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AENEAS

innovAtive ENErgy storage systems onboArd vesselS

Deliverable D1.1: First version of operational profiles and ESS requirements for a broad range of vessels

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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 document is part of **Work Package 1**, **Operational scenario Specification and Requirements**, which main objective is to draw and define the main vessels characteristics that are currently electrified by using batteries and those which will be electrified in the near future and that are suitable for the application of new ESS systems.

The scope of this document is to draft vessels requirements for the development of new ESS for different marine applications. To understand the required performance of the product under development, it is important to know the features of different vessels and their use. Indeed, a first overview of the fleet is given with general description of its use, arrangement and energy systems. Plus, a brief description of the company's data collectors is given to explain the source of electrical data that are depicted in the document.

Different typologies of ship are illustrated providing for each of them information about electrical and technical equipment for the three phases of the vessels at sea: navigation, port stay and manoeuvring phases. To fully understand the purpose of electrical storage systems, some marine battery applications are described which represent needs for the optimization of electrical energy use, such as load levelling or peak shaving.

In the last part of the document, the safety and integration requirements for the installation of new ESS and system installation and innovation are provided.

1 Introduction

1.1 Rationale of this deliverable

The objective of this deliverable is to draw a first version of operational profiles and ESS requirements for a broad range of vessels.

This deliverable belongs to the WP1 whose lead beneficiary is Grimaldi Euromed S.p.A. The WP1, Operational Scenario Specification and Requirements, aims to determine operational profiles, safety and integration requirements of SSB, SC and hybrid SSB/SC for vessels, to define 3 use-cases to demonstrate the 3 ESS at TRL 5 and to develop a monitoring and evaluation framework with the help of all partners.

GRIM, assisted by INLS, analysed operational profiles of short sea and seagoing vessels operated by GRIM and inland water transport vessels operated by INLS. Real-world operations data come from data collector systems, connected to several ship sensors and to the Ship Automation system. This data include power demands for different seasons and operation over the year. From this total set of data, GRIM and INLS derived electrical load and power operational profiles for the ESS, which will be input for the simulation in WP2.

GRIM and INLS also madean inventory of operational requirements for the different ship types, with input of SOER and FS from shipyard point of view, and with input from FV from port point of view. Such operational requirements include operational range (navigation distance and time), auxiliary power requirement, waiting times and locations (for possible energy charging), necessary speed, thrust performance and peak shaving demands, load levelling, costs, integration with onboard electric grid, gravimetric and volumetric energy density, and required space for ESS onboard integration. For the integration of possible renewable energy systems, such as solar and wind systems onboard, GRIM provided input from their current fleet.

All partners contributed in defining sustainability TCO requirements and AUTH provided the interface to the assessment in WP6. ISSN with help of SOER, FS and GRIM defined the safety requirements and safety critical risks that shall be covered for safe ESS installation onboard of the different ship types, based on operation and safety requirements from certification and type approval of marine battery systems.

The first main result is a first version of a complete set of requirements and operational profile of each ship type, as input for the definition of the use-cases of the following tasks.

<u>Attainment of the objectives and explanation of deviations</u>

All related task objectives of this deliverable have been achieved and no deviations have been taken.

2 Short Sea Shipping and inland water transport

Transport represents almost a quarter of Europe's greenhouse gas emissions and is the main cause of air pollution. The transport sector remains one of the only sectors of the EU economy where emissions are still above 1990 levels[1]. To achieve climate neutrality, it is needed to reduce transport emissions by 90% by 2050. Road, rail, aviation, and waterborne transport will all have to contribute to the reduction. Achieving sustainable transport means putting users first and providing them with more affordable, accessible, healthier and cleaner alternatives to their current mobility habits.

The European Green Deal refers to the need to achieve clean, climate neutral shipping and waterborne operations and to the importance of research and innovation in this respect. Waterborne transport remains an important emitter of GHG and the sector needs to step up its efforts on a significant scale and through a wide range of measures. Within the International Maritime Organisation (IMO) global agreement was reached in 2018 to cut total shipping GHG emissions by at least 50% by 2050 compared to 2008. Actually, by the same date the Union aims to cut all transport CO2 emissions by at least 90%. The maritime transport is an important mode of transport, carrying out 80% of world trading activities, thus playing a key role in global economy[2]. Strong efforts have thus to be carried out to develop innovative solutions in order to decarbonize waterborne transport, including technologies that significantly improve energy-efficient and foster the use of sustainable energy resources.

Electric energy storage within most waterborne applications deployments is founded upon traditional battery technologies. However, specific operational requirements (e.g. autonomy, power peaks, etc.), in particular in adverse conditions outside sheltered waters, remain a concern as conventional batteries (e.g. li-ion) are not able to meet these strenuous and flexible demands. As a consequence, the sizing and selection of the right type of batteries became an important new aspect of ship design.

So, the aim of the deliverable D1.1 is to determine the requirements needed from Grimaldi and Inland Shipping vessels in terms of electrical requirements in order to match the integration of different electrical storage systems on board of the vessel. From this perspective, other energy storage currently under development can be useful because they might be valuable for waterborne application in the future to overcome the drawbacks of traditional batteries such as the solid-state batteries and super-capacitors.

The final goal of this deliverable is to determine the input required for the following work packages and so to define the operational requirements of the ESS which are to be designed in this project. The result will be an overview of all typologies of the vessels of the shipowners in terms of technical specifications.

The short-sea shipping is the maritime transport of goods over relatively short distances as opposed to the intercontinental cross-ocean deep-sea shipping and encompasses the movement of cargo and passengers mainly by sea along a coast, without crossing an ocean.[3] Roughly 40% of all freight moved in Europe is classified as short-sea shipping, but the greater percentage of this cargo moves through Europe’s heartland on rivers and not oceans.[4] In the context of European Union transport it is defined as maritime transport of goods between ports in the EU on one hand, and ports situated in geographical Europe short sea shipping. It also includes feeder services: a short-sea network between ports with the objective of consolidating or redistributing freight to or from a deep-sea service in one of these ports, the so-called hub port. Therefore, Short Sea Shipping concerns both local and international sea transport, and includes coastline routes and connections with the islands, river and lake transport, the traffic between the EU Member States and Norway, Iceland and the non-European Countries of the Baltic Sea, Black Sea and Mediterranean Sea, the sorting routes of ports that have interests in oceanic traffics. The Short Sea Shipping is a transport mode that can be considered both complementary and alternative to people and freight road transport. In both cases there are several benefits, among which significant cost-saving, reliability in terms of distance covered on time and reduction of polluting emissions. As for the inland navigation, it is a transport system allowing ships and barges to use inland waterways (such as canals, rivers and lakes). These waterways have inland ports, marinas, quays, and wharfs.

The Grimaldi Short Sea Shipping is in the Mediterranean area by deploying a fleet of modern Ro/Ro and Ro/Ro-Passenger ships which are operating on Italian cabotage and international routes linking Italy, Greece, Spain, Tunisia, Malta, Libya, Montenegro and Morocco. As far as the Northern Europe/Mediterranean trade is concerned, Grimaldi Euromed conceived and developed the Euro-Med Network concept, a veritable maritime conveyor belt designed to transport any type of vehicle between Northern Europe and the Mediterranean, often including direct delivery up to a single dealer's location.

As follows, it is shown a list of short sea Grimaldi vessels and their routes:

Table 2.1: Routes of short sea Grimaldi vessels

Adriatic line		
Ancona - Igoumenitsa - Patrasso	**Brindisi - Igoumenitsa**	**Venezia - Bari - Patrasso**
Florencia	Cruise Smeralda	Eurocargo Alexandria
Venezia	Igoumenitsa	Eurocargo Cagliari
		Eurocargo Genova
		Eurocargo Roma

East/West		
Civitavecchia - Barcellona	**Livorno - Savona - Barcellona - Valencia**	**Sagunto - Cagliari - Salerno**
Cruise Barcelona	ECO Valencia	ECO Mediterranea
Cruise Roma	ECO Barcelona	ECO Adriatica
	ECO Livorno	
	ECO Savona	

North/South			
Genova – Livorno - Catania - Malta	**Genova - Salerno - Palermo**	**Livorno - Palermo**	**Napoli - Palermo**
Eurocargo Malta	Eurocargo Palermo	Zeus Palace	Cruise Ausonia
Eurocargo Venezia	Eurocargo Ravenna		
ECO Italia			

North/South		
Ravenna - Brindisi - Catania	**Salerno - Catania - Malta**	**Venezia - Bari - Patras**
ECO Catania	Eurocargo Savona	Eurocargo Alexandria
ECO Malta	Eurocargo Catania	Eurocargo Cagliari

Sardegna				
Civitavecchia - Arbatax - Cagliari	**Genova - Livorno - Cagliari**	**Genova - Porto Torres**	**Livorno - Olbia**	**Napoli - Cagliari - Palermo**
Corfù	Eurocargo Livorno	Eurocargo Sicilia (ex Finnmaster)	Cruise Europa	Europa Palace
			Cruise Sardegna	

Navigation on the Danube must be understood as a system of single, strongly interrelated elements. These elements are the waterways on the Danube, the vessels and their cargoes (types of goods), the ports as nodes linking inland navigation with road and rail modes, the River Information Services (RIS) together with the legal and policy framework. The potential of navigation on the Danube can be fully realised when all these elements interact.

The Danube rises in the Black Forest Mountains in Germany and flows into the Black Sea in Romania and Ukraine. The river is 2,845 km long - 2,415 navigable km - and connects 10 countries. Since early history, the Danube has been a major trade route in Europe. It is an important source of energy and drinking water, as well as a unique wildlife habitat and recreational area. Waterway capacity on the Danube is a key factor of the inland navigation system and is mainly determined by the prevailing nautical conditions (i.e. the navigability of the Danube with an effective vessel draught loaded throughout the year). This has a direct influence on the potential capacity utilisation of vessels operating on the river. Good nautical conditions and continuous maintenance of the waterway infrastructure enable the sector to offer reliable and competitive transport services. This is a crucial prerequisite for the sustainable integration of inland navigation as an environmentally friendly mode of transport into the logistical concepts of a modern economy.

Inland ports facilitate the combination of waterway, road and rail transport modes. Working in multimodal logistics chains, rail and road act as partners in inland waterway transport, enabling pre-transport and final transport operations with ports acting as a key interface. In recent decades, the Danube ports have undergone a substantial transformation from conventional inland ports to modern logistics hubs. In addition to their basic function as transhipment hubs and storage sites, ports today offer a wide range of logistics services, including commissioning, distribution and project logistics. Because they serve as production sites as well as freight collection and distribution centres, they are highly integrated into regional economies and contribute substantially to economic growth and job creation.

The three most important port locations in terms of transhipment volumes on the Danube are Izmail (Ukraine), Linz (Austria) and Galati (Romania). The Romanian seaport of Constanta occupies a special place. It is connected to the Danube via the Danube-Black Sea canal and plays an important role as a transhipment gateway to the Black Sea, facilitating trade with Asia, the Middle East and the Black Sea region.

There are two basic types of inland vessels, and these are classified into: motor vessels, which are equipped with an engine and a cargo liner, and convoys consisting of a cargo or pusher vessel and one or more non-motorised barges which are connected to the pusher vessel. On the Danube, the predominant share of cargo traffic is carried by such convoys. The most common types of cargo transported on the Danube and its navigable tributaries are ores, scrap iron, mineral raw materials, solid fuels, building materials and agricultural goods. In addition to freight, passenger transport also plays an important role as day trips and river cruises become increasingly popular.

A cornerstone of the technological modernisation of inland navigation was the implementation of River Information Services (RIS). RIS are tailor-made information and management services for inland navigation that increase transport safety and contribute to improving the cost-effectiveness, reliability and predictability of transport. It includes electronic navigational charts, vessel tracking and up-to-date online information on water levels.

The port of Constanta is located on the west coast of the Black Sea, 179 nM from the Bosphorus Strait and 85 nM from the Sulina Branch, through which the Danube flows into the sea. It covers 3,926 ha of which 1,313 ha is land and the remaining 2,613 ha is water. The two offshore breakwaters to the north and south shelter the port, creating the safest conditions for port activities. The current length of the northern breakwater is 8,344 m and the southern breakwater is 5,560 m. The Port of Constanta has a handling capacity of over 100 million tonnes per year and 156 berths, of which 140 berths are operational. The total length of the quay is 29.83 km and depths range from 8 to 19 metres. These characteristics are comparable to those offered by the most important European and international ports, allowing the reception of tankers with a capacity of 165,000 dwt and bulk carriers of 220,000 dwt.

