neigum and W. Zhanle, “Technology, economic, and environmental analysis of second-life batteries as stationary energy storage: A review,” *Journal of Energy Storage,* vol. 103, 2024.

[22] “Context analysis – PESTEL,” EC INTPA.D.4 - Quality and results, evaluation, knowledge management, [Online]. Available: https://wikis.ec.europa.eu/spaces/ExactExternalWiki/pages/50109048/Context+analysis+%E2%80%93+PESTEL. [Accessed May 2025].

[23] VOLTA Foundation, “2024 Battery Report,” 2024.

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Abbreviations and Definitions

Term	Definition
AC	Alternating Current
BESS	Battery Energy Storage System
BMS	Battery Management System
BP	Battery Passport
BS	Battery System
CE	Circular Economy
CII	Carbon Intensity Indicator (CII)
CM	Condition Monitoring
DC	Direct Current
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
EMSA	European Maritime Safety Agency
ETS	EU Emissions Trading System
EU	European Union
EV	Electric Vehicle
GT	Gross Tonnage
HV	High Voltage
IMO	International Maritime Organisation
INN	Innovation
KER	Key Exploitable Result
LCA	Life Cycle Analysis
LFP	Lithium-Iron-Phosphate
LTO	Lithium-Titanate
MBF	Maritime Battery Forum
NMC	Nickel-Mangan-Cobalt
OCV	Open Circuit Voltage
SSMP	Ship Energy Efficiency Management Plan
SoC	State of Charge
SoH	State of Health
SoS	State of Safety
SoX	State of X
TG	Target group
UPS	Uninterruptable Power Supply
WP	Work Package

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Annex – Detailed ship type numbers

