ITALIAN CENTRE OF EXCELLENCE ON LOGISTICS
TRANSPORT AND INFRASTRUCTURE

UNIVERSITY OF GENOA

PhD in Transport and Logistics

XXXV series

GREEN INVESTMENT OPTIONS IN FERRY, RO-RO AND RO-PAX INDUSTRY

From theory to practice

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ABSTRACT

An increased focus on sustainability issues and climate change from customers as well as the whole society, jointly with more restrictive regulatory requirements, are triggering shipping lines to progressively adopt green strategies, aiming at reducing emissions and pursuing higher (energy) efficiency standards (Pallis and Vaggelas, 2019). In the shipping sector, the Ferry segment expresses global fleet of about 15,400 ships with a total gross tonnage (GT) exceeding 31 million, and globally transports about 4.27 billion passengers per year and 373 million vehicles; furthermore, it has a contribution on world GDP of 60 billion dollars and allows the employment of more than 1 million people (Interferry, 2019). Because of the importance of the traffic volumes handled both in terms of passengers and cargoes, as well as due to the related impacts originating from business operations, the Ferry, Ro-Ro and Ro-Pax industry is challenged to implement green strategies (Chang and Danao, 2007). Corporate Social Responsibility (CSR) paradigms and related theoretical constructs are expected to reshape future goals, strategies and implantation trajectories of major Ferry, Ro-Ro and Ro-Pax companies and improve firm performance (Lun et al., 2015). This PhD thesis scrutinizes green strategies and related investment options which are expected to allow Ferry, Ro-Ro and Ro-Pax group owners, operating European-flagged vessels, to reach sustainability goals without negatively affecting their economic/financial performance.

The document proposes a conceptual framework that addresses the most promising green investment options which Ferry, Ro-Ro and Ro-Pax companies can exploit for making the business more sustainable, reducing environmental impacts and improving energy and material

efficiency during day-by-day operations. Using insights from a systematic literature review conducted in the first sections of this PhD thesis, the most relevant green solutions widely investigated at academic level are examined and discussed for the purpose of this PhD thesis.

After an exhaustive description of the state of the art and the state of the play regarding green investment options in Ferry, Ro-Ro and Ro-Pax industry, this PhD thesis proposes an analysis of the most effective green strategies and practices concretely developed and planned in the industry. Empirical evidence shows that the most promising investment options relate to ship propulsion systems, such as the adoption of hydrogen and fuel cells (Trillos et al., 2021), alternative fuels (Very Low Sulphur Fuel Oil, Ultra Low Sulphur Fuel Oil and Liquefied Natural Gas), efficiency systems for auxiliary engines and ship design solutions. As confirmed by outcomes gathered in our final empirical dataset, i.e., the "green" sample, among the different solutions analysed, the most adopted green investment options by European companies operating in Ferry, Ro-Ro and Ro-Pax industry are: a) the refitting of bulbous bow, aimed at the implementation of the current design of the hull to increase the overall hydrodynamics of the ship; b) the installation of onboard batteries as a source of energy for ship propulsion; c) the use of Liquefied Natural Gas (LNG) as alternative fuel for the ship propulsion, that contributes to a 100% reduction in sulphur oxides emissions, 80-85% of nitrogen oxides emissions, 95% of particular matter emissions and 20-30% of carbon dioxide emissions compared to HFO/MDO (Burel et al., 2013).

The empirical analysis above mentioned is performed on 1,680 Ferry, Ro-Ro and Ro-Pax ships with flag from European Countries, with data gathered through IHS Maritime & Trade that holds the largest maritime ships database in the world, further integrated with data and information collected from several technical sources (e.g., news press, sustainability report and press release of European companies). Variables investigates within IHS Maritime & Trade regard the type of main and auxiliary engines and fuel type, hull materials, bulbous bow and other technologies and equipment aimed at mitigating the pollution and reducing harmful emissions. The outcomes shed light on the viability and feasibility of some green investments options by shipping companies operating in Ferry, Ro-Ro and Ro-Pax industry at European level.

To deal with this limited result, due to the lack of comprehensive dataset capable to scrutinize the diverse green solutions implemented on board European-flagged vessels, it was decided to develop an original and detailed dataset, capable to provide additional information concerning the approaches, decisions and strategies adopted by each group owners and related future trends about the adoption of green strategies in the sector. Through the examination of different sources (e.g., news press, specialised journals, communications by the companies on their corporate website, academic papers, etc.), information related to innovative technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions have been extracted for each ship of the database, i.e., the “overall” or “extended” sample. In this way, it has been possible to provide an exhaustive overview of the heterogeneous green solutions, equipment and components installed on board of ships that are part of the “green” sample and the related source, to allow the evaluation and examination from the point of view of the institutionalism of the source. In this way it was possible to focus on top ten best performer group owners of the “green” sample, to analyse the managerial and governance behaviours and attitudes implemented by them and to deepen in brief case histories the main strategies adopted by them.

CHAPTER 1

BACKGROUND ON THE PHD RESEARCH ACTIVITIES

1. Background on the PhD research activities

This PhD thesis is the result of investigations and research conduct within the PhD course of Maritime and Science Technologies, Curriculum of Logistic and Transport between 2019 and 2022. The research grant related to my PhD scholarship is co-financed by Italian Centre of Excellence on Logistics Transport and Infrastructure (CIELI) at University of Genoa and by Grandi Navi Veloci S.p.A. (GNV), leading Italian shipping company operating in the fields of coastal navigation and passenger transport in the Mediterranean Sea.

For GNV, I have carried out, within my PhD path, several activities in Business Development structure in Sales & Marketing Department in which I have been placed with the role of Business Development and Corporate Project Analyst and in other related departments for joint and multidisciplinary activities (Legal Department, Finance Department, Port Operations Department, etc.). Among these activities, I was responsible in charge of the scouting of solutions for the funding and the co-funding at national and European level in order to find opportunities to GNV and related operations and activities. In this vein, I took care of the submission (and the related data and documents collection for drawing up the application, reporting and invoicing of contributions, etc.) of the application to:

- the 16 calls launched by Ministry of Infrastructure and Sustainable Mobility (MIMS) for the use of ships used for the assistance of migrants;
- the call launched by the Marseille Prefecture for the chartering of a ship for the assistance of the Ukrainian refugees in France;

- the call launched by MIMS for the maritime territorial continuity with Sicily, Sardinia and Tremiti Islands;
- the Article 89 of Decree-Law n. 104/2020, n. 104 for the establishment of a compensation fund for the damage suffered by the maritime transport sector as a result of the pandemic by COVID-19;
- the "Marebonus" incentive by the Ex Minister of Infrastructures and the Transports aimed to support the transport of goods and freight by sea (Law of Stability 2016);
- the disciplinary to public evidence for the assignment in concession ex art. 18, law n. 84/1994 of some berths and relative areas behind (including the marine station and the subsistence area), in the Port of Civitavecchia;
- the contribution provided for in Article 1, paragraph 2-ter, letter a) of Decree-Law 6 May 2021, n. 59, converted with amendments, by Law 1 of July 2021, No. 101, as governed by the Decree of the Minister of Sustainable Infrastructure and Mobility n. 389 of 12 October 2021 (supported by the additional fund of PNRR[1]) for the refitting of n. 11 Ro-Pax ships in the GNV fleet.

In GNV, I have carried out other activities: back-office activities related to database of Ferry, Ro-Ro and Ro-Pax ships, database of MICE events (Meetings, Incentives, Conferences and Exhibitions), database of harbour costs, files related to the annual presentation of the GNV budget, charter-in and charter-out contracts; simulation activities of charters, changes of deployment, positioning/repositioning simulations, new lines and new markets; monitoring and maintenance activities related to weekly sales targets and objective per trade and distribution channel. In addition, I have arranged the institutional letter for the MIMS from "Assarmatori" on the eligible green investment options to the recovery fund (PNRR) in shipping industry for the renewal of the Ferry, Ro-Ro and Ro-Pax fleet.