Several projects are currently underway to build new cargo handling facilities and to improve transport connections between the Port of Constanta and its Land. These projects are mainly located in the southern part of the port.

The Port of Constanta is both a seaport and a river port. The facilities offered by the port allow any type of ship to be received. The port is connected to the Danube through the Danube-Black Sea Canal, which is one of the strengths of the Port of Constanta. Due to its low costs and the large volumes of cargo that can be transported, the Danube is one of the most advantageous modes of transport, an efficient alternative to European rail and road transport.

Large quantities of cargo are transported by river between Constanta and the Central and Eastern European countries of Ukraine, Moldova, Bulgaria, Serbia, Austria, Slovakia and Germany.To cope with future growth in river traffic, the Constanta Ports Administration has completed a barge terminal. Such investments will improve navigation conditions and develop facilities for river vessels in the southern part of the port.

2.1 Shipping company Grimaldi group

The Grimaldi Group is today the largest Italian ship-owning group and the first operator in the world for the maritime transport of cars and rolling cargo, as well as the European leader in the Motorways of the Sea. It owns more than 100 ships and operates a network of port terminals and logistics companies. The Neapolitan company is also active in the passenger sector and in container transport.[5] Its commercial coverage includes various geographic areas of the Mediterranean Sea, Northern Europe, the Baltic, West Africa, North and South America. Furthermore, the Group controls or has significant equity interests in 21 port terminals in the Mediterranean, Northern Europe, the Baltic Sea and West Africa and in various logistics companies in different countries. In particular, **Grimaldi Euromed SpA**, one of the most important companies of the Group, has played a crucial role since the mid-1990s in the development of vehicle maritime transport and integrated logistics throughout Europe.

The Grimaldi Group's **mission** is to provide efficient, reliable, innovative and high-quality services for maritime transport of freight and passengers, by constantly working to identify the needs and expectations of the customers. The Group is dedicated to excellence, social responsibility and transport solutions that promote sustainable mobility for the environment.

In addition to the quality and efficiency of the services offered, the Grimaldi Group stands out for its strong focus on **environmental issues**, which in recent years has resulted in important investments aimed at reducing harmful emissions. As matter of fact, efficiency and eco-sustainability are the heart of the Grimaldi Group's strategy. The Neapolitan Group is in fact among the first shipping companies to choose to install, on board of its ships, **scrubbers** for the purification of exhaust gases and mega lithium batteries, capable of supplying ships during port stops.[6] Furthermore, the Group is actively committed to supporting the implementation of the IMO's new regulations on sulphur emissions, as a founding member of the Clean Shipping Alliance.

In recent years, the Group has commissioned the production of new, more environmentally friendly ships, as well as converting almost all of the existing ones so as to reduce their environmental impact.

Figure 2.1: Grimaldi representative ships

Indeed, the new buildings called **Grimaldi Green 5th Generation** (GG5G), developed by the Group's Technical and Energy Saving Department in partnership with the Danish naval architect design firm Knud E Hansen, are hybrid Ro-Ro (roll-on/roll-off) cargo vessels and include vessels like as Eco Valencia and sisters. They are equipped with the latest generation of electronically controlled engines and with scrubbers for the exhaust gas purification and reduction of sulfur and particulate emissions. From this perspective, the ECO Mode is essential for the optimisation of main electrical loads (pumps, ventilation, air conditioning) during port stay with dedicated algorithms; plus, they use exhaust gas cleaning systems to reduce SOx < 0.1% and PM < 70%. They are also equipped with 350 m2 of solar panels with a peak power of 60 kWp which make it possible to reduce the current load in the port, thus increasing the autonomy of the batteries. These are the 5 MWh lithium-ion batteries in order to achieve the purpose "Zero Emissions in port" and to make peak shaving, boosting, blackout prevention and hybrid manoeuvres. From an energy efficiency perspective, the granting of more than 10,000 Energy Efficiency Certificates ("White Certificates") by Gestore Servizi Energetici (GSE) to Grimaldi Euromed was significant. These were issued for projects related to its "Eco Hybrid ships".

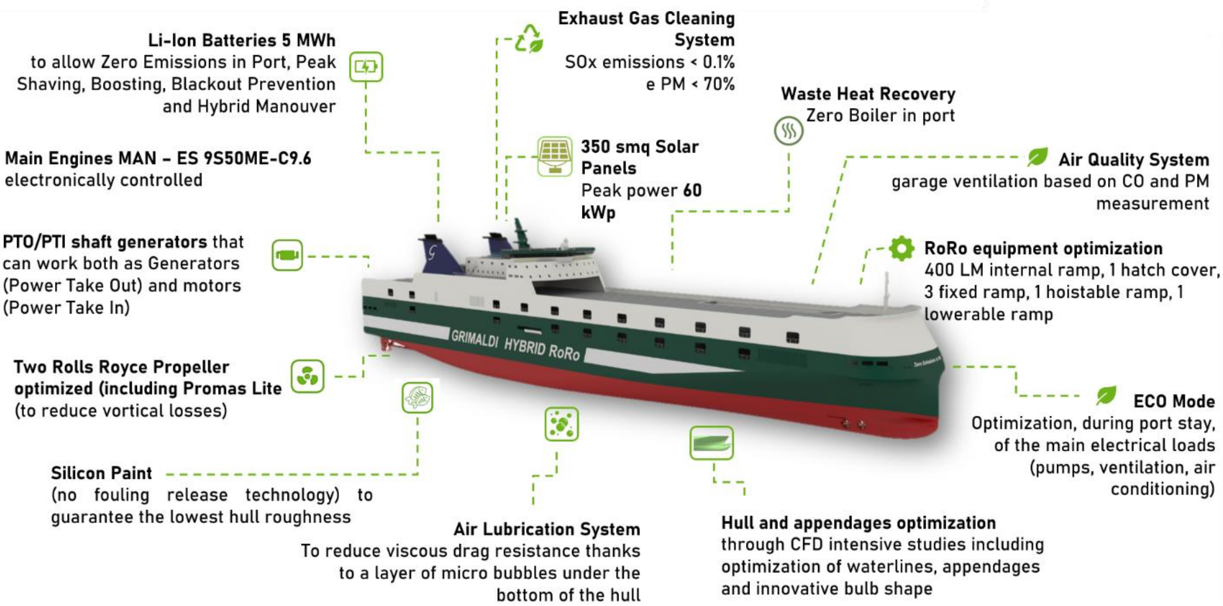

Figure 2.2: Innovative technological solutions of Grimaldi green 5th generation

The zero emission in port project aims to have ships in port with the auxiliary engines turned off and therefore without CO2 emissions[7]. Thanks to the use of batteries during port stays CO2 emissions were reduced by more than 2,300 tonnes in one year. Over the past three years, while the number of ships operated increased by 7%, direct CO2 emissions per ship generated by the Group's activities decreased by 3% thanks to investments in energy and operational efficiency projects.

In relation to other harmful emissions, starting in 2014 the Group began a system that carefully collects and monitors figures related to sulphur dioxide (SO2) emissions. In the last three years, against a 7% increase in Group operated ships, SO2 emissions fell by 88% per ship. These trends attest to the Group's commitment to pursuing the objectives set by the IMO as regards the reduction in SO2 emissions.

In 2021, the Group signed the Getting to Zero Coalition's Call to Action (a coalition it has been a part of since 2020), in which it commits to the **Net Zero CO2 Emission target** by 2050. At the same time, the International Chamber of Shipping (ICS) lodged a submission with the IMO, requesting that the targets initially envisaged be strengthened, with particular reference to the 2050 emission reduction target from -50% to net zero CO2. This is the first time that the shipping industry has demanded a more stringent law than the one imposed by the regulator itself, demonstrating a commitment to decarbonisation, so that engine and technology manufacturers, as well as distribution logistics for future green fuels, are encouraged to accelerate their work.

The Group is confirming its commitment to decarbonisation even in the **Cruise ship series**, which has made possible for significant results to be achieved, increasing the volume of goods transported, while reducing consumption and harmful emissions. Decarbonisation and energy efficiency are at the very core of the Grimaldi Group's agenda when it comes to reducing its environmental footprint. The research and development activities carried out, include the patent obtained by Grimaldi Euromed for the filtration of microplastics in the sea in order to remove microplastics from seawater without the use of polluting chemical compounds. Filtration is currently active on the Cruise Barcelona, Cruise Roma, Cruise Smeralda, Cruise

Ausonia and Cruise Bonaria ships. Along with the installation of wash water filtration (WWF) systems to improve the quality of washwater discharge, research activities were conducted to capture micro plastics in the sea. Based on the results of these experimental campaigns, a prototype system for filtering this washwater discharge, during navigation was developed. The system was patented and was installed in June 2021 on board the Cruise Roma, operating on the Civitavecchia-Porto Torres-Barcelona route. This system is able to remove approximately 64,680 microplastic particles from the sea during a single 18-hour journey. In order to make the whole process more sustainable, a system was developed for the regeneration and reuse of the filter fabric. In this way, the same filter fabric can be reused for several cycles, thereby reducing the waste produced.[8]

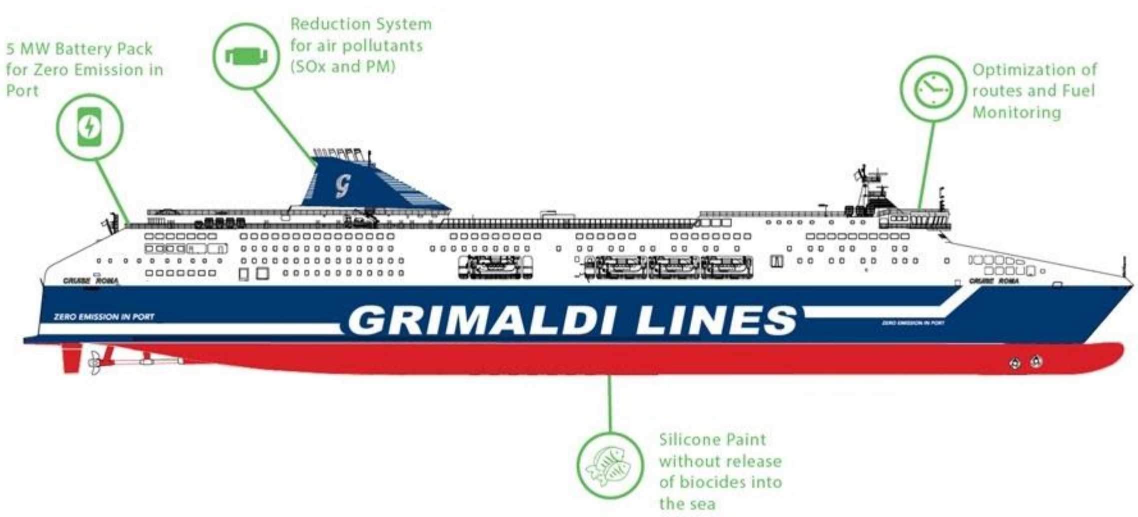

Figure 2.3: Innovative technological solutions of Grimaldi Cruise series ship

Grimaldi is expecting indeed solutions to improve overall energy efficiency and drastically lower emissions of its waterborne transport vessels through innovative electric energy storage, which is safe and cost competitiveness compared to its lithium ion batteries. These solutions should enable hybrid and fully electric shipping under all conditions that specific ships might encounter, including adverse conditions outside sheltered waters. The innovative ESS should have high energy density so that it can be suitable for long distance navigation and it can facilitate the achievement of the zero emission in port even in cases of long port stays. Plus, this technology should operate the peak shaving during navigation in order to level the electrical load and to increase durability and performance of the whole system. In a more specific, Grimaldi is expecting some enhancements through such technology in terms of:

- Operating lifetime and cycle life depending on operational profiles
- Convenient system costs in €/kWh
- Volumetric energy density in Wh/L with a decrease of space occupancy
- Increase of safety level
- Energy and power
- Mechanical integration and electrical integration

2.2 Shipping company Inland Shipping srl

Inland Shipping provides logistic services like freight forwarding, storage & transshipment and operations assistance. **Inland Shipping** is involved in different research projects for Autonomous shipping.