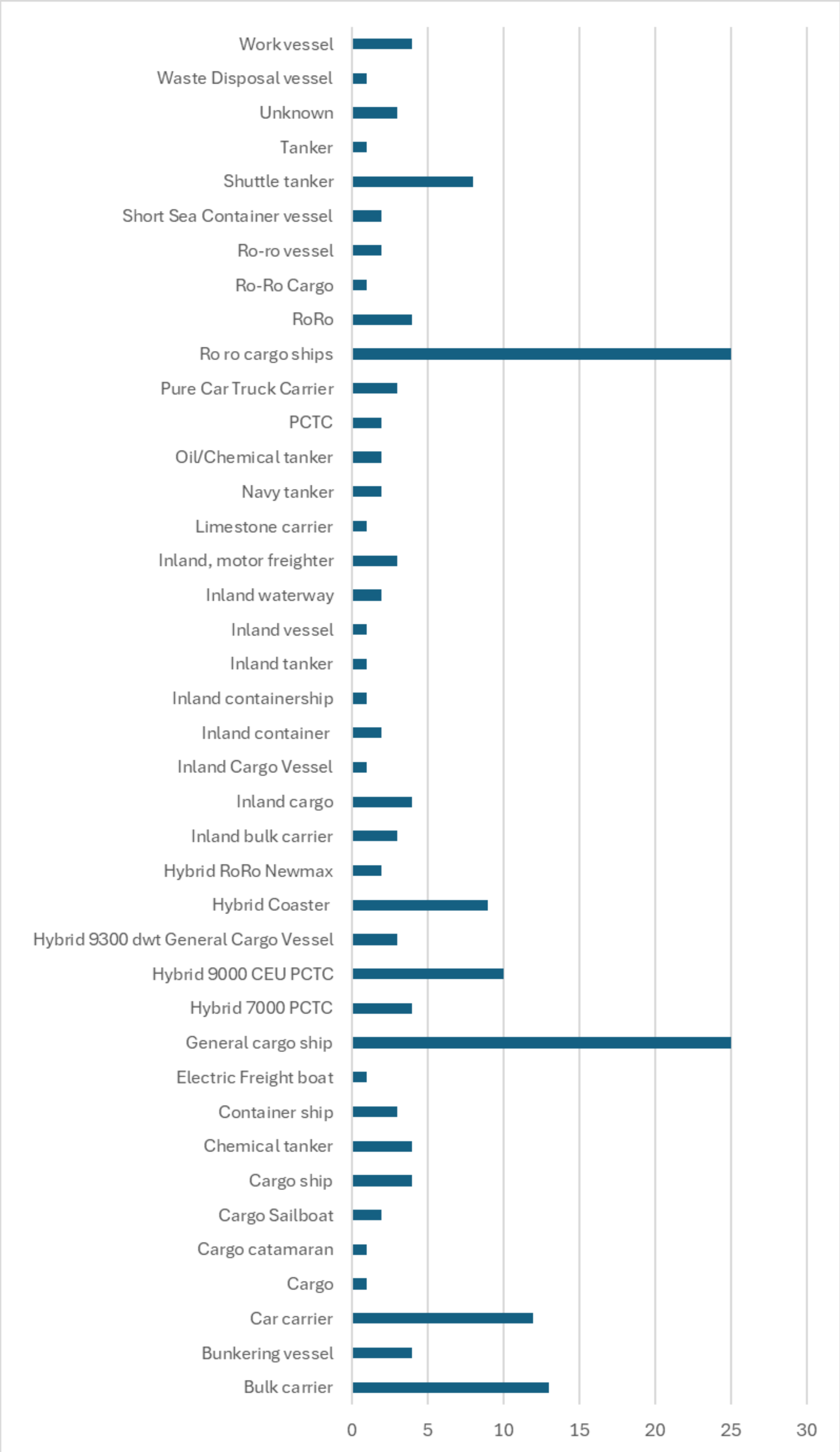

Figure 38. Number of ships per cargo ship type.

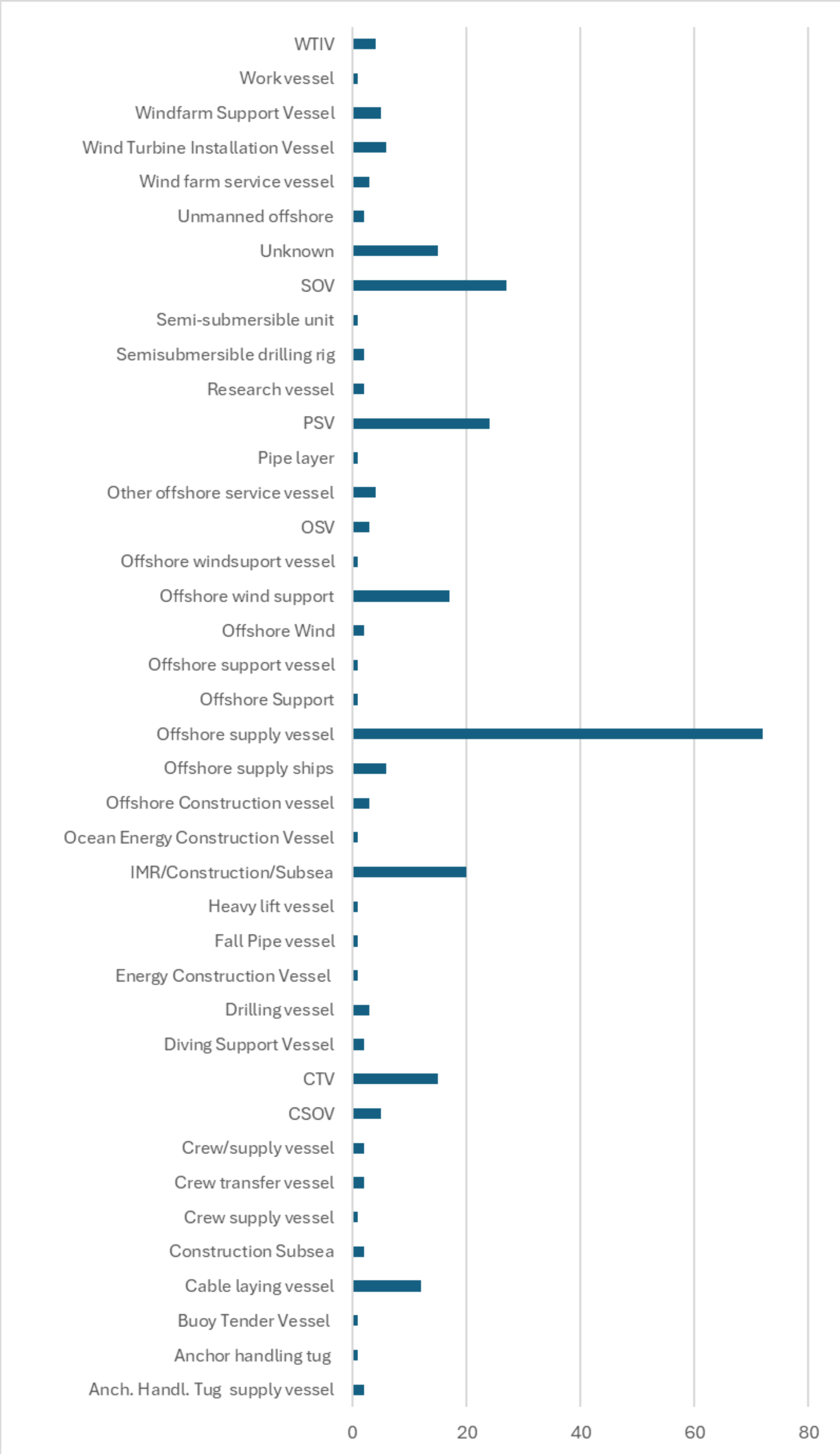

Figure 39. Number of ships per offshore ship type.