In accordance with my role in GNV, I collaborated in the research activities and publications below.

- Conference paper during transport and shipping annual conference held during the period of my PhD:

[1] The Piano Nazionale di Ripresa e Resilienza (PNRR; in English National Recovery and Resilience Plan, abbreviated in Recovery Plan or NRRP), is the plan that was approved in 2021 by Italy to relaunch its economy after the COVID19-pandemic, in order to allow the green and digital development of the country.

  - Parola F., Satta G., Morchio G., Vitellaro F. (2020), "Green strategies in the cruise industry: from theory to practice", Cartagena Cruise Dialogue Conference, Cartagena[2] (Colombia).
  - Satta G., Parola F., Morchio G., Vitellaro F. (2020), "Green strategies in the cruise industry: towards an overarching conceptual framework", International Association of Maritime Economists (IAME) Conference[3] 2020 "Sustainable Development of Shipping and Trade" (Online event).
  - Morchio G., Notteboom T., Satta G. (2021), "Green strategies in the ferry and ro-pax industry: an assessment of viable investment options", IAME Conference 2021 "Accelerating Transitions in Ports and Shipping" (Online event).
  - Della Valle M., Buratti N., Morchio G., Satta G., Vitellaro F. (2021) "Communication strategies for crisis management in shipping companies: towards an overarching theoretical framework", IAME Conference 2021 "Accelerating Transitions in Ports and Shipping" (Online event).
  - Satta G., Persico L., Morchio G., Tropea C. (2021), "Market opportunities for cruise lines in the outbound distribution channels: assessing the predictors of new bookings", Società Italiana di Management (SIMA)[4] (Online event).
  - Morchio G., Notteboom T., Satta G., Vottero B. (2022), "Green finance in bulk shipping", IAME Conference 2022 "Impact of COVID-19 on the Maritime Industry: Challenges and Responses" (Online event). At the IAME 2022 conference, this paper won the Best Paper Award (for Maritime Policy and Management).
- Academic papers on national and international Journals, dedicated to transport, shipping and tourism sectors:
  - Satta G., Parola F., Morchio G., Vitellaro F. (2020), "Green strategies in the cruise industry: from theory to practice", Research Transportation in Business and Practice[5].

[2] An International academic-industry dialogue on how best to accommodate the seemingly unstoppable growth of cruise activities.
[3] The IAME Conference is an annual opportunity for the world scientific community to meet and discuss current research topics and contribute to the development of maritime economics and management as a well-established academic discipline.
[4] SIMA organizes an annual conference aimed at, in the academic field, making the discipline grow, represent it and protect it in its institutional environment of reference and at, in the economic and social field, promoting the advancement and transfer of entrepreneurial and managerial culture.
[5] Research in Transportation Business & Management (RTBM) publishes research on international aspects of transport management such as business strategy, communication, sustainability, finance, human resource management, law, logistics, marketing, franchising, privatization and commercialization.

- Satta, G., Parola, F., Vitellaro, F., & Morchio, G. (2021). LNG Bunkering Technologies in Ports: An Empirical Application of the SWOT Analysis. KMI International Journal of Maritime Affairs and Fisheries[6], 13(1), 1-21.
- Morchio, G., & Satta, G. (2022). Blueprints. In Encyclopedia of Tourism Management and Marketing[7], Edward Elgar Publishing.
- Morchio G., Carozzo V., Satta G., Vottero B. (2022), "Tecnologie e opzioni di investimento "green" nel settore Ferry, Ro-Ro e Ro-Pax", Impresa e Progetto[8].
- Satta G., Parola F., Morchio G., Vitellaro F. (under review). "Green strategies for cruise lines: investment options and innovative solutions", Journal of Corporate Social Responsibility and Environmental Management[9].
- Morchio G., Notteboom T., Satta G., Vottero B. (under review), "Green finance in bulk shipping", Maritime Policy and Management[10].

In accordance with the research activities, the research projects[11] I took part to as a member (CIELI team) and the university, doctoral and advanced courses that I conducted during the PhD course, this PhD thesis investigates the state of the art and the state of the play on green investment options in Ferry, Ro-Ro and Ro-Pax industry.

Due to the extreme level of coherence between the topics treated in this PhD thesis and those analysed in the project activities and publications listed above, it is possible to state that this PhD thesis is the result of an intense research activity in the field, thanks to the involvement of

[6] Peer-review international journal of ocean policy studies and marine data analytics.
[7] The largest tourism management and marketing ontology, offering a holistic examination of this interdisciplinary field.
[8] Impresa Progetto - Electronic Journal of Management (IPEJM) is an academic online Journal that is issued twice a year, presenting and disseminating cutting-edge findings from research studies by Italian and international scholars and researchers in economics and business studies.
[9] It publishes theoretical and practical contributions about tools and practices associated with the social and environmental responsibilities of businesses in the context of sustainable development and also publishes case studies and cross-country surveys of best practice helping organizations improve performance and accountability in these areas.
[10] A multi-disciplinary and international refereed journal that brings together papers on the different topics that concern the maritime industry.
[11] Euopean Project INTERREG Italy-France Maritime "Aria bene comune" (acronym: AER NOSTRUM), Euopean Project "Strategie per la crescita sostenibile e green strategies nel settore marittimo portuale"; Euopean Project INTERREG Italy-France Maritime "Strategie transfrontalIere per la valorizzazione del Gas NAturale Liquido" (acronym: SIGNAL); Euopean Project INTERREG Italy-France Maritime "Tecnologie e Dimensionamento di Impianti per la RETE di distribuzione primaria di GNL nei porti dell'area transfrontaliera" (acronym: TDI RETE-GNL).

both academic experts and practitioners in the sector, and the implementation of project activities with strong integration with the issues and topics widely argued in the PhD thesis.

This PhD thesis focuses on the response of the Ferry, Ro-Ro and Ro-Pax industry to the increased focus on sustainability issues and climate change from customers as well as the whole society. In this vein, this PhD thesis scrutinizes green strategies and related investment options which are expected to allow Ferry, Ro-Ro and Ro-Pax group owners, operating European-flagged vessels, to reach sustainability goals without negatively affecting their economic/financial performance.

The document proposes a chapter (Conceptual framework: impacts and drivers) with a focus on the conceptual framework that addresses the most promising green investment options which Ferry, Ro-Ro and Ro-Pax companies can exploit for making the business more sustainable, reducing environmental impacts and improving energy and material efficiency during day-by-day operations. This chapter proposes a first paragraph, with environmental impacts as an essential prerogative to adopt innovative green strategies and procedures, and a second one focusing on the main drivers at the basis of the competitive advantage in shipping industry.

An analysis of theoretical constructs that are at the basis of the strategic objective of major Ferry, Ro-Ro and Ro-Pax companies is proposed in Chapter 3 (Theoretical construct) in order to analyse the reactions of such shipping firms to the environmental challenges.

In the fourth Chapter (Green strategies: literature review) a systematic literature review has been carried out, in order to analyse the growing importance assumed by green investment options that shipping companies operating in Ferry, Ro-Ro and Ro-Pax sector can implement to contain environmental impacts and ensure the sustainable growth of the sector.

Following the systematic literature review, the fifth Chapter (Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the art) deepens the technical solutions and investments options that emerged in the systematic literature review as the main opportunities for Ferry, Ro-Ro and Ro-Pax companies aimed at reducing their environmental impact and pollutant emission. In each its paragraphs, all technical solutions and investments options are extensively deepened, supported both by scholars and academics in the sector, and then by the real feasibility of these technology and investment options in the Ferry, Ro-Ro and Ro-Pax industry, with a specific focus on the European companies.