Since its foundation in 2012, Trading Line began with a humble setup of one pusher and 10 barges with a total capacity of 20,000 tons. Through consistent growth and a strategic long-term vision, we amplified our capacity to a staggering 128,000 tons of dry-bulk (across 46 units) and 20,000 tons of liquid by 2022. The resounding vision of our company is to expand our footprint up to 100 vessels and offer comprehensive services across the full length of the Danube, from Constanta to Regensburg.

Our unique proposition is reflected not only in the size and youth of our fleet, but also in its remarkable speed. We proudly operate the youngest, largest, and fastest vessels on the Danube, each primed and ready to accommodate diverse types of cargo. With a perfect blend of flexibility and reliability, our fleet ensures the utmost satisfaction for all our clients.

Inland Shipping transcends the traditional boundaries of shipping, offering more than just transport. Our services encompass the full logistics spectrum, including freight forwarding, storage, transshipment, and operations assistance. We are committed to making logistics hassle-free, offering seamless and efficient solutions for our clients.

We're also pioneers in innovation, constantly pushing the boundaries of what's possible. As part of our dedication to innovation and future-oriented solutions, Inland Shipping actively participates in various research projects related to autonomous shipping. Our forward-thinking approach ensures we're not just part of the industry's future, but that we're shaping it.

Ultimately, Inland Shipping isn't just a transport solutions provider - we're trailblazers in our industry, continuously seeking out opportunities to improve, innovate, and inspire. By trusting us with your logistics needs, you're choosing a partner who is committed to excellence, efficiency, and the future of transportation.

Furthermore, Inland Shipping represents more than a logistics service - we see ourselves as partners with our clients, journeying with them towards success. We understand that each cargo is not just a parcel of goods, but a commitment to fulfill, a business deal to close, or a customer to satisfy. We respect the trust that our clients place in us, and we strive to provide the level of service that will exceed their expectations.

Our clients have learned to rely on us for consistent, on-time delivery, and exceptional service. But our commitment doesn't end there. At Inland Shipping, we continuously monitor the performance of our fleet and operations, using this data to improve efficiency, reduce environmental impact, and maintain the quality of our services.

We understand the importance of adapting to change and leveraging advancements in technology. Our involvement in cutting-edge research projects on autonomous shipping exemplifies our drive to stay at the forefront of industry developments. We firmly believe in the potential of autonomous shipping to revolutionize the transport industry, reduce costs, and improve safety. By investing in this area of research, we aim to contribute to the wider industry and society and drive sustainable growth for our company.

A dedicated team of highly skilled professionals stands at the core of Inland Shipping. Our team brings together years of experience and deep knowledge of the industry, committed to providing the best service to our clients. We pride ourselves on a strong company culture of teamwork, continuous learning, and innovation. Our team is our greatest asset, and their dedication and expertise have been instrumental in achieving our strategic objectives.

In our persistent pursuit of safety, efficiency, and cutting-edge innovation, Inland Shipping is currently testing live camera technology for our next generation of remote-operated cranes. This technological advancement in logistics and construction is a landmark initiative that allows our cranes to be controlled from the office, giving operators a real-time view of the work area and ensuring exceptional precision in operations.

Our office-based remote-operated cranes are set to mark a transformative step in industrial operations. Slated for debut in 2024, these cranes represent a significant leap in industry standards, propelling us towards an exciting future of optimized and secure operations.

True to our core values of transparency and accountability, we are proud to extend the visibility of our operations to our clients. All our customers will be granted access to the live camera feeds of these cranes. This unprecedented move in our industry ensures maximum transparency, allowing clients to follow the handling of their cargo in real-time.

This endeavor to enhance safety and operational efficiency reflects our ongoing commitment to leveraging advanced technology for the betterment of our services. Inland Shipping remains poised at the helm of industry innovation, reaffirming our dedication to delivering unparalleled logistics and transport solutions to our clients.

3 Data Collector Systems

3.1 Hermes system

On board of all Grimaldi ships, a data collector system, called Hermes, has been installed and its aim is to enhance the efficiency in the maritime transport chain by **digital data sharing** enabling supply chain and ships visibility. This is done through seamless integration throughout the transport chain. Hermes aligns the customers and the vector (Grimaldi), as the initiator of the transport, with other transport actors and infrastructure owners (such as car manufacturer, terminals, ports and all stakeholders involved in the commercial chain). Grimaldi operates approximately 150 ships, which are equipped with IoT devices, and provides a service tower for managing the fleet as well as the interface to its clients through digital means. To become more efficient and be able to provide better information services to their drivers and clients, Grimaldi wants to increase their integration and information exchange with other transport producers and infrastructure owners.

Hermes Fleet Performance Monitoring System is **the real-time fleet performance monitoring** which is able to supervise ship conditions, supporting the user to improve ship efficiency and obtain relevant savings.

The system is equipped with a real-time dashboard showing the position, speed, trim, and power of each ship. The fleet is under control, continuous monitoring, thanks to alerts created directly by the user and automatically issued in case of equipment malfunction or abnormal vessel behaviour.

Data that comes from automation, navigation systems and any other devices installed onboard are acquired, stored and verified. The system monitors hull, propeller, electric loads, battery systems and engine performances and identifies **critical issues**, supporting ship managers to take a series of maintenance measures to avoid breakdowns or to improve ship efficiency.

Analysis is Hermes performance’s real strength when it comes to operation improvement and information sharing between operators and vessels. The software can compare ship efficiency over different periods of time and estimate the paybacks of refitting and/or retrofitting actions. Benchmarking against sister vessels may suggest corrective actions on trim and propulsion optimization. Ship performance degradation over time could signal when a specific maintenance job has to be done. Big data and machine learning are used to configure Grimaldi targets and support decision-making.

Grimaldi will **share information with all partners of AENEAS project** providing more accurate information about vessel operational profiles including data coming from Battery Management System (BMS). The solution adopted connects isolated information sharing communities (local data sharing environments) through standardized access points (APIs), connectors allowing for peer-to-peer exchange of data between the local data sharing environments building upon that the information provider as well as the information consumer are identified and allowed access to the data. Plus, data sets to be used in the data sharing between the different environments are derived.

In general, the benefits of the Hermes system data-sharing environment for business is to enable the mutual and secure availability of **high-quality data** between companies and offers opportunities for structural innovations, new data driven business services and the ability to deal with data differently.

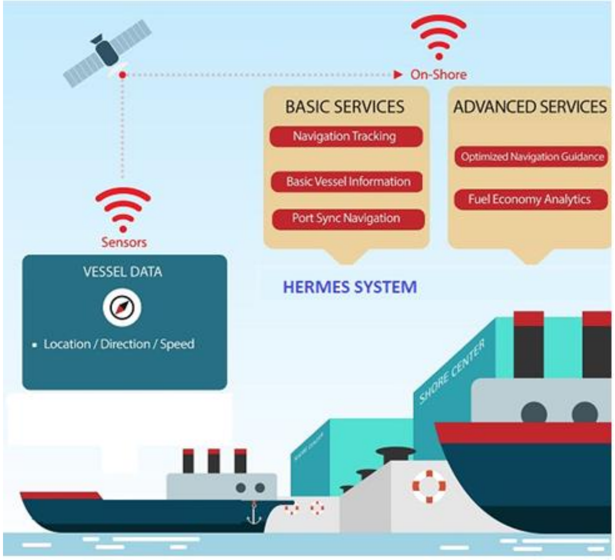

Figure 3.1: Hermes principle of operation

On board of each ship is installed an IoT gateway in which arrive all data registered by **different sensors**. It serves as the connection point between the cloud and controllers, sensors and intelligent devices. All data moving to the cloud, or vice versa, goes through the gateway, which can be either a dedicated hardware appliance or software program. Some sensors generate tens of thousands of data points per second. Our gateway provides a place to preprocess that data locally at the edge before sending it on to the cloud. When data is aggregated, summarized and tactically analyzed at the edge, it minimizes the volume of data that needs to be forwarded on to the cloud, which can have a big impact on response times and network transmission costs. Another benefit of the IoT gateway is that it can provide additional **security** for the IoT network and the data it transports. Because the gateway manages information moving in both directions, it can protect data moving to the cloud from leaks and IoT devices from being compromised by malicious outside attacks with features such as tamper detection, encryption, hardware random number generators and crypto engines.

Lots of **data source** are used: ECDIS (Electronic Chart Display and Information System) for the geographic information, the torquemeter, mass flowmeter, the output diesel generators power, BMS, electric loads and a pitch indicator. All data above mentioned are acquired through **serial device servers** and Isolated Analog Input Modbus TCP Modules.

The Hermes system was built considering the data management concept concerning the capability that enables an organization to ensure that high data quality exists throughout the complete lifecycle of the data. The system is data governance compliant. The Hermes system implementation allows **to monitor ships wherever they are**. Plus, the **data quality** is offered by an upstream filtering of information made before exporting the data ashore. The filtered information published on the portal is the average of each single data exported.

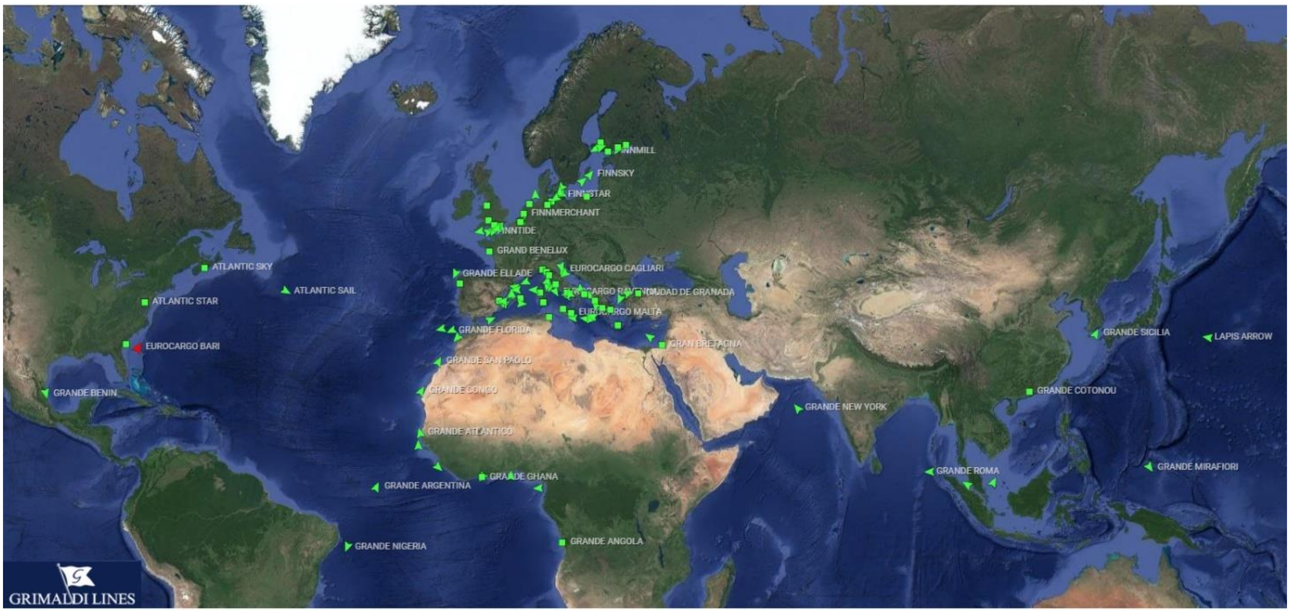

Figure 3.2: Grimaldi fleet in the world

3.2 ST-Brain

With this dashboard, you can easily locate your fleet, monitor their current speed, and track their progress from departure to arrival. The system also stores historical nautical events, such as groundings and collisions, giving you an extensive archive to assess and discuss any operational, training, or third-party purposes.

Take advantage of our advanced tracking and monitoring capabilities and make informed decisions to enhance your fleet's safety and performance.