Annex – Stakeholder mindmap

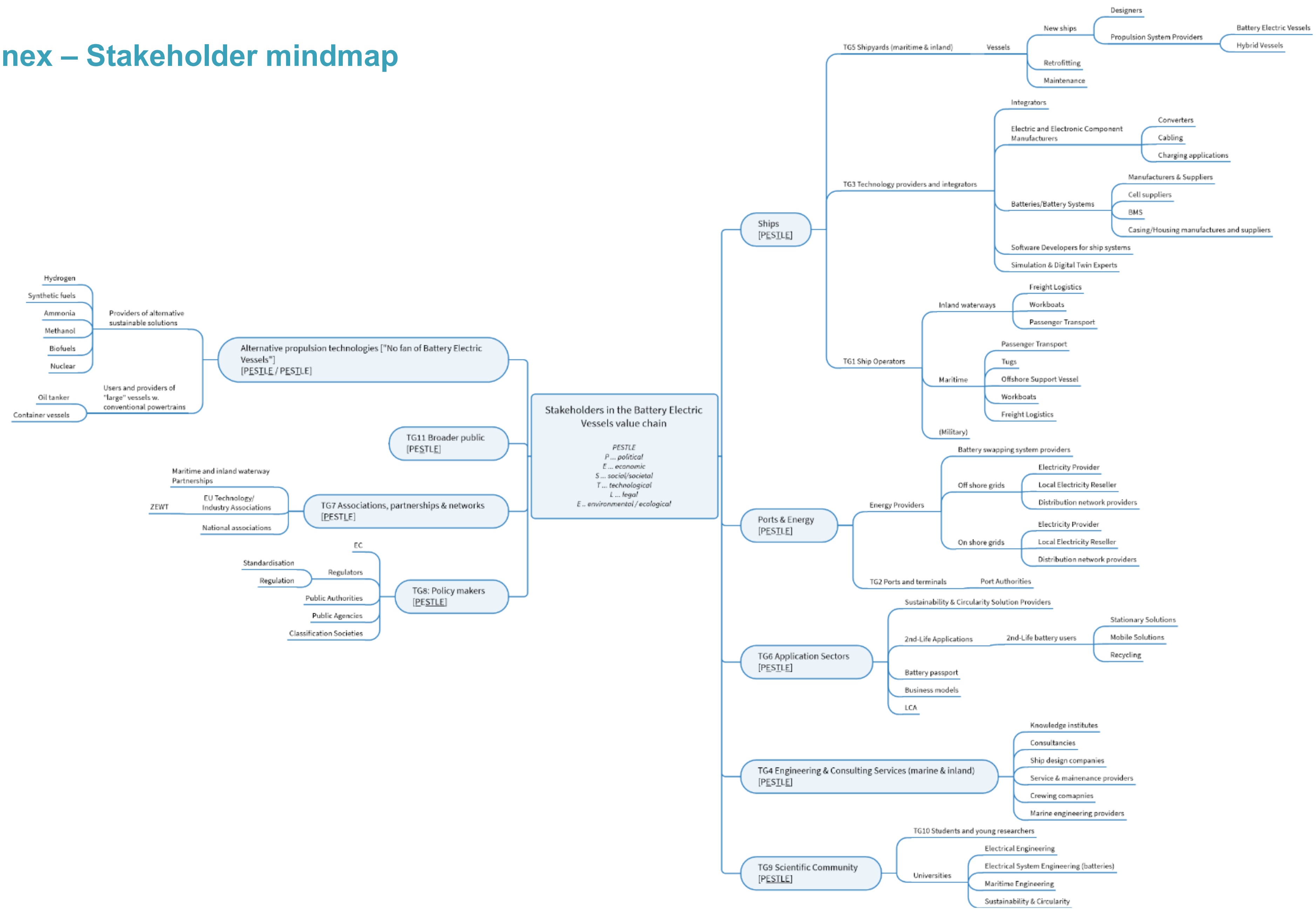

Figure 40. Enlarged version of Figure 37: TGs) identified and extended upon from the proposal, drawn from the electric shipping value chain

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