The sixth Chapter of this PhD thesis (Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the play) examines in detail the state of the play of the adoption of technical solutions and investments options from shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry, in order to test the conceptual framework proposed within the fifth Chapter. This analysis is also aimed to identify the best group owners, basing on the greater incidence of "green" ships respect to the total of the fleet and on their managerial and governance behaviours.

The seventh Chapter (Conclusions) discusses the results of sixth Chapter, clearly demonstrates how the two research objectives have been met and discusses the contributions of this PhD thesis to academia and the business world. This Chapter focuses also on the limitations of the research and the difficulties that I encountered and presents some ideas for future research and implementation.

CHAPTER 2

CONCEPTUAL FRAMEWORK: IMPACT AND DRIVER

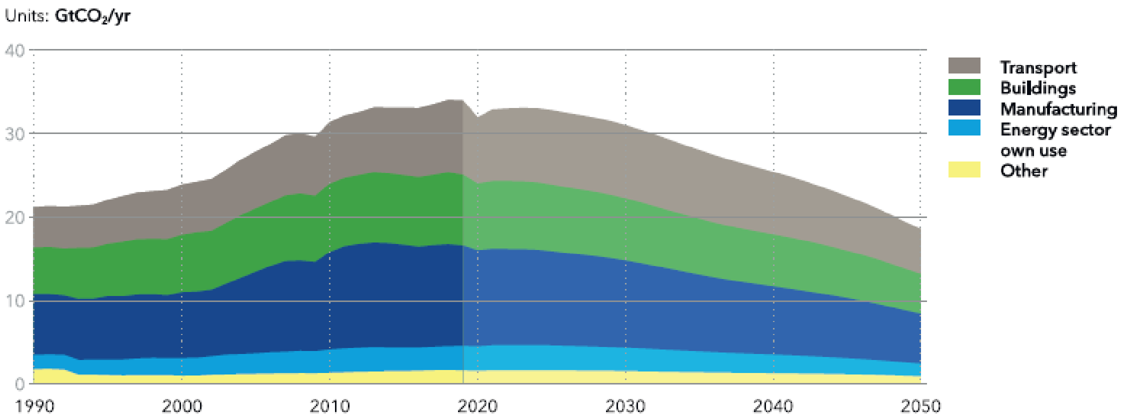
2. Conceptual framework: impacts and drivers

Although shipping sector constitutes globally the most environmentally efficient mode of transport due to the handling of large amount of goods (Miola et al., 2009; Cristea et al., 2013), this sector however, determines significant negative environmental impacts with the risk of damaging the ecosystem worldwide.

From a sectoral perspective, manufacturing is currently the largest contributor to energy-related carbon dioxide (CO_2) emissions with 12 Gt CO_2 emitted in 2019, constituting 35% of all annual energy-related emissions. The transport sector made up 26% of emissions, almost 9 Gt CO_2, while buildings which is the remaining major demand sector, emitted 8.5 Gt CO_2, 25% of global energy-related CO_2 emissions in 2019 (DNV-ETO, 2021[12]). The transport sector had a sharp decline in emissions in 2020, due to changing travel patterns associated with the COVID-19 pandemic. However, it is only by the late 2020s that transport emissions started to decline, because even though a growing number of electric vehicles (road transport) contributed to reduce transport-related emissions, such trend has been initially countered by a transport growth and a lack of emission reductions in hard-to-abate sectors, such as shipping and aviation. The transport sector will increase its share to represent 29% of emissions, however reduced to 5.4 Gt CO_2 in 2050 (Figure 1).

[12] DNV (formerly DNV-GL) is an international accredited registrar and classification society, and ETO is the acronymous of Energy Transition Outlook report.

Figure 1. World energy-related CO_2 emissions by sector.



Source: DNV-ETO, 2021.

The main environmental impacts caused by the sector include, for example, the emission of greenhouse gases (GHG) and other harmful emissions into the air (SOx[13], NOx[14], PM[15], etc.), the landfill of waste at sea, noise pollution, the transfer of Non-Indigenous Species (NIS) with the practice of loading and unloading of ballast water and the physical damage caused to the seabed (EMSA, 2021). According to International Maritime Organization[16] (IMO), in the year 2018 sea transport emitted 1.056 million tons of CO_2, i.e., the 2.89% of global emissions emitted for the same year (4th IMO GHG Study, 2018). In addition, due to the constant and sustained growth rates of the sector, future forecasts are not favourable: IMO declares that these emissions could increase to 90-130% of 2008 by 2050 if no containment measures are taken (4th IMO GHG Study, 2020), and that in the same year sea transport could represent 15% of the emissions released globally.

In this context, also considering the growing global attention in favour of the fight against climate change, the international community, in compliance with national government institutions and industry associations, defined a regulation aimed at preserving and protecting the environment. In this file, it is possible to identify many international conventions for the protection of environmental sustainability, such as the regulations produced by the IMO and the regulations dictated by the EU, including the regulations applied to the shipping sector proposed under the package of standards known as "Fit for 55" proposed on 14 July 2021 and currently

[13] Sulphur oxides.
[14] Nitrogen oxides.
[15] Particulate matter.
[16] The International Maritime Organization is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships.

under approval. The Fit for 55 is a package proposed by the European Commission designed to reduce the European Union's greenhouse gas emissions by 55% by 2030. Measures include additional support for clean transport, renewables, the Carbon Border Adjustment Mechanism on emissions for high-carbon imports, etc.

At the same time, shipping companies are called to play a role both in compliance with regulations triggering them towards a greater assumption of responsibility for the social and environmental effects deriving from the exercise of business activities. Shipping companies also try to achieve a balance of the interests of the different categories of stakeholders.

Shipping companies could adopt different strategies aimed at mitigating the negative externalities of the sector through apposite green strategies. According to the main academic literature, green strategies are divided into three basic categories (Wan et al., 2018; Serra and Fancello, 2020): i) technical solutions or hard investments, relating to the adoption of devices aimed at promoting the energy efficiency of the ship in terms of propulsion systems; ii) operations procedures or soft investments; iii) Market-Based Measures (MBM), representing an incentive mechanism and a market instruments leading to the economic internalisation of environmental impacts.

The shipping industry is going through a phase of deep transformation, as the increasing global attention to the issues related to climate change is requiring enormous efforts by the industry in order to reduce its own climatic footprint (Aijjou et al., 2018) in order to reach, by 2050, the "zero-emission" target. In this context, particular importance must be given to the maritime transport of people and goods via Ferry, Ro-Ro[17] e Ro-Pax[18], because of its specificities. Indeed, companies operating in the Ferry, Ro-Ro and Ro-Pax sector play a fundamental role in this context, because of their traffic volumes, the relevance of the impacts generated per passenger/mile and per ton/mile, and because of the possibility of exploiting technologies not yet mature enough for the other shipping segments.

Until 60 years ago, the maritime transport of passengers was the main mode of transport, together with land transport. This situation has changed over time, also because of the increasingly important role of aviation, particularly of low-cost airline companies. In this vein, the maritime transport of passengers via Ferry and Ro-Pax ships competes with other modes of transport because of some aspects:

[17] Roll-on/Roll-off ship are cargo ships designed to carry wheeled cargo (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, such as a self-propelled modular transporter.
[18] Roll-on/Roll-off Passengers ships are specific type of Ro-Ro ships that is configurated for combined transport of passengers and wheeled cargo and vehicles.