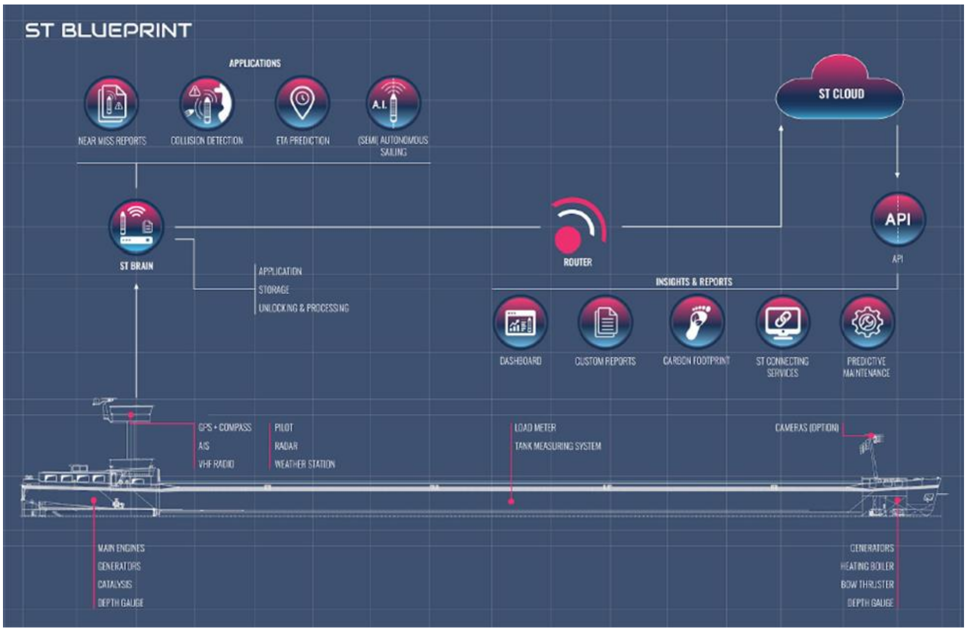

Figure 3.3:ST-Brain

In the figure from top, we can find the next characteristics of the system:

- **DATA PROCESSING**
  - Data storage
  - Connectivity
  - Virtual Private Network
  - IEC 60945 Type approval
- **ST CLOUD PLATFORM**
  - Data storage
  - Online access to equipment on board
  - A.I. Application Platform
- **DATA COLLECTION**
  - Unlocking (nautical) data on board
  - Send data to cloud
  - Deliver added value

- **INSIGHTS**
    - Safe and direct performance insights
    - Incident reconstructions
    - Data usage for development
- **SAFETY**
    - Support of products for captains
    - Collision avoidance (fixed and moving)
    - ST Autonomous Lane Assist
- **DIGITALISATION**
    - Sailing and rest time reporting
    - Fleet & management reporting
    - Footprint of your ship and cargo
    - Monitoring loading and unloading process
- **MAINTENANCE**
    - Online access to devices
    - Maintenance management
    - Predictive maintenance
- **CREW**
    - Reduces crew workload
    - Building a case towards policymakers
    - Possible crew reduction
    - Business case changed

4 Grimaldi vessels

In this chapter, a brief general description of every typology of vessel owned by Grimaldi is provided. Then, for each typology, a general arrangement of an example ship and technical details are presented. In particular, every electrical user and utility on board is analysed in order to make the electrical load balance during the phases of navigation, port stay and manoeuvring. This analysis aims to highlight the users which contribute to the electrical demand. As follows, it is shown an overview of Grimaldi's fleet among which two series will be chosen as case studies for this project.

4.1 Grande Mirafiori – PCTC

The Pure Car & Truck Carrier (PCTC) Grande Mirafiori further enhanced the weekly Ro-Ro connection operated between the Mediterranean and North America (Canada, United States and Mexico). The vessel has a length of 199.90 meters, a beam of 36.45 meters, a gross tonnage of 65.255 and a cruising speed of 19 knots and can, in fact, transport approximately 7.600 CEU (Car Equivalent Unit) or alternatively 5.400 linear meters of rolling cargo and 2.737 CEU. With its four mobile bridges, it can take on any type of rotating load (trucks, tractors, buses, excavators, etc.) up to 5.3 meters in height. Furthermore, the vessel is equipped with two access ramps, one lateral and one aft, the latter capable of loading cargo units weighing up to 150 tons. From an environmental point of view, the Grande Mirafiori is a highly efficient ship. It is equipped with an electronically controlled Man Energy Solutions engine, as required by the new regulations for the reduction of NOx emissions, as well as an exhaust gas purification system for the reduction of SOx. Finally, it complies with the latest regulations in terms of ballast water treatment[9].

Figure 4.1: Grande Mirafiori

4.1.2 Electric load: navigation, port stay, manoeuvring

The following table includes power values during the main three phases of the vessel. These power values refer to an average time in order to calculate the required energy. Then a peak power value is provided which is the highest instantaneous value of power required.

Table 4.1: Electrical information of a PCTC ship

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	702	1372	745
Timing	min	378	72	2052
Energy	kWh	4422.6	1646.4	25479
Peak power	kW	1770	2731	2870

4.2 Grande Amburgo – ConRo

A ConRo vessel transports containers and rolling loads. Grande Hamburg is a mixed cargo ship, vehicle carrier, trailer carrier, container carrier and special cargo built by Fincantieri at the Castellammare di Stabia shipyard in Italy[10]. With a length of 213,29 meters and a gross tonnage of 56.738, it can reach a maximum speed of 19 knots. Plus, this ship's hull is siliconic, so there's less consumption and more speed. It offers several connections between main ports of Europe and Latin America such as London, Antwerp, Hamburg, Paranaguà and Zarate.

Figure 4.2: Grande Amburgo

4.2.1 Electric load: navigation, port stay, manoeuvring

Table 4.2: Electrical information of a ConRo ship

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	1093	1102	1127
Timing	Min	2124	342	1818
Energy	kWh	38692	6281	34148
Peak power	kW	1539	2823	2755

4.3 Eco Livorno – RoRo

The Eco Livorno is the third unit of the GG5G class, which includes the largest and most ecofriendly Ro-Ro vessels in the world. It is a RoRo (roll-on/roll-off) ship designed to carry wheeled cargo, such as cars, motorcycles, trucks, semi-trailer trucks, buses, trailers, and railroad cars, that are driven on and off the ship on their own wheels or using a platform vehicle. With a transport capacity of over 500 trailers, these green giants are able to halve CO2 emissions compared to the previous series of Ro-Ro ships operated, and even to reduce them to zero while they are at berth: during port stays, GG5G-class ships can in fact use the electrical energy stored by mega lithium batteries with a total power of 5MWh, which are recharged during navigation thanks to shaft generators and 350 m^2 of solar panels. Moreover, they are equipped with electronically controlled engines and an exhaust gas cleaning system for the abatement of sulphur and particulate emissions[11].

Figure 4.3: Eco Livorno

The Ro-Ro ships are hybrid Ro-Ro cargo vessels, and they are equipped with many technologies, as follows the main ones:

- Solar panels
- Lithium-ion batteries
- PTO/PTI (Power Take Out and Power Take In) shaft generators
- Silicon Paint
- Air Lubrification System
- Exhaust Gas Cleaning System
- Waste Heat Recovery

4.3.1 Electric load: navigation, port stay, manoeuvring

In the following tables, it is easily understandable that the main energy consumptions come from the main engines and its auxiliary services, cargo loads and the recharging battery bank during navigation. During manoeuvring phase, as expected, main engine and propulsion auxiliary services are the main energy consumers. During port stay the main energy consumptions come from the heeling and ballast pumps and car deck vent fan system due to handling operations.

Table 4.3: Electrical information of a Eco ship

	M.U.	Sea Going	Manoeuvring	Port stay
Mean power	kW	1515	1055	701
Timing	Min	1050	432	420
Energy	kWh	26513	7596	4907
Peak power	kW	3041	3958	1371

4.3.2 Battery cycle analysis

The recharging cycles of batteries on board during navigation are shown in the tables below.

For each trip, the nautical miles are provided (nm) and mean power battery for both portside and starboardside are given. The mean power battery represents the charge power of the battery during navigation and it is given by the sum of mean power battery PS and SB. Then, it is given the depth of discharge before and after the navigation and the energy charge.

Table 4.4: Battery cycle analysis

	nm	Nav. hrs	**Mean pow. battery nav. PS** [kW]	**Mean pow. battery nav. SB** [kW]	**Mean pow. battery nav.** [kW]
Barcelona-Livorno	387	19.5	-63	-65	-128
Barcelona-Savona	340	19.1	-81	-83	-164
Barcelona-Valencia	155	9.3	-177	-179	-356

	SOC FIN %	SOC IN %	DOD %	No. array	Energy1	Energy2
Barcelona-Livorno	46	93	47	12	-3367	-3366
Barcelona-Savona	31	92	61	14	-4533	-4508
Barcelona-Valencia	29	91	62	14	-4732	-4630

Referring to the tables some observations are described below:

- “SOC IN” is the percentage of charge at the beginning of the route and “SOC FIN” is the percentage of charge at the end of the route.
- In “Mean power battery”, “SB” means “Starboard side” and “PS” means “Port Side”.

- The mean power battery tends to have higher values when navigation times are shorter and vice versa but this tendency is influenced also by the SOC IN and SOC FIN and so by the energy given to the batteries.
- Negative power values mean the battery charging during navigation.
- The parameter "Energy1" is calculated based on **DoD** and **No. array**.
- The parameter "Energy2" is calculated based on **Mean pow battery** and **Nav hrs**.

4.4 Cruise Roma – Cruise Ferry

MS Cruise Roma is the longest cruise-ferry in the world. It is a RoPax (Rolling loads and Passengers) ship which is so designed to provide maximum efficiency and the seamless transfer of vehicles, cargo and passengers.

It was the first of a series of four sister ships, the others being Cruise Barcelona (also operated by Grimaldi Lines), Cruise Europa and Cruise Olympia (operated by Minoan Lines). They are the largest ferries under Italian flag. Before the lengthening the ship had 470 cabins, including 60 suites, one à la carte restaurant, a self-service restaurant, a cafeteria, an ice-cream parlour, a swimming pool, a disco, a casino, a conference room, a boutique, a shopping centre. Cruise Roma is operated on the route linking Civitavecchia, Italy to Barcelona, Spain via Porto Torres (Sardinia), together with her sister Cruise Barcelona[12].

Figure 4.4: Cruise Roma

4.4.1 Electric load: navigation, port stay, manoeuvring

Table 4.5: Electrical information of a Cruise ship

	M.U.	Navigation	Manoeuvring	Port Stay
Mean power	kW	2570	2462	988
Timing	Min	1236	54	210
Energy	kWh	52942	2215.8	3458
Peak power	kW	3094	5706	2271

4.4.2 Battery cycle analysis

The recharging cycles of batteries on board during navigation are shown below:

Table 4.6: Battery cycle analysis

	Miles	**Nav. hrs**	**Mean pow. battery nav. PS** [kW]	**Mean pow. battery nav. SB** [kW]	**Mean pow. battery nav.** [kW]
Barcelona - Civitavecchia	443	20.2	-87	-94	-181
Barcelona - Porto Torres	304	13.0	-94	-99	-193
Porto Torres – Civitavecchia	171	7.6	-66	-68	-134

	SOC FIN %	**SOC IN** %	**DOD** %	**No. array**	**Energy1**	**Energy2**
Barcelona - Civitavecchia	20	92	72	41	-3651	-3664
Barcelona - Porto Torres	25	75	50	41	-2506	-2507
Porto Torres – Civitavecchia	75	92	18	41	-892	-1016

4.5 Grande Scandinavia – Multipurpose

Grande Scandinavia with a length of 182,08 meters and a gross tonnage of 52.589, it can reach a maximum speed of 21 knots and it is meant for the carriage of a wide range of cargoes. It offers several connections between main ports in the Mediterranean Sea such as Valencia, Salerno, Alexandria and Ashdod.

Figure 4.5: Grande Scandinavia

4.5.1 Electric load: navigation, port stay, manoeuvring

Table 4.7: Electrical information of a Multipurpose ship

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	870	1057	753
Timing	Min	2484	228	690
Energy	kWh	36018	4017	8660
Peak power	kW	1213	1927	1389

4.6 Catania – RoPax

The “Catania" ferry connects the ports of Genoa, Catania, Corinth and Patras dedicated to both freight transport and passenger transport.

With a length of 186 meters and a gross tonnage of 26.000, the vessel is capable of carrying 2.250 linear meters of rolling cargo plus 170 cars at a speed of 23 knots, thus guaranteeing not only greater cargo but also a faster and more efficient service.