- Ferry and Ro-Pax ships can provide a service that other modes of transport cannot offer, for example the transport of a passenger together with his vehicle;
- also from the point of the environmental issues, Ferry and Ro-Pax ships can also compete with other modes of transport, being able to provide a service capable of containing congestion in urban areas and therefore the main emissions attributable to road transport;
- Ferry and Ro-Pax ships become a specific part of the urban transport of some nations and territories, for example, in response to the needs of territorial continuity in the case of connections between the islands and the mainland (for examples, links between the Italian peninsula and the major and minor islands).

Essentially, the main characteristics of Ferries, Ro-Ro and Ro-Pax ships vary according to the market, affecting the following variables: length of routes, type of cargo to be transported, capacity in terms of passengers and vehicles required by the market, required speed, meteorological situation of the sea to be crossed, etc. As anticipated, the "Ro-Pax" ship consists of a class of ferries intended for the transport of passengers with specific accommodation on board (cabins, pullman seats and, where appropriate, seats) and the vehicle belonging to passengers, which will be transport within the ship's garages. At the same time, the Ro-Ro ships are vessel transporting wheeled cargo, be it cars, trucks, buses, trailers or even industrial vehicles, and related driver, in the case of guided vehicles/vehicles.

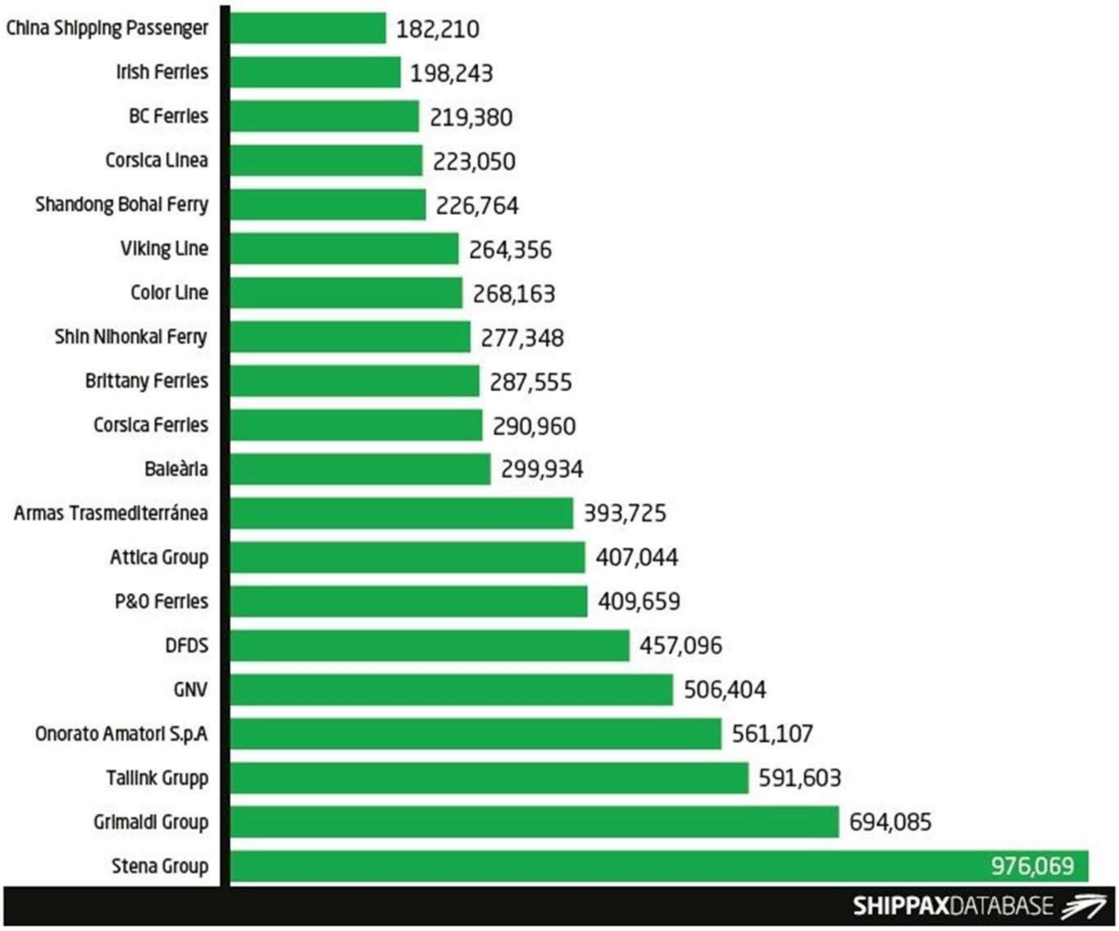
Among the most important reasons why the ferry industry needs a special focus, specifically regarding to the ecological transition, we can mention the liner shipping character, the many short-distance connections, the traffic volumes, the impact of the field for pax for kilometre and for ton for kilometre that is greater than the other shipping industries, etc. Such specificities generate a remarkable impact on the environmental footprint and feasibility of certain solutions and technologies that today are still not mature for the other segments of the shipping, like for example, the cold ironing and the battery-electric solutions.

The ferry industry has a global fleet of about 15,400 ships with a total gross tonnage exceeding 31 million tons and transporting about 4.27 billion passengers per year and 373 million vehicles in the world. Moreover, its contribution to world GDP is 60 billion dollars and allows the employment of more than 1 million people (Interferry, 2019). The Shippax[19] classification

[19] Shippax is a provider of data and information about the ferry, cruise, Ro-Ro and hi-speed market. It reports about news and analyses, comments and gathers statistics and information that are then published in the annual publications, monthly magazine and website. Shippax online database is the most comprehensive passenger shipping database available on the market, updated continuously with ship information, addresses and financial information.

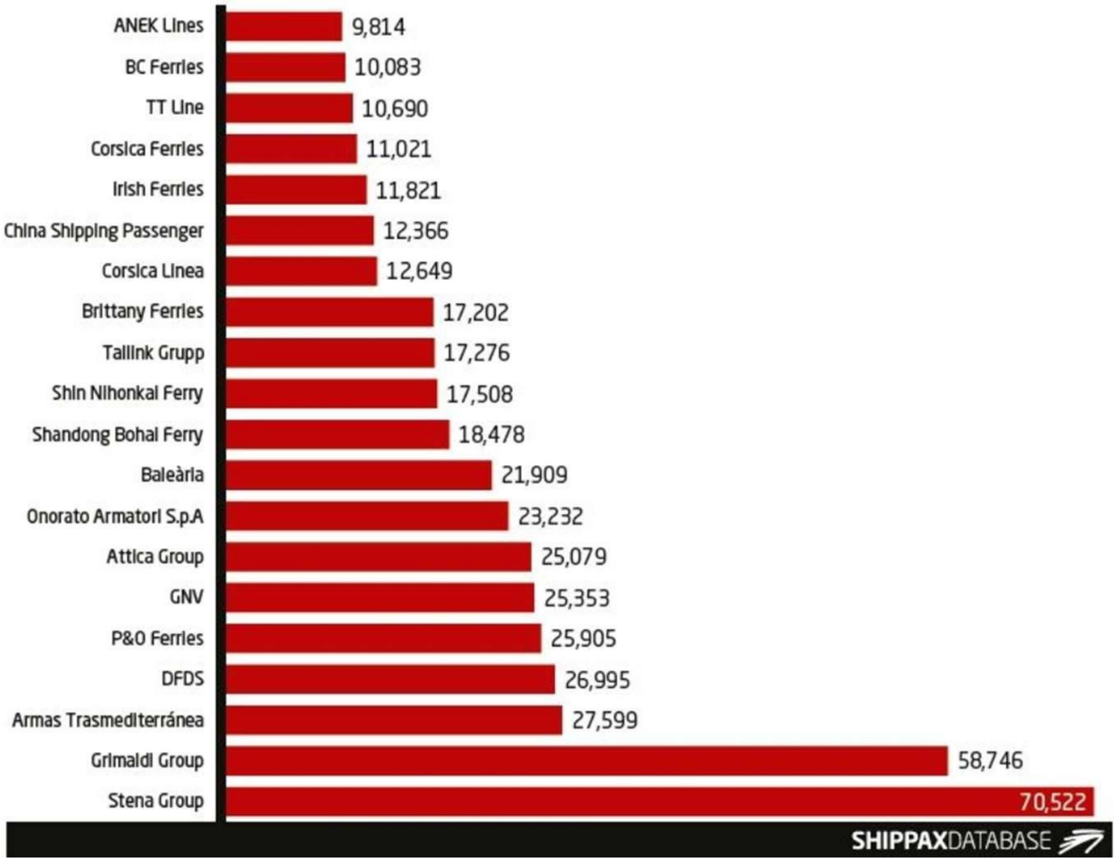
(2020) is shown in Figure 2 and evidences the greatest shipping companies in the Ferry, Ro-Ro and Ro-Pax industry in terms of GT: the three shipping companies Grimaldi Group, Grandi Navi Veloci and Onorato Armatori are in the top five ranking. The Figure 3, instead, refers to the capacity of transport of shipowner’s fleet in terms of linear meters: the Grimaldi Group fleet always appears to the second place, while Great Navi Veloci scale of a position followed from the Onorato Armatori.