Furthermore, thanks to the wide range of services offered on board, hauliers and passengers can enjoy a pleasant crossing in maximum comfort. The modern ferry is able to accommodate more than 800 passengers in 93 cabins - divided between internal, external and suites - and 62 comfortable seats; there are also numerous services offered on board, such as a self-service restaurant, cafeteria, Vesuvio club room, video games and slot machine area, shops, and solarium with sunbeds and bar[13].

Figure 4.6: Catania

4.6.1 Electric load: navigation, port stay, manoeuvring

Table 4.8: Electrical information of a RoPax ship

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	430	1103	963
Timing	Min	288	30	592
Energy	kWh	2064	552	9502
Peak power	kW	1206	2065	2322

5. Inland Shipping's vessels

5.1 Mayon

Mayon is a pushboat of distinction, blending robust power, efficient design, and superior comfort.

Figure 5.1: Mayon

Constructed at the S.N. ST. Pieter Hemiksen yard, the Mayon was delivered on December 7, 1966. Ever since its maiden voyage, this pushboat has stood the test of time and consistently outperformed the competition.

Sporting a length overall of 33.25 meters, a moulded breadth of 9.53 meters, and a moulded depth of 7.76 meters, the Mayon is engineered to optimize both power and space. Despite a maximum draft of just 1.78 meters, the vessel has an impressive gross tonnage of 410.101 tons, showcasing its substantial capacity. Accommodating a total of eight crew members, the Mayon has been designed with comfort at its core.

Under the hood, the Mayon is powered by two Mitsubishi S6R2-MPTKF main engines, offering a total power output of 2x 480 kW. The vessel utilizes ISO 8217/Diesel as its fuel type, guaranteeing efficient and reliable operation. It also features two Mitsubishi 6D14 (57 kW) shaft generators, enhancing its power generation capacity.

The Mayon's tank capacities include 0.85 cubic meters for fuel oil, 59.1 cubic meters for diesel oil, and 8 cubic meters for fresh water, ensuring operational readiness even for extended durations.

5.1.2 Electric load: navigation, port stay, manoeuvring

Table 5.1: Electrical information of Mayon

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	915	921	45
Timing	h	128	2	21
Energy	MWh	117	1.8	0.95
Peak power	kW	1074	1074	114

5.2 Pushboat Bondar 95

Pushboat Bondar 95 is a symbol of strength, adaptability, and superior technical design.

Figure 5.2: Pushboat Bondar 95

Crafted by the reputable SN Christof Ruthof-Mainz shipyard and delivered in 1962, the Bondar 95 stands as a robust and reliable player in our fleet. Measuring 36 meters in length overall, with a moulded breadth of 9.42 meters and a moulded depth of 9 meters, the Bondar 95. Even with a maximum draft of only 1.92 meters, this pushboat carries an impressive Gross Tonnage (GT) of 551 tons, exemplifying the skillful engineering behind its design.

The Bondar 95 is specifically engineered to accommodate a crew of eight people, promising comfortable and efficient living conditions for the team onboard. The heart of the Bondar 95 lies in its robust CUMMINS KTA 38M1 main engines. With a power output of 2x 672 kW and running on diesel, these engines guarantee efficient and reliable operations. Further adding to the pushboat's functionality are the three CUMMINS 4B 3.9 DM shaft generators and two Fiamm Power Cube APC 12V-225AH emergency power batteries.

Tank capacities on the Bondar 95 include 72.4 cubic meters for diesel oil and 14 cubic meters for fresh water, reinforcing the vessel's capacity to undertake extensive operations.

With its operational area extending to all Danube and Rhine ports, the Bondar 95 is a versatile asset, capable of managing a maximum cargo amount of a whopping 11402.30 tons. Despite this immense capacity, the pushboat maintains its agile performance, thanks to its dual propeller design.

5.2.1 Electric load: navigation, port stay, manoeuvring

Table 5.2: Electrical information of Bondar95

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	1250	1278	50
Timing	h	128	2	21
Energy	MWh	160	2.5	1.05
Peak power	kW	1440	1440	96

5.3 Statendam

Statendam is an outstanding example of a KVB type pusher, designed for superior performance, reliable operation, and comfortable accommodation.

Figure 5.3: Statendam

Statendam, built by the renowned JSC Limenda Shiprepairing & Shipbuilding Yard in Kotlas, Russia, was delivered on the 27th of July, 2015. It effortlessly combines robust design with innovative features to deliver unmatched service in the maritime industry.

The vessel spans an overall length of 95.27 meters, complemented by a moulded breadth of 11.45 meters and a depth of 6.83 meters. With a maximum draft of 3.5 meters, Statendam is adept at navigating a variety of water conditions, underlining its versatility. Boasting a gross tonnage of 2744 tons, Statendam stands out with substantial cargo capacity, while providing a comfortable environment for a crew of eight.

At the heart of Statendam is the power provided by three Cummins QSK19-M main engines. The total power output stands at an impressive 2x 597 +1x 559 kW, ensuring dependable and efficient performance. Fuelled by ISO 8217/Diesel, Statendam also features a John Deere shaft generator, and its bow thrusters are powered by Cummins QSx15C-418KW, adding to its remarkable maneuverability.

Statendam’s tank capacities further underline its long-term operational capabilities, with a diesel oil tank capacity of 59.1 cubic meters and a fresh water capacity of 8 cubic meters. Operating mainly in the Danube and Rhine, Statendam caters to all ports in these areas, ensuring its ability to meet diverse shipping requirements.

5.3.1 Electric load: navigation, port stay, manoeuvring Statendam

Table 5.3: Electrical information of K3

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	1683	3352	55
Timing	h	84	2	22
Energy	MWh	141.3	6.7	1.2
Peak power	kW	3785	3785	158

5.4 Floating Crane K2/K3

Floating Crane K2/K3 is a marvel of maritime engineering, showcasing strength, versatility, and advanced design.

Figure 5.4: Floating Crane K2/K3

As a non-propelled crane pontoon, the K2/K3 is perfectly designed to serve a variety of heavy lifting needs. With an overall length of 45.36 meters, a moulded breadth of 22.36 meters, and a moulded depth of 43.57 meters, the K2's massive dimensions underline its superior lifting capabilities. Despite a maximum draft of just 2.01 meters, the vessel boasts a Gross Tonnage (GT) of 802 tons and a Net Tonnage (NT) of 240 tons.

The crane's machinery is where the K2/K3 truly shines. Powered by two Siemens 3-MOT 1LA8 405-6PM80-Z (grapple) electric engines and three Jolectra KEIS3 513 AM6-E (rotation) engines, the K2 offers unparalleled operational efficiency. This setup provides a total power output of 2x 300 kW and 3x 63 kW, all while being fuelled by electric power. The crane also houses a Caterpillar 3516 DITA shaft generator and a Scania DC9 6SA shaft generator, contributing to its overall operational efficiency.

Tank capacities of the K2/K3 include 1.2 cubic meters for fuel oil and 2.4 cubic meters for diesel oil, ensuring the crane's readiness for prolonged operations. The K2/K3 primarily serves the Constanța Port and is designed for optimal performance in a port environment. Its superior grapple capacity of 25 tons testifies to its heavyweight handling capabilities, further cementing the K2's position as a crucial asset for port operations. In essence, the K2/K3 Floating Crane isn't just a piece of machinery .

Built by FIGEE Netherlands with capacity of cargo hook 32Mton and with grab of 25Mtons. Total height of crane above water level 45m, Highest lifting of grabs = 30 m above water level (under the grab). Lifting speed of grab loaded 140 m / min and lifting speed of grab empty 160 m/m. Load / discharge capacities per hour is for coal 550 Mtons/hour and for - iron Ore 900 Mtons/hour.

5.4.1 Electric load: navigation, port stay, manoeuvring K2

Table 5.4: Electrical information of K2

	M.U.	Navigation	Manoeuvring	Port stay
Average power	kW	55	1329	55
Timing	h	2	69	71
Energy	MWh	0.11	91.7	3.9
Peak power	kW	63	1463	63

5.4.2 Electric load: navigation, port stay, manoeuvring K3

Table 5.5: Electrical information of K3

	M.U.	Navigation	Manoeuvring	Port stay
Mean power	kW	60	1478	60
Timing	h	2	69	71
Energy	MWh	0.12	102	4.3
Peak power	kW	115	1627	115

6 Ship energy systems

6.1 Grimaldi ship energy systems

As for the ships' power generation systems, the electric power production and distribution systems are designed in order to ensure economical, safe and easy operation and service under normal conditions. The diesel generators and the shaft generators are designed for continuous parallel operation. During normal sea going condition and Main Engines running in rpm range of 70-100 %, the shaft generators are sufficient for the Vessel's electric load with 50% reefer load according to electrical load balance calculation. PTI functionality is used for the peak shaving in sailing condition. This functionality allows to keep main engines load constant and to absorb propellers load peak (due to bad weather or else) with PTI supplied from batteries. Scope of this functionality is to reduce the fuel consumption. Furthermore, PTI provides peak-shaving (emergency from Battery Pack) integrated with Main Engine fuel rack control. In PTI mode the shaft line power is limited to the maximum of SMCR main engine power. It is possible to run any number and configuration of diesel generators in parallel on the main switchboard. In port the power is supplied through batteries or an auxiliary diesel generator or shore connection.

A certified **Battery Management system** (BMS) is installed and interfaced with battery charger. Following parameters to be monitored and displayed in the Alarm Controlled Monitoring System (IACMS):

- internal charging/discharging of the battery, battery temperature
- cell to cell balancing during charging, cell voltage, cell temperature
- battery current
- State of Charge
- State of Health
- ambient temperature
- etc.

Under following cases, the battery is disconnected to the main bus-bar automatically:

- Over pressure
- Cell High Temperature
- Cell over voltage
- Manual E-Stop at ECR and Bridge Center Console

The ship is equipped with an energy management system (**EMS**) that controls the electrical energy consumption of the ship. The system monitors and controls in order to provide the following functions:

- Making sure that the batteries are fully re-charged when entering into port.
- Making sure that load sharing from batteries to shaft motor only takes place when batteries can be re-charged fully prior to port stay.
- Making sure that in port mode not essential electrical consumers are turned off so that batteries will last as long as possible (ECO MODE).

- Making sure that gensets are running as efficient as possible with respect to load; however due to operational issues crew can override and run with more gensets.

7 Grimaldi marine battery application

7.1 Load levelling

Load levelling is an application of batteries which is used to keep the load on the main engine, which also provides the electrical energy, at one level by discharging the batteries when the demand is higher than the set load and charging the batteries when the demand is lower than the set load. This application is used to make the engine run at a more efficient load and to reduce the required maintenance, which can be increased by large load fluctuations.[14]

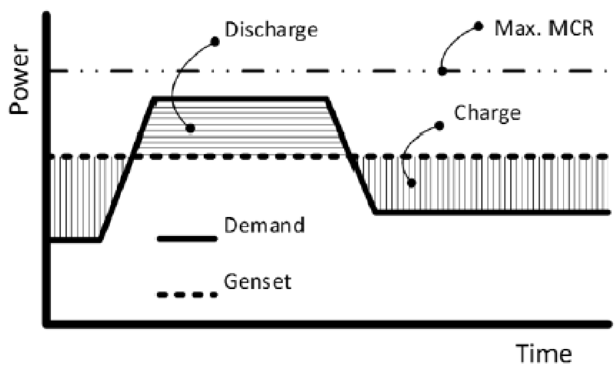

Figure 7.1: Load levelling

7.2 Boost function

The boost function is an application where the batteries are used to increase (boost) the performance of a propulsion system by providing additional power to cover the peaks in demand. This feature is only available for the Ro-Ro series ships since they are equipped with PTO/PTI shaft generators that can work both as Generators (Power Take Out) and motors (Power Take In). Indeed, the PTI mode can provides additional power to the propulsion in order to reach in a shorter time a lower browsing speed with a consequent fuel saving during navigation. Then, the batteries are charged when the demand is below a certain level again. [14]