Figure 2. Overview of the main shipping companies in ferry industry in terms of gross tonnage.



Source: Shippax, 2020.

Figure 3. Overview of the main shipping companies in ferry industry in terms of linear metres of capacity.



Source: Shippax, 2020.

The ferry transport is increasing for 84% if compared to the second Quarter of 2021; currently it is positioned above the pre-pandemic levels with a +7.2%, referring to the second trimester of 2019. The industry of transport of goods by Ro-Ro ships through heavy vehicle and trucks is increased too, with a +7%, compared to 2021 (MIMS, 2022). Compared to the second quarter of 2019, the industry appears to have increased displacements by 6%, thus improving performance by a percentage point.

This PhD thesis deepens the current knowledge on green strategies for Ferry, Ro-Ro and Ro-Pax segment, by scrutinizing several alternative investment options. For this purpose, first a taxonomy of environmental impacts is provided and discussed. Then, grounding on both mainstream academic literature and recent anecdotal evidence, this PhD thesis proposes an original conceptual framework which disentangles technologies and technical solutions Ferry, Ro-Ro and Ro-Pax companies can rely on when pursuing green strategies. The identification of the available green options is based on the implementation of a systematic literature review conducted on 350 academic contributions, to identify and analyse technological solutions that companies operating in Ferry, Ro-Ro and Ro-Pax industry can implement to pursue the objective of monitoring environmental impacts and ensuring the sustainable growth of the sector. In this way, three categories of green investment options (technical solutions for energy and environmental efficiency, ship propulsion system and alternative fuels and ballast water treatment systems) are identified, and for each of them alternative investment options are compared and discussed, highlighting both weaknesses and strengthens. Among them, VLSFO[20], ULSFO[21], LNG[22], biofuels, methanol and hydrogen as alternative fuel; exhaust gas cleaning systems, hull air lubrication, new bulbous bow and antifouling paints, as some technical solutions for energy efficiency; and cold ironing and electrification of berth.

In order to support the research design, the proposed conceptual framework is then tested by empirically investigating and assessing the current state of the art of the adoption of green strategies among the Ferry, Ro-Ro and Ro-Pax industry. This is made through a multiple case study analysis, the actual adoption rate of each category of green strategies and related investment options by major Ferry, Ro-Ro and Ro-Pax companies. This analysis is performed with a data gathering through I Maritime & Trade to examinate the viability and the feasibility of green investments options pursued by shipping companies operating in Ferry, Ro-Ro and Ro-Pax industry at a European level. Variables investigated with IIHS Maritime & Trade concern the investment options related to main and auxiliary engines, ballast tanks, fuel, hull materials and other technologies and equipment aimed at mitigating pollution and reducing harmful emissions.

Given the environmental impact of the Ferry, Ro-Ro and Ro-Pax industry and the growing expectations from the main stakeholders, companies operating in this shipping segment are challenged to implement new green strategies for achieving higher sustainability and competitiveness levels.

As green strategies in the Ferry, Ro-Ro and Ro-Pax industry still remain an underexplored topic in extant literature, this PhD thesis is intended to further develop the academic knowledge on this matter. In particular, the aim of this PhD thesis is twofold. First, it studies and develops an ad-hoc conceptual framework addressing viable green investment options in the segment domain (research objective n. 1: **RO.1**). The conceptual framework is described starting from the description of the impacts in the ferry, Ro-Ro and Ro-Pax sector and, for each of them, defines

[20] Very Low Sulphur Fuel Oils.
[21] Ultra-Low Sulphur Fuel Oil.
[22] Liquefied Natural Gas.

the main green investment options available. In this vein, for each green investment options available data and information are depended, including technical, managerial and economic-financial based information. Second, it applies the proposed model to major European Ferry, Ro-Ro and Ro-Pax companies in order to assess the current state of the art in the industry as well as the real commitment of companies in pursuing green strategies (research objective n. 2: **RO.2**). Based on the characteristics of the specificities of these main green investment options, RO.2 is responsible for identifying and mapping Ferry, Ro-Ro and Ro-Pax ships characterized by that sustainable equipment and for that shipping companies with most reacting approaching in investing in green strategies are focused on. In this vein, I further developed a database including technical, managerial and economic-financial based information. For this purpose, two distinct samples of ships have been designed and populated and also an in-depth analysis of the green strategies performed by the most active European shipping companies operating in the focused target has been developed. The first database, i.e., the "overall" or "extended" sample, is an ad hoc dataset on green investment options in the Ferry, Ro-Ro and Ro-Pax industry and has been developed grounding on IHS Maritime & Trade database. Through the in deep analysis of the "overall" sample an additional dataset, i.e., "green" sample, is developed to identify and map the latest green technologies and investment options adopted by companies operating in the Ferry, Ro-Ro and Ro-Pax industry.

Relatedly, this PhD thesis addresses one of the urgent main challenges for maritime transport and, in particular, for the Ferry, Ro-Ro and Ro-Pax industry and related environmental impacts to answer the following research questions:

I. How can Ferry, Ro-Ro and Ro-Pax companies reduce the environmental impact of their operations?
II. What are the most adopted green strategies by companies in the industry?
III. What is the incidence of "green" ships on the total of the existing ships belonging to the European Ferry, Ro-Ro and Ro-Pax fleet?
IV. What are the main environmental benefits for the Ferry, Ro-Ro and Ro-Pax industry?

Given the wide scope of these research questions as well as the peculiarities of the Ferry, Ro-Ro and Ro-Pax industry, the PhD thesis studies and develops an ad-hoc conceptual framework addressing viable green investment options in the segment domain in order to apply the proposed model to major companies in the industry in order to assess the current state of the art of the industry as well as the real commitment of companies in pursuing green strategies.

In this vein, the research questions are perfectly in line with the proposed research objective (RO.1 and RO.2), that are fixed for this PhD thesis. For achieving the research agenda set in RO.1, first, the next paragraph (2.1 Environmental impacts) focuses on the classification of environmental impacts according to a comparison of several reports and studies proposed by international institutions and academic researchers. In this context, it is necessary to acknowledge theoretical constructs such as Corporate Social Responsibility (CSR) and Stakeholder Relationships Management (SRM) paradigms (Carroll, 1991; Freeman, 2010), that are therefore expected to reshape the future strategic objective of major Ferry, Ro-Ro and Ro-Pax companies. These steps constitute a pre-condition for investigating available green technologies, assets and equipment which allow Ferry, Ro-Ro and Ro-Pax companies to reduce their environmental impact (RO.2).

2.1 Environmental impacts

The identification and quantification of the environmental impacts caused by shipping is an essential prerogative to adopt innovative green strategies and procedures. Literature on the assessment of the environmental impacts caused by marine transport is scarce and limited (Andersson et al., 2016; Walker et al., 2019). However, studies on the environmental consequences in the shipping industry can be found in specific areas, including oil spills (Neuparth et al., 2012), the management of plastic waste (Li et al, 2016), the transfer of non-indigenous species via ballast water (Bax et al., 2003), antifouling paints (Konstantinou and Albanis, 2004; Yebra et al., 2004) and underwater noise pollution (UNEP, 2012; Peng et al., 2015). Nonetheless, an overall assessment of the environmental impacts of maritime transport cannot be found (Jägerbrand et al., 2019).

The environmental impacts from the shipping industry can be classified into special categories for study and research purposes, and both literature and specialized supranational institutions propose different possibilities, as reported in Table 1. Despite the different options proposed, this thesis refers to the classification provided by the European Maritime Safety Agency (EMSA) in the European Environmental Report on Maritime Transport of 2021, that classifies the environmental impacts of shipping in atmospheric emissions, release of harmful liquid substances, landfill of solid waste, noise pollution, transfer of native species, physical damage to the seabed and risk of collision with marine species. Furthermore, the classification provided by EMSA is compared with other environmental impacts classifications from the following sources:

- European Maritime Transport Environmental Report, EMSA, 2021.

- Jägerbrand, A. K., Brutemark, A., Sveden, J. B., & Gren, M. (2019). A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. *Science of the Total Environment*, *695*, 133637.
- Walker, T. R., Adebambo, O., Feijoo, M. C. D. A., Elhaimer, E., Hossain, T., Edwards, SI., ... & Zomorodi, S. (2019). Environmental effects of marine transportation. In *World seas: an environmental evaluation* (pp. 505-530). Academic Press.
- Joumard, R., Gudmundsson, H., & Folkeson, L. (2011). Framework for assessing indicators of environmental impacts in the transport sector. *Transportation research record*, *2242*(1), 55-63.
- Environmental Impacts of International Shipping, OECD, 2011.

Table 1. Classification of environmental impacts from shipping industry.

Classification	***Source***				
	European Maritime Transport Environmental Report (EMSA), 2021	*A review on the environmental impacts of shipping on aquatic and nearshore ecosystems, Jägerbrand et al., 2019*	*Environmental Effects of Marine Transportation, Walker et al., 2019*	*Framework for Assessing Indicators of Environmental Impacts in the Transport Sector, Joumard et al., 2011*	*Environmental Impacts of International Shipping, OECD, 2011*
Greenhouse Gas	Air emission		Air pollution	Greenhouse effect	Energy use and emission of GHG
Atmospheric pollution			Air pollution		
Air pollution	Air emission	Air emission	Air pollution	Air pollution	Exhaust emissions
Direct (restricted) toxicity of air pollution	Air emission	Air emission	Air pollution	Air pollution	Exhaust emissions
Phototermical pollution				Air pollution	
Acidification				Air pollution	
Ozone depletion	Air emission			Air pollution	
Dust	Air emission			Air pollution	Other environment problems related to Port Activity
Maritime pollution	Water pollution	Discharge to water	Effects on terrestrial habitat and marine ecosystem	Soil and water pollution	Other environment problems related to Port Activity
Oil Spills	Water pollution	Discharge to water	Spills from ships	Soil and water pollution	Other environment problems related to Port Activity
Water discharge	Water pollution	Discharge to water	Ballast water containing aquatic invasive species (AIS)	Other impacts	Other environment problems related to Port Activity
Antifouling	Water pollution	Discharge to water			Other environment problems related to Port Activity
Wastewater	Water pollution	Discharge to water		Soil and water pollution	
Sewage, sludge and spills	Water pollution	Discharge to water	Spills from ships	Soil and water pollution	Other environment problems related to Port Activity
Pollution of soil, surface water and groundwater	Water pollution / Physical disturbance of the seabed	Discharge to water		Soil and water pollution	Other environment problems related to Port Activity
Ballast water containing aquatic invasive species (AIS)	Non-indigenous species	Discharge to water	Ballast water containing aquatic invasive species (AIS)	Other impacts	Other environment problems related to Port Activity

Classification	***Source***				
	European Maritime Transport Environmental Report (EMSA), 2021	*A review on the environmental impacts of shipping on aquatic and nearshore ecosystems, Jägerbrand et al., 2019*	*Environmental Effects of Marine Transportation, Walker et al., 2019*	*Framework for Assessing Indicators of Environmental Impacts in the Transport Sector, Joumard et al., 2011*	*Environmental Impacts of International Shipping, OECD, 2011*
Hull-fouling	Non-indigenous species	Discharge to water			
Non-indigenous species	Non-indigenous species	Discharge to water	Ballast water containing aquatic invasive species (AIS)	Other impacts	
Ship generated waste	Marine litter				
Other waste sources	Marine litter			Other impacts	
Noise	Noise	Physical impacts	Underwater noise	Noise and vibration	Other environment problems related to Port Activity
Vibration				Noise and vibration	
Visual qualities of landscape or townscapes	Physical disturbance of the seabed	Physical impacts	Effects on terrestrial habitat and marine ecosystem	Impacts on land	Other environment problems related to Port Activity
Shoreline erosion and resuspension of sediments	Physical disturbance of the seabed	Physical impacts	Ship strikes on marine megafauna	Soil and water pollution	Other environment problems related to Port Activity
Dredging	Physical disturbance of the seabed	Physical impacts	Effects on terrestrial habitat and marine ecosystem	Impacts on land	Other environment problems related to Port Activity
Risk of collision of vessel with marine species	Risk of collision of vessel with marine species				
Wildlife collisions	Risk of collision of vessel with marine species	Physical impacts	Ship strikes on marine megafauna	Impacts on land	
Ship strikes on marine megafauna	Risk of collision of vessel with marine species		Ship strikes on marine megafauna	Impacts on land	
Effects on terrestrial habitat and marine ecosystem	Risk of collision of vessel with marine species		Effects on terrestrial habitat and marine ecosystem	Impacts on land	
Ship grounding and sinking		Physical impacts	End-of-Like Ship Disposal		
Shipbreaking		Physical impacts	End-of-Like Ship Disposal		
Accident	Risk of collision of vessel with marine species	Physical impacts	End-of-Like Ship Disposal	Accident	
Artificial light		Physical impacts		Other impacts	

Classification	Source				
	European Maritime Transport Environmental Report (EMSA), 2021	*A review on the environmental impacts of shipping on aquatic and nearshore ecosystems, Jägerbrand et al., 2019*	*Environmental Effects of Marine Transportation, Walker et al., 2019*	*Framework for Assessing Indicators of Environmental Impacts in the Transport Sector, Joumard et al., 2011*	*Environmental Impacts of International Shipping, OECD, 2011*
Land loss		Physical impacts	Effects on terrestrial habitat and marine ecosystem	Impacts on land	Other environment problems related to Port Activity
Soil erosion		Physical impacts	Effects on terrestrial habitat and marine ecosystem	Impacts on land	
Hazardous and noxious substance spills			Spills from ships	Soil and water pollution	
Hydraulic changes and risks				Soil and water pollution	
Spills and operational discharges of oil and cargo (also dry cargo release)		Discharge to water	Spills from ships		Other environment problems related to Port Activity
Ship based garbage management	Marine litter		Garbage management	Non-renewable resource use and waste handling	
Marine Litter	Marine litter	Discharge to water	Garbage management	Non-renewable resource use and waste handling	Other environment problems related to Port Activity
Non-renewable resource use	Marine litter		Garbage management	Non-renewable resource use and waste handling	
Non-recyclable waste	Marine litter		Garbage management	Non-renewable resource use and waste handling	Other environment problems related to Port Activity
Direct waste from vehicle	Marine litter		Garbage management	Non-renewable resource use and waste handling	Other environment problems related to Port Activity
Electromagnetic pollution				Other impacts	
Introduction of illnesses				Other impacts	
Fire risk				Other impacts	
Technological hazards				Other impacts	

Source: Author's elaboration on EMSA, 2021; Jägerbrand et al., 2019; Walker et al., 2019; Joumard et al., 2011; OECD, 2011.