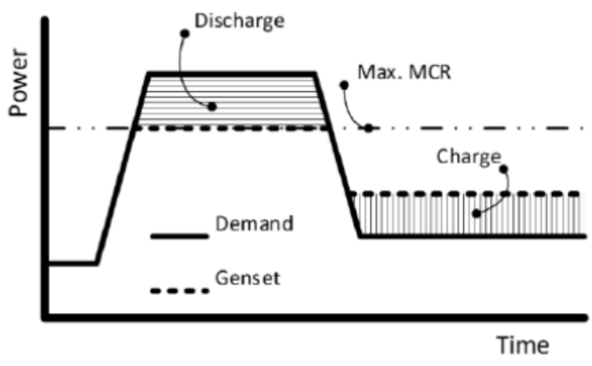

Figure 7.2: Boost function

7.3 Peak shaving

The peak shaving application uses the battery to take care of sudden peaks and fluctuations in power demand. This reduces the peaks in load demand on the generator, reducing the required maintenance. It can also be used as a bridging function between starting up of an additional generator. [14]

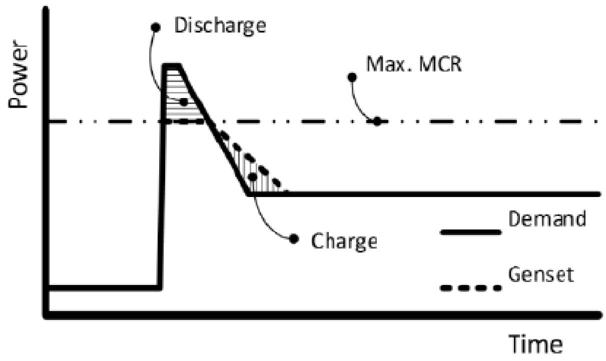

Figure 7.3: Peak shaving

7.4 Cycle analysis

The challenge in designing a battery powered vessel comes with sizing and selecting the right type of battery for the right type of application. Each type of battery has a different combination of maximum C-rate and estimated number of cycles that can be performed until the end of life of the battery cells. However, the operational requirements of most vessels do not exactly fit to the specifications of the marine battery systems available on the market. Either the power demand of the vessel or the number of cycles can be too high to achieve a practical design life of the battery system. A common approach to deal with this problem is to oversize the battery system. This allows the batteries to deal with the highest required C-rates, because if the required power remains the same while the installed energy is increased, then the resulting C-rate on the batteries is reduced. Additionally, the DoD is reduced for every cycle, which results in a longer lifetime of the batteries.

The concept of ESS is considered to be able to be sized more accurately to fit the demands in C-rates and number of performed cycles of the vessel, resulting in a more optimized battery system in costs, weight or volume as well as fulfilling the lifetime requirements. To determine which types of vessels and their application of batteries would potentially benefit the most from ESS, different types of operational requirements which define the required type and size of the batteries are individually evaluated from each other and later compared for similarity.

Primary cycles are the most common types of cycles that a vessel will perform with the installed battery system, e.g. a ferry travelling between two ports. The battery requirements for the Grimaldi application are based essentially on the combination of primary cycles. [14]

8 System installation and innovation

As described in the document produced and published by EMSA, called "Study on Electrical Energy Storage for Ships. Battery Systems for Maritime Applications – Technology, Sustainability and Safety", the battery systems installed on ships are in a complex situation, given that environmental regulations and the decarbonisation objectives set for 2030 and 2050 do not conform to the development and technological progress of the industry, as well as the new technologies with which it is intended to achieve these environmental objectives. This in turn implies that the regulations related to the design, manufacture and implementation of energy storage systems have to be accelerated in order to cover, support and certify the installation of said systems on board ships. In this sense, energy storage systems will favor compliance with environmental objectives and regulations, allowing energy generation systems based on the use of fossil fuels to be replaced by new systems that will eliminate greenhouse gas emissions. That is why encouraging the use and implementation of energy storage systems on board ships, which are powered by renewable energy sources, will allow, in the long term, to achieve the electrification of the maritime sector and, consequently, the elimination carbon emissions.

It must be taken into account that the criteria and requirements that are going to be exposed below do not distinguish between types of ships. In other words, what is stated below is valid for both Cruise Seies ships and Ro-Ro Series ships.

8.1 Classification rules applicable for maritime battery installations

Referring again to the document issued by EMSA, the "Study on Electrical Energy Storage for Ships. Battery Systems for Maritime Applications – Technology, Sustainability and Safety", energy storage systems are in an early stage of development and research, being a complex technology that is in its maturation phase. For this reason, and to ensure that this new technology is developed properly, and following all the necessary security standards, the role of Classification Societies is essential.

Given the immaturity of this technology, the Classification Societies must carry out a detailed and precise follow-up of it, identifying both the key aspects and the risks associated with it, this task being essential to guarantee a high level of security and design of these new Emerging technologies.

It should be noted that, within the maritime sector, given the great variety of existing ships, not only in category but also in typology, Classification Societies must analyze and evaluate on a case-by-case basis in order to identify that current regulations are applied accordingly. the appropriate way as well as to identify possible existing regulatory gaps that need to be solved. In summary, the participation of the Classification Societies both in the design and implementation and installation processes are crucial, since it is these expert entities who provide the level of confidence and security necessary to favor and encourage the use and installation of classification systems. energy storage on board ships.

In the table below, you can see the classification societies that currently have current regulations applicable to the installation of lithium ion battery systems on board ships.

Table 8.1: Overview of applicable Class requirements for battery installations and their status

Source: EMSA. Study on Electrical Energy Storage for Ships. Battery Systems for Maritime Applications – Technology, Sustainability and Safety. May 2020

Short name	Association	Title of document	Type
ABS	American Bureau of Shipping	Use of Lithium batteries in the Marine and Offshore Industries	Guideline
BV	Bureau Veritas	Rules for Classification of Ships – Electric Hybrid	Rules – Pt F, Ch 11, Sec 22
DNV	Det Norske Veritas	Rules for Classification of Ships – Battery Power	Rules – Pt 6, Ch 2, Sec 1
LR	Lloyds Register	Large Battery Installations	Guideline
RINA	Italian Naval Register	Large Li-ion battery installation	Guideline

The choice of the Class rules and the choice of Class notation depends on how the batteries are used in combination with the other power sources for the function in the ship. The following table gives a short description of some key requirements for Class approval of a battery system installation.

Table 8.2: Selected components required for Class approval of a battery system installation.

Source: EMSA. Study on Electrical Energy Storage for Ships. Battery Systems for Maritime Applications – Technology, Sustainability and Safety. May 2020

Rules Component	Short description
Safety Description	The safety description is specific to the battery system and provides key details and aspects of that system that can be used as input to other engineering or risk assessment exercises. This should include things like, cell size, expected offgas contents and quantities BMS and module features and propagation test results. Specific items to be included are listed in the Class rules.
Safety Asseement	The Safety Assessment is specific to the vessel on which the batteries are being installed. It thus utilizes input from the safety description and explains how key risks are handled in the installations. Specific items to be included are listed in the Class rules.
Standardized Tests	Rules that may be applicable in addition to the battery rules: - Dynamic positioning - Electrical installations

	- Control and monitoring systems
Propagation Test	The propagation test that is required for DNV classed vessels is outlined in the DNV rules. It is based on IEC 62619 with additional provisions and the requirement that it is performed and passed, three times.

8.2 Regulatory gaps for battery system installation

As already mentioned in the previous section, energy storage systems are in a very early stage of development, given their technological novelty, so today there are gaps within the regulation, which are emerging according as this technology reaches higher levels of maturity, it being necessary that said regulatory gaps are solved in parallel with the technological advances that are being achieved. In this sense, and following the document published by EMSA "Study on Electrical Energy Storage for Ships. Battery Systems for Maritime Applications – Technology, Sustainability and Safety", below are the items which are considered the most representative when considering to improve the technological development of energy storage systems.

Legal GAP: Legal gaps are gaps for the use of batteries and the associated charging infrastructure that can severely limit or even block the use of batteries in shipping. These gaps are typically gaps in legislation and regulations.

Harmonization GAP: Harmonization gaps are gaps in the EU-wide harmonization of methods, rules, guidelines, provisions and safety aspects for batteries. An exemple could be harmonization of conditions and procedures for safe charging.

Knowledge GAP: Specific knowledge gaps are points where more research is needed in the implementation and development of batteries for the maritime use and applications identified in this document. Recommendations formulated for these gaps are suggestions for improvement, as well as R&D and product development.

The following table gives a high-level summary of the identified gaps in the gap analysis performed in this document.

Table 8.3: Gap analysis table-high level summary of identified gaps

Source: EMSA. Study on Electrical Energy Storage for Ships. Battery Systems for Maritime Applications – Technology, Sustainability and Safety. May 2020

High level gap description	Recommendation/Assessment	Gap category
BMS capability assessment	Battery Management Systems (BMS) are a vital component of the battery safety. Yet they are overlooked in many assessments because they are difficult to evaluate. These systems are studied in the most detail in DNV GL Type Approval. Wider deployment of more detailed practices for assessment such as HIL would have significant benefit at further reducing risk levels.	Harmonization
Battery cell quality assurance for safety	Battery cell quality and consistency is a key driver of safety yet is not currently evaluated under the existing regulatory framework. Implementation of more transparent documentation and processes could improve system safety characteristics.	Knowledge
Battery cell quality assurance for lifetime	Battery lifetime is difficult to assess. Although this is an engineering task and thus does not make sense to impose explicit rules, there are opportunities for further standardizing what is reported as far as lifetime for battery cells, even just as far as definitions.	Knowledge
Thermal runaway test procedures	As battery system safety properties improve, thermal runaway and propagation testing generates new challenges regarding the development of procedures for tests and criteria to define the requirements. Whether a cell has sufficiently entered 'thermal runaway' and that an acceptable propagation test has been performed is difficult to define. In addition, as safety properties improve to address the core problem of internal manufacturing defect more directly, this specific phenomenon may be more necessarily the focus of testing.	Harmonization, Knowledge
Allowances for batteries as backup/spinning reserve	The specific requirements stated for spinning reserve power (for example DP) would not allow for the use of batteries on retrofits, unless major updates at power consumers, producers, safety equipment and automation	Legal, Harmonization

High level gap description	Recommendation/Assessment	Gap category
	were installed. These specific requirements vary for different authorities.	
Certification of different battery fire suppression systems	Each battery installation will require project/installation-specific capacity and functionality for the fire suppression systems. A view to the future will require adequately addressing at high-level regulatory framework the findings from the *Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression* (DNV-GL, 2020). Actual volumes and release rates need to be calculated and are dependent on the battery system, technology and specific battery room arrangement design.	Legal, Harmonization, Knowledge

8.3 Safety and health in shipbuilding and ship repair for battery system installation

The International Labor Organization Code (ILO Code) of practice on safety and health in shipbuilding and ship repair provides practical guidance for the use of all those, both in the public and private sectors, who have obligations, responsibilities, duties and rights regarding safety and health in shipbuilding and ship repair.

This code is applicable to all shipbuilding and ship repair facilities irrespective of the nature of the facility (pier, dry dock, building dock, slipway, workshops of contractors or other types of assembling locations).

The code provides guidance, in accordance with the provisions of national laws and regulations, to:

a) All government authorities, shipowners, employers, workers and their respective organizations and industry associations, whether they have a legislative or advisory role, whose activities influence the safety, health and welfare of workers in shipbuilding and ship repairing.

b) All individuals at the level of shipbuilding and ship repair facilities, that are employers, persons in control of premises, workers, contractors and subcontractors, as appropriate to their duties and responsibilities for occupational safety and health (OSH).

For the battery system production facilities, company health and safety regulations need to address both regular industrial and electronics manufacturing hazards and particular hazards related to battery manufacturing. Standard industrial operations such as lifting, risk of crushing, crane operations with associated risks are not treated here. The focus is on the particular hazards related to battery manufacturing.

Production of battery systems can pose several hazards. The main hazards are chemical and electrical. Chemical hazards can occur if electrolyte leaks out of the cells, a thermal event or if a short-circuit leads to overheating internally in the battery or sub-assembly or overheating externally to the battery or subassembly. The short-circuit currents can be very substantial even for cells or sub-assemblies containing battery cells and can also lead to serious injuries and loss of life.

A battery manufacturing environment is special in the sense that it will contain sub-assemblies with both high voltage and sensitive electronics. This can pose special challenges for protective gear since conductive materials are preferred to minimize the risk of damage from static electricity, whereas electrically insulating materials are strongly preferred to avoid short circuit risks. To prevent hazards arising from the difference in requirements it is therefore recommended that the manufacturing facilities have different and clearly marked zones for electronics sensitive to static electricity.

Transportation of battery system

In order to ensure safety during transport, nearly all lithium batteries are required to pass section 38.3 of the UN Manual of Tests and Criteria (UN Transportation Testing) which is identical to IEC 62281. Note that this UN regulation is the only mandatory set of regulation for lithium-ion batteries today.

Tests 1-8 of this specification are as follows:

- T1 – Altitude Simulation (primary and secondary cells and batteries).
- T2 – Thermal Test (primary and secondary cells and batteries).
- T3 – Vibration (primary and secondary cells and batteries).
- T4 – Shock (primary and secondary cells and batteries).
- T5 – External Short Circuit (primary and secondary cells and batteries).
- T6 – Impact (primary and secondary cells).
- T7 – Overcharge (secondary batteries).
- T8 – Forced Discharge (primary and secondary cells).

Further the UN rules defines a large battery to have a gross mass of more than 12 kg and a large cell as a cell with a gross mass of more than 500 g. These definitions are important for the number of samples that are required for the testing. The UN Transport of Dangerous Goods regulations also defines specific requirements for the packaging used when transporting batteries. The International Maritime Dangerous Goods Code (IMDG)[26] is relevant in case of transportation on ships, and will also apply for transportation of batteries as goods.

Storage before installation

When storing battery cells a certain degree of self-discharge is inevitable. This could be both reversible and irreversible. The higher the storage temperature and the higher the state of charge of the cells, the higher the losses will be due to increased impedance. As of April 2016, updates to UN 38.3 dictate that cells cannot ship at a state of charge above 30%. It is important that cells and modules are not stored for long periods in a hot environment. If the average storage temperature or temperature during transportation is above 30 - 35 ºC, degradation due to calendar effects will accelerate. Considerations for storage prior to installation shall also include appropriate temperature and SOC safeguards.

In the following table, the risk assessment for electrical works in shipyards (including battery installation) are presented.

Table 8.4: Risk assessment - Electrical works in shipyards

Hazard Identifications			Risk Evaluation		Risk Control	
Ref	**Work Activity**	**Hazard**	**Possible injury/Ill-health**	**Existing Risk Controls**	**Additional Controls**	**Implementation Person**
1	Access location of emergency generator room (Location identification)	- Debris and liquids on floor	- Body injuries due to slips, trips and falls	- Housekeeping - Sufficient lighting	Use of torchlights	Supervisor
2	Switch off battery charger and check cable	- Live power supply terminals	- Fatal electric shock	- PPE (rubber glove, rubber-soled safety boots) - Correct tools - VSCC Meeting - Barricade work area and display warning sign - Brief worker on procedure - Deploy skilled electrician - Cover battery	Nil	Supervisor
3	Disconnect link and cable	- Slipping of spanner	- Hand injuries	- Use correctly sized or adjusted spanners	Nil	Supervisor
4	Take out battery from battery box	- Heavy object,	- Back injuries - Hand injuries	- Procedure for safe manual lifting	Nil	Supervisor

	manually and clean the box	manual lifting		- Require two persons to lift - Correct posture (bending legs, not the back) - PPE (gloves)		
5	Replace new battery into battery box	- Heavy object, manual lifting	- Back injuries - Hand injuries	- Procedure for safe manual lifting - Require two persons to lift - Correct posture (bending legs, not the back) - PPE (gloves)	Nil	Supervisor
6	Reconnect battery link back to cable	- Live terminals of battery	- Minor electric shock	- Use correct tools - PPE - Insulation of the tools breaker	Nil	Supervisor

8.4 System use from the port point of view

During operations ships need to recharge their batteries by connecting to the electrical grid of the port. Operators from the port shall ensure that the electricity supplied from the grid comes from renewable sources.

As mentioned in previous chapters, the installation and innovation systems developed for the vessel are leaded by the Classification Societies.

The port shall be taken into account when the batteries are charged during the port stay and not only during the navigation. The recently reached agreement FuelEU initiative in March 2023, as part of the Fit for 55 packages FuelEU Maritime makes mandatory from January 2030 that at least 90% of demand for OPS shall be met in TEN-T maritime ports, and sets requirements for OPS for inland waterway vessels at berth. The mandatory requirements of EU emission trading system is tightening into the maritime industry including all the energy used in European ports and consumed during voyages. The use cases analysed here recharge the batteries during navigation, and use the batteries while the vessel is all fast.

Some insights can be defined to determine the required capacity of the batteries and the recharging capacity during the port stay, including the vessel operational range (distance that the vessel will sail), the auxiliary power requirement, the charging locations and the waiting times.

1. Operational range
2. Auxiliary power requirement
3. Charging locations
4. Waiting times

In the case of the Port of Valencia, the shortest regular navigation distance is between Valencia and Ibiza with 100 nautical miles. For such distances the batteries state of the art is not mature enough to provide fully electric navigation. However, services boats, tugs and pilots could be fully electrified and contribute to reduce the emissions inside the port facilities. For cargo vessel using hybrid systems the batteries could be used during the vessel approach to the port facilities, to reduce the emissions during the port stay.

If the vessel stays longer than the battery capacity, instead of turning on auxiliary power engines, a system to recharge the batteries and provide energy to the vessel from shore (OPS) shall be considered. Taking into account the peak demands of energy and the mandatory requirements of the European Union to electrify the power supply of the vessels.

Diagram 8.1 summarizes the main milestones during a vessel call which can be grouped as follows:

1) Arrival: Including End of Sea Passage, Anchoring, and inbound manoeuvring with the support of pilots and tugs until the vessel is all fast
2) At berth: At this stage the vessel is all fast and will be working on cargo operations (load / discharge). At this stage the vessel shall be connected to OPS
3) Departure: Starts with the first line released, including outbound, manoeuvring with pilots and tugs, until the Start of Sea Passage

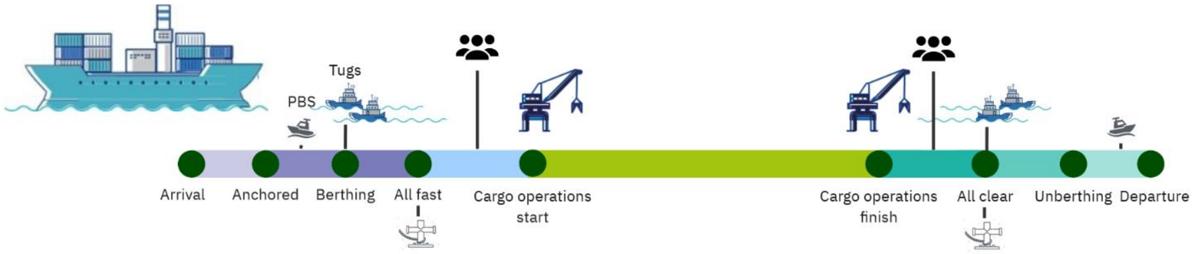

Figure 8.1: Main milestones during a vessel call

During 2022 the Port of Valencia had around 6,000 vessel calls and 7,000 all-fast milestones. The difference is mainly because some vessels sail to more than one single dock during a vessel call.

The figure 8.2 represents Valencia port restricted waters, the Pilot Boarding Station (PBS) and the anchorage areas.

The port restricted waters are defined according to below zones.

- Zone 1 encompasses the water inside the breakwaters
- Zone 2 includes the anchorage areas and the surrounding waters of the port facilities

Figure 8.2: Valencia port restricted waters

9 Safety risk assessment and integration requirements

9.1 Operational risk assessment for ESS integration

Safety is defined as "the property (or quality) of the system necessary and sufficient to ensure that the number of events that could be harmful to workers, the stakeholders or the environment is acceptably low". This definition is focused on two aspects: number of events and acceptable level. Obviously, they have their own meaning, but both are linked between them. Each safety critical system (i.e. maritime domain) uses a predictive approach and, for this reason, requires the assessment of risks in the overall operating environment in order to minimize the probability and severity of hazards. For the AENEAS project, the operational risk assessment is meant as a tool used to describe the overall process aimed at:

- Identifying hazards and risk factors that have the potential to cause harm (hazard identification).
- Analyzing and evaluating the risk associated with those hazards (risk evaluation).
- Determining appropriate ways to mitigate the hazards (mitigation).

A qualitative assessment is conducted based on a high-level risk assessment approach described in the figure below. Qualitative risk analysis describes risks using defined descriptive terms.

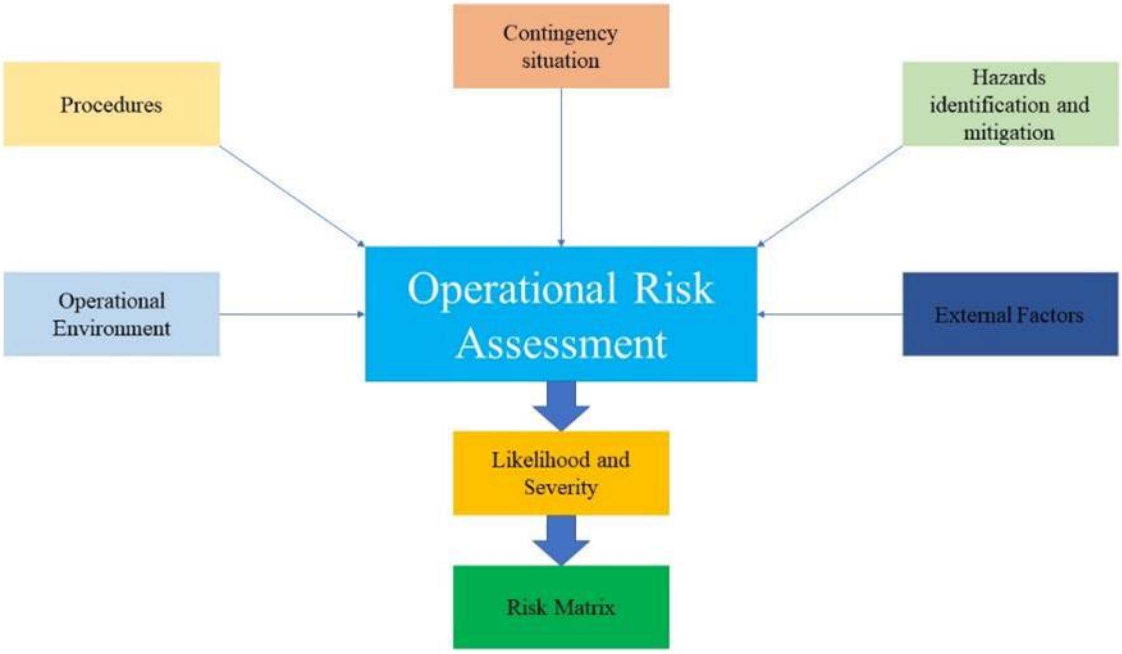

Figure 9.1: High-level risk assessment approach

A qualitative risk assessment foresees:

- A detailed description of the **operational environment**. All the elements of the operational environment have a vital role to ensure successful operations and maintain performance of the overall environment. The AENEAS project is targeting, the integration of ESS on board ships

- A detailed description of **procedures**. This block refers to procedures of the whole operational enviroment and ship's electrical equipmentsection 5.3, 6.3.
- Identification of **contingency situations**. It is important to assess the ability of the new operational concept to work through (robustness), or at least recover from (resilience) any contingency situation, external to the integration of ESS and not under control, that might be encountered relatively infrequently.
- **Identification of hazards**. Before the risks associated with integration of ESS on board ships in a given environment of operations can be assessed, a systematic identification of the hazards shall be conducted. In fact, a pre-condition for performing the operational risk assessment for the introduction of a new concept is to understand the impact it would have in the overall maritime risk picture. In the following section the hazards related to the integration of ESS on board ships and their mitigation will be detailed.
- **External factors identification** (e.g. external fires, external short circuit).

Qualitative risk assessment based on a risk matrix allows to determine safety risk tolerability. Table 16 presents a typical safety risk probability classification. It includes five categories to denote the probability related to an unsafe event or condition, the description of each category, and an assignment of a value to each category.