To provide a brief description of the main environmental impacts caused by the operation of Ferry, Ro-Ro and Ro-Pax ships, this PhD thesis assesses the adaptation of the taxonomy adopted in the latest GRI Standards (Global Reporting Initiative) and in the CDP (ex-Carbon Disclosure Project) and applies it to the Ferry, Ro-Ro and Ro-Pax industry. Notably, GRI standards are the global guidelines for sustainability reporting and include a set of economic, environmental and social KPIs. GRI is an international independent standards organization that helps businesses, governments and other organizations understand and communicate their impacts on issues such as climate change, human rights and corruption. So, companies are expected to monitor related GRI's KPI while doing business. CDP, conversely, is an international non-profit organization that provides firms, local authorities, governments and investors with a reporting system of environmental performance. Each year the program requests information on greenhouse gas emissions, energy use and the risks and opportunities related to climate change from the world's largest companies. This reporting system includes four monitoring programs, i.e., Climate Change Program, Water Program, Forests Program and Supply Chain Program.

The proposed taxonomy comprehends a heterogeneous cluster of environmental impacts related to day by day shipping operations (Parola et al, 2020) such as the ones already represented in Table 1: air pollution (e.g. nitrogen oxides, sulphur oxides and other significant air emissions); GHG emissions (from fuel, ship generators and refrigerants, etc.); negative impacts on biodiversity; impacts of energy consumption (electric, heating, cooling, steam consumptions); light pollution both at sea and at port; noise pollution that includes both at port and underwater noise emissions; waste of resources, materials and energy; negative impacts on water and effluents (e.g., management of water discharge-related impacts, water consumption, etc.) (Table 2).

Table 2. Taxonomy of environmental impacts in Ferry, Ro-Ro and Ro-Pax industry.

Environmental impact	***Description***
Air pollutants	NOx, SOx, PM and other significant air emissions; Combustion emissions from burning waste.
GHG emissions	Direct GHG emissions (from fuel to propel); Indirect GHG emissions (from ship refrigerants to cool appliances); Emissions of ozone-depleting substances; GHG emissions from electricity purchased at the port of call for power the ship while docked.
Biodiversity	Significant direct or indirect impacts of activities, products, and services on biodiversity, habitats protected or restored; Implications on animal and plant species, especially national conservation list species; Ballast water.
Energy	Energy consumption (electric consumption, heating consumption, cooling consumption, steam consumption) onboard and at the dock.
Light pollution	Light pollution, both at sea and at port; Distresses and harms to animal species and other living beings.
Noise pollution	Noise emissions, especially at port and near densely populated area; Underwater noise emission.
Materials	Non-renewable materials used; Percentage of non-recycled input materials; Percentage of non-reclaimed products and their packaging materials.
Effluents and Waste	Significant spill overs of waste by type and disposal method; Hazardous waste; Waste in shipboard incinerators; Waste generated in operation; Waste-to-landfill per passenger.
Water and Effluents	Water discharge-related impacts; Water consumption; Water withdrawal from different sources (ocean; river; rainwater, etc.); Disposal of oil bilge water, black water, and grey water; Usage of potable water.

Source: Parola et al, 2020.

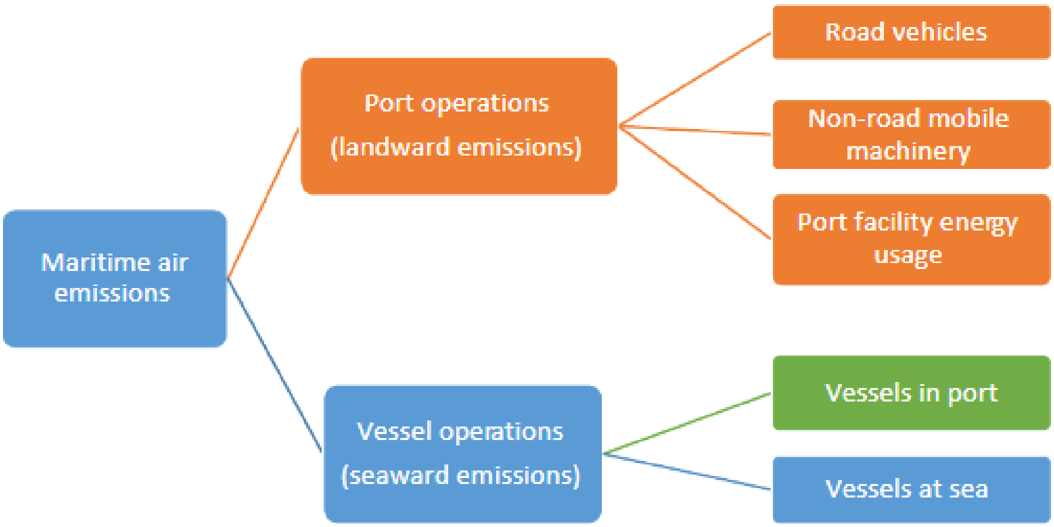
In the next paragraphs the analysis of each category of environmental impacts, in accordance with the classification of EMSA (2021):

- air emissions (Par. 2.1.1);
- water pollution (Par. 2.1.2) that are classified in three categories by European Maritime Transport Environmental Report (STEAM, 2021), i.e., oil spills and other harmful substances, water discharges and the use of antifouling paints;
- marine litter (Par. 2.1.3);
- underwater radiated noise (Par. 2.1.4);
- non-indigenous species (Par. 2.1.5).

2.1.1 Air emissions

Considering the huge and constantly growing sector of worldwide trade and transportation, the cleanest means of transport per kg of material/good has devastating effects on our health and the environment (Koumentakos, 2019). The many sources of air pollution caused from the maritime industry can be seen in Figure 4. Reducing transportation and trade cannot be considered as a realistic solution; therefore, making the maritime industry more efficient and environmentally friendly is unavoidable (Koumentakos, 2019).

Figure 4. Source of maritime air pollution.



Source: Koumentakos, 2019.

As reported in Table 1 and in Table 2, air emissions can be further differentiated in greenhouse gases, i.e., the so-called GHGs, and air pollutants.

According to WHO (World Health Organization, a specialized agency of the United Nations responsible for international public health) air pollution is the contamination of air due to the presence of substances in the atmosphere that are harmful to the health of humans and other living beings, or cause damage to the climate or to materials. The common air pollutants are particulate matter (PM_{10} and $PM_{2.5}$), ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO) and sulphur dioxide (SO_2).