Table 9.1: Probability class used in the operational risk assessment

Likelihood Class	Qualitative
Frequent (5)	Likely to occur many times (has occurred frequently)
Occasional (4)	Likely to occur sometimes (has occurred infrequently)
Remote (3)	Unlikely to occur, but possible (has occurred rarely)
Improbable (2)	Very unlikely to occur (not known to have occurred)
Extremely Improbable (1)	Almost inconceivable that the event will occur

While the Table 17 presents the severity category associated to the hazard identified. Catastrophic hazards effect involves multiple fatalities, massive effect damage over large area. A hazardous event is one that involves a large reduction in safety margins, physical distress or a workload such that operational personnel cannot be relied upon to perform their tasks accurately or completely: single fatality or permanent disability. A major hazard involves significant reduction of safety and a significant increase of workload for the crew to perform their task: major injury, long term absence and localized effect. A minor hazard involves slight injury, a few lost work days with minor effect and a slight increase of workload for the crew to perform their task. Finally, “no safety effect” do not have effect on the people, safety and crew workload or at least superficial injuries and slight effect and damage with no effect on the workload crew‘s.

Table 9.2: Proposed hazard severity categories

Severity Category	**Injuries**	**Safety**	**Crew workload**
Catastrophic (A)	Multiple Fatalities	Massive effect damage over large area	
Hazardous (B)	Single fatality or permanent disability	Major damage	Compromises safety
Major (C)	Major injury, long term absence	Significant decrease and localized effect	Significant increase
Minor (D)	Slight injury, a few lost work days	Minor damage	Slight increase
Negligible (E)	No or superficial injuries	Slight effect and damage	No effect

The combination of Likelihood and severity generates the risk matrix, used to assign a risk level for each identified hazard.

Table 9.3: Risk Matrix

Safety Risk	**Severity**				
Probability	**Catastrophic (A)**	**Hazardous (B)**	**Major (C)**	**Minor (D)**	**Negligible (E)**
Frequent (5)	5A	5B	5C	5D	5E
Occasional (4)	4A	4B	4C	4D	4E
Remote (3)	3A	3B	3C	3D	3E
Improbable (2)	2A	2B	2C	2D	2E
Extremely improbable (1)	1A	1B	1C	1D	1E

The index obtained shall be exported to a safety risk tolerability table that describes the tolerability criteria. Safety risks are assessed as acceptable, tolerable or intolerable.

Table 9.4: Tolerability index

Safety Risk Description	Recommended Action
Intolerable	Take immediate action to mitigate the risk or stop the activity. Perform priority safety risk mitigation to ensure additional or enhanced preventative controls are in place to bring down the safety risk index to tolerable.
Tolerable	Can be tolerated based on the safety risk mitigation. It may require management decision to accept the risk.
Acceptable	Acceptable as is. No further safety risk mitigation required.

9.1.1 Identification of Hazards

The purpose of most safety-related systems is to mitigate the hazards (and associated risks) that are existing in the operational environment of the system concerned. These hazards are, therefore, not caused by the system – rather, the main purpose of introducing the system is to eliminate those hazards or at least maintain the associated risks at a tolerably low level.

For the AENEAS project, the hazards and risks are generally those that are inherent in maritime sector and specially the ones related to the integration of ESS on board ships. The main objective is to provide as much mitigation as possible. For this reason, the identification of hazards refer to hazards in maritime environment investigated in the report 2019-0217, Rev. 04 – Electrical Energy Storage for Ships produced by EMSA (European Maritime Safety Agency).

Table 9.5: List of hazards

Hazard No.	Hazard	Hazard category
Hz#1	Internal short circuit	Thermal runaway
Hz#2	Overcharging	Overcharge
Hz#3	External fires	External heat
Hz#4	External short circuit	External short circuit
Hz#5	Fast discharging	High current
Hz#6	Long term undercharge of batteries	Undercharge
Hz#7	Failure of cooling system	Cooling system
Hz#8	Entry of water	Water
Hz#9	Puctures cell	Defective cell
Hz#10	Electrical connection	Electric
Hz#11	Defective cell	Cell failure
Hz#12	Assembly error	Design
Hz#13	Inappropriate support system	Design

Hz#14	Collision	Collission
Hz#15	Gas inside the battery compartment	Gas development
Hz#16	Human error	Human Factors

9.1.2 Preliminary operational risk assessment

This section provides a full set of a preliminary operational risk assessment evaluation. For each of the above-mentioned hazards will be assigned a combination of likelihood and severity which will determine whether a recommended action is needed based on the tolerability index:

Table 9.6: Preliminary risk assessment

Hazard No.	Hazard Category	Severity /Likelihood	Mitigation mean	Class
Hz#1	Thermal runaway	Remote (3), Minor (D)	Emergency Shutdown; Design: insulation between modules, Temperature monitoring	3D
Hz#2	Overcharge	Improbable (2), Major (C)	Emergency Shutdown; Fire extinguishing system in the battery compartment	2C
Hz#3	External heat	Remote (3), Hazardous (B)	Emergency Shutdown; Fire extinguishing system in the battery compartment, Cooling system, Temperature monitoring system, Alarm	3B
Hz#4	External factor	Improbable (2), Minor (D)	Emergency Shutdown, Cooling system, Temperature monitoring system, Alarm	2D
Hz#5	High current	Improbable (2), Major (C)	Emergency Shutdown, Cooling system, Temperature monitoring system, Alarm	2C
Hz#6	Undercharge	Improbable (2), Major (C)	Redundant battery systems	2C
Hz#7	Cooling system	Improbable (2), Hazardous (B)	Emergency Shutdown; Fire extinguishing system in the battery compartment, room open to air, Temperature monitoring system, Alarm	2B

Hz#8	Water	Improbable (2), Minor (D)	Emergency Shutdown; Alarm	2D
Hz#9	Defective cell	Improbable (2), Major (C)	Redundant battery systems, shutdown defective cell, reduce the voltage	2C
Hz#10	Electric	Remote (3), Hazardous (B)	Emergency Shutdown; Fire extinguishing system in the battery compartment, Temperature monitoring system, Alarm	3B
Hz#11	Cell failure	Improbable (2), Major (C)	Redundant battery systems	2C
Hz#12	Design	Improbable (2), Major (C)	Emergency Shutdown; Design: insulation between modules, Temperature monitoring	2C
Hz#13	Design	Extremely improbable (1), Major (C)	Emergency Shutdown; Design: insulation between modules, Temperature monitoring	1C
Hz#14	Collission	Remote (3), Hazardous (B)	Place batteries in areas where collision probability is low, training and procedures	3B
Hz#15	Gas development	Remote (3), Hazardous (B)	Emergency Shutdown, Ventilation room, Fire extinguishing system in the battery compartment, Gas sensors, Alarm	3B
Hz#16	Human Factors	Improbable (2), Catastrophic (A)	Procedures and training	2A

9.2 Safety requirements for ESS integration

A safety requirement is any quality requirement that specifies a minimum, mandatory amount of safety in terms of a system-specific quality criterion and a minimum level of an associated metric. The main goal of safety requirement is to prevent workplace injuries and/or fatalities as well as the suffering and financial hardship these events can cause for employers. For the AENEAS project, a risk-based approach has been followed for setting up appropriate requirements for the integration of a new concept on board ships. In fact, based on the Preliminary operational risk assessment executed in section 8.1.2, this section defines the safety requirements for the integration of ESS on board ships. The following table shows the safety requirements identified for the integration of ESS on board ships.

Table 9.7: Safety requirements for the ESS integration

Requirement ID	Requirement text	Hazard No.
REQ-AENEAS-D11-001	The ESS shall be installed in a well designed module well separated from other modules and easily accessible for the human	Hz#1, Hz#2, Hz#3, Hz#4, Hz#10, Hz#12, Hz#13, Hz#14 Hz#15, Hz#16
REQ-AENEAS-D11-002	The ESS shall be installed in a proper module well separated from external heat sources	Hz#1, Hz#2, Hz#3, Hz#4, Hz#10, Hz#12, Hz#13, Hz#14 Hz#15, Hz#16
REQ-AENEAS-D11-003	The ESS shall be able to be automatically shutted down in case of thermal ruanaway and/or any other contigency situation that requires an emergency shutdown	Hz#1, Hz#2, Hz#3, Hz#4, Hz#5, Hz#7, Hz#8, Hz#10, Hz#12, Hz#13, Hz#15
REQ-AENEAS-D11-004	The ESS shall contain IoT sensors for temperature monitoring in case of thermal runaway	Hz#3, Hz#4, Hz#5, Hz#7, Hz#10, Hz#12, Hz#13
REQ-AENEAS-D11-005	The ESS module shall contain an alarm in case of high temperature coming from inside/outside the ESS module	Hz#4, Hz#5, Hz#7, Hz#10, Hz#15
REQ-AENEAS-D11-006	The ESS alarm shall be understable with different sound and clearly visible to the crew	Hz#4, Hz#5, Hz#7, Hz#10, Hz#15
REQ-AENEAS-D11-007	The ESS module shall contain a cooling system in case of high temperature coming from inside/outside the ESS module	Hz#2, Hz#3, Hz#4, Hz#5, Hz#7
REQ-AENEAS-D11-008	The ESS module shall contain a fire extinguishing system in order to prevent a cascade effect in case of fire	Hz#2, Hz#3, Hz#7, Hz#10,
REQ-AENEAS-D11-009	The ESS shall contain IoT sensors for gas detection in case of gas development	Hz#15

REQ-AENEAS-D11-010	The ESS shall be installed in a compartment in which the ventilation system is installed for heat/gas dissipation in case of fire/gas development	Hz#1, Hz#2, Hz#3, Hz#4, Hz#5, Hz#7, Hz#8, Hz#10, Hz#12, Hz#13,
REQ-AENEAS-D11-011	The ESS shall be able to be automatically shutted down in case of battery overcharge	Hz#1, Hz#2, Hz#3, Hz#4,
REQ-AENEAS-D11-012	The ESS shall have a redundand battery system in case the batteries are undercharged	Hz#6, Hz#9, Hz#11
REQ-AENEAS-D11-013	The ESS shall be able to automatically exclude the defective cell	Hz#9, Hz#11
REQ-AENEAS-D11-014	The ESS shall be able to automatically reduce the voltage in case of defective cell	Hz#9, Hz#11
REQ-AENEAS-D11-015	An alarm shall be activated in case of defective cell	Hz#9, Hz#11
REQ-AENEAS-D11-016	The ESS shall be able to be automatically shutted down in case of water coming from other compartment	Hz#8
REQ-AENEAS-D11-017	An alarm shall be installed within the ESS module for the entrance of water within the batteries compartment	Hz#8
REQ-AENEAS-D11-018	The ESS system shall be installed with a reduntant battery system in case of cell failure	Hz#9, Hz#11
REQ-AENEAS-D11-019	The ESS system shall be installed in areas where collision probability is low	Hz#12, Hz#13, Hz#14
REQ-AENEAS-D11-020	All the crew shall be well trained about ESS system	Hz#14, Hz#16
REQ-AENEAS-D11-021	All the crew shall be well trained about the procedure to follow for the integration of ESS system	Hz#14, Hz#16
REQ-AENEAS-D11-022	A safety check list shall be available for the installation of ESS on board ships	Hz#14, Hz#16
REQ-AENEAS-D11-023	All the crew shall know the procedure to be followed in both normal and abnormal conditions when working with ESS systems	Hz#14, Hz#16

10. Conclusions

In this deliverable Grimaldi Euromed S.p.A and Inland Shipping S.r.l. defined a preliminary operational profiles and requirements for a broad set of vessels for the development of new ESS for different marine applications. They gave high level detailed information for all typologies of vessels owned by the two companies. In particular, general description of the different vessel analyzed (dimensions, routes…) and electrical information are provided.

Issnova, Soermar and Freire Shipyard defined the safety requirements and safety critical risks that shall be covered for safe ESS installation onboard of the different ship types, based on operation and safety requirements from certification and type approval of marine battery systems. Fundacion Valencia gave an input about system installation and innovation from the port point of view.

All the provided information of this deliverable will serve as baseline for the task 1.2 in which

Issnova will independently choose one use-case vessel for the demonstration at TRL 5 for each of the ESS. The optimal use-case for each ESS will be chosen, based on a comparison of the investigated vessels in this deliverable on several KPIs taken from the vessel and ESS requirements.

11. References

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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
ESS	**Energy Storage Solutions**
SOx	**Sulphur Oxides**
PM	**Particulate Matter**
PTI	**Power Take In**
PTO	**Power Take out**
SSB	**Solid State Battery**
SC	**Supercapacitor**
RIS	**River Information Services**

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