GHGs are compound gases that trap heat or longwave radiations in the atmosphere; their presence in the atmosphere makes the Earth's surface warmer. The main GHGs, also known as heat-trapping gases, are carbon dioxide, methane (CH_4), nitrous oxide (N_2O), and the fluorinated gases, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) sulphur hexafluoride, and nitrogen trifluoride (IPCC, 2013). Carbon dioxide composes 64.3% of GHGs and it enters the atmosphere through the burning of fossil fuels, solid waste, trees and wood products, and certain chemical reactions. Methane is released in the atmosphere by the production and transport of coal, natural gas and oil, livestock and agricultural practices, and the decay of organic waste in municipal solid waste landfills. Nitrous oxide is emitted also during the combustion of fossil fuels and solid waste. Fluorinated gases are synthetic gases generated from industrial processes and are known as stratospheric ozone-depleting substances or high global warming potential (GWP) gases, since they can be 1,000 times more powerful than carbon dioxide and can remain in the atmosphere for 1,000 years.

The increase in the atmosphere of GHGs, in particular of carbon dioxide, caused exclusively by human activities and behaviours, has led to a rise in temperatures that is increasing year by year, endangering the health of the planet. This topic is an extremely relevant and current issue for the shipping industry because this segment contributes significantly to the emission of greenhouse gases in the atmosphere. IMO has calculated that the emissions of greenhouse gases deriving from shipping operations, including CO_2, CH_4 and N_2O (expressed as CO_2 equivalent or CO_{2eq}, have been 1,076 million tons in 2018 with an increase of 9.6%, compared t^{o} 2012 (4th IMO GHG study, 2020). In absence of dedicated provisions and with the shipping sector that is expected to strongly increase its traffic volumes in the next few years, the IMO estimates that the emissions will be able to increase between 50 and 250% within 2050, representing 15% of global GHG emissions (3rd IMO GHG study, 2014).

At EU level, maritime transport is a substantial CO_2 emitter, representing 3 to 4% of the EU's total CO_2 emissions, or over 144 million tons of CO_2 emitted in 2019 (2020 Annual Report on CO_2 Emissions from Maritime Transport, European Commission).

In Table 3 and in

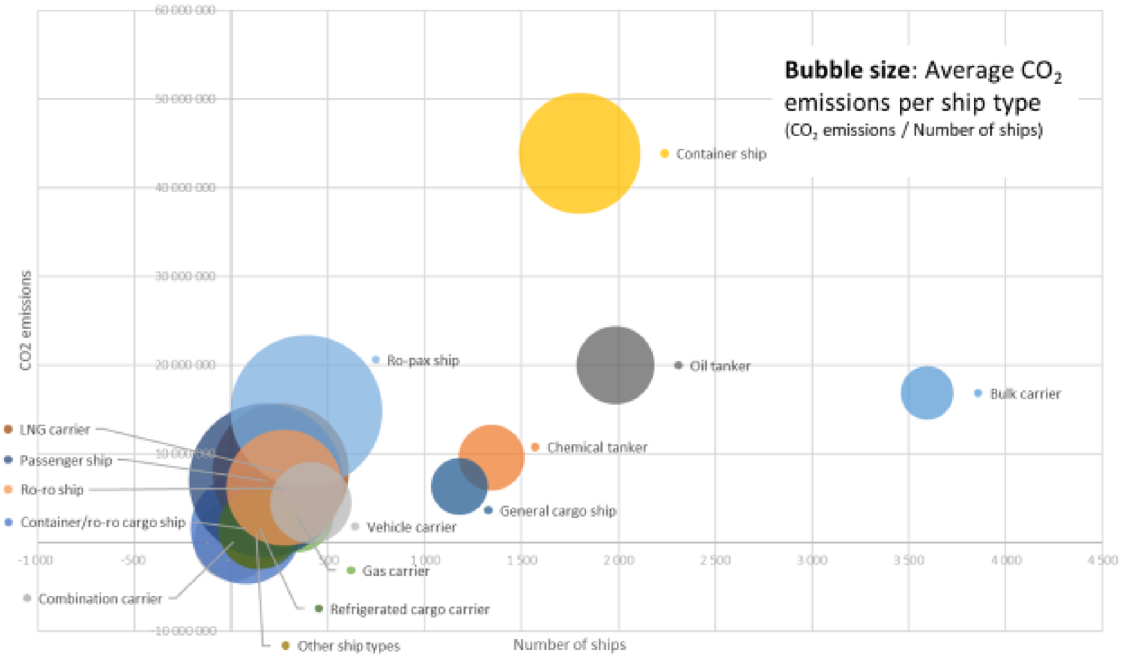
Figure *5* the total amount of CO_2 emissions in 2019 are reported, considering different shipping segments: together Ro-Ro and Ro-Pax ships together are responsible for the emissions of 21 million tons of CO_2 in both 2018 and 2019 (around 16% of emissions).

Table 3. Total CO_2 emissions in 2019.

	Number of Ships	Total CO_2 Emissions	Emissions per ship
Bulk carrier	3 594	16 870 584	4 694
Chemical tanker	1 345	9 617 620	7 151
Combination carrier	11	113 047	10 277
Container ship	1 801	43 866 890	24 357
Container/ro-ro cargo ship	76	1 535 326	20 202
Gas carrier	341	3 037 244	8 907
General cargo ship	1 180	6 334 615	5 368
LNG carrier	256	7 978 707	31 167
Oil tanker	1 985	19 995 167	10 073
Other ship types	129	1 100 145	8 528
Passenger ship	179	6 999 324	39 102
Refrigerated cargo carrier	145	1 613 701	11 129
Ro-pax ship	389	14 816 053	38 088
Ro-ro ship	275	6 186 496	22 496
Vehicle carrier	411	4 504 030	10 959

Source: European Commission, 2020.

Figure 5. Total CO_2 emissions in 2019.



Source: European Commission, 2020.

More in detail, CO_2 emissions from international maritime transport in the EU decreased by 17% between 2005 and 2015. They are, however, projected to go up by 18% by 2030 compared to 2015 and by 39% by 2050. In comparison to 2005, this is equivalent to a stabilization of emissions by 2030 and a 16% increase by 2050, which is not in line with the economy-wide climate neutrality objectives. The CO_2 emissions from inland and domestic navigation in the EU have decreased over time (to about 26% below 1990 levels) and amount to about 16 million tons of CO_2. This decrease is related also to the renewal of the fleet that took place over the last years (European Maritime Transport Environmental Report, 2021).

As a result of onboard combustion of fuel and energy transformation processes, each ship releases numerous pollutants into the atmosphere. Among them, sulphur oxides, nitrogen oxides, particulate matter, carbon monoxide, and many other depending on the nature of ship operations (European Maritime Transport Environmental Report, 2021).

Over time, numerous studies have estimated that the shipping sector emits between 14% and 15% of nitrogen oxides from fossil fuel combustion (Corbett and Koehler, 2003; Endresen et al., 2003; Eyring et al., 2005; Johansson et al., 2017). The IMO in its most recent greenhouse gas study calculated that nitrogen oxide emissions from the shipping industry amounted to 19.65 million tons in 2017 (4th IMO GHG study, 2020).

With reference to particulate matter, specifically $PM_{2.5}$, the IMO has calculated that the shipping sector emitted 1.43 million tons of $PM_{2.5}$ in 2017; with the global estimate of particulate emissions amounting to around 70 million tons, the shipping sector is responsible for around 2 % of global particulate emissions (Gössling et al., 2021).

At the European level, sulphur oxide emissions from ships that called ports located in the European Economic Area in 2019 amounted to around 1.63 million tons, about 16% of global sulphur oxide emissions from international shipping (STEAM, 2021). Among sulphur oxides, a central role is played by sulphur dioxide, or SO_2, which results from the use of marine fuels in the main engine and auxiliary engines. Sulphur dioxide is a harmful gas that affects the respiratory system and the functioning of the lungs, and causes eye irritation (WHO, 2018); in addition, it contributes to the acidification of the soil and the aquatic ecosystem of rivers, lakes and seas. Because of its harmful effects on humans and the ecosystem, the sulphur content of fuels in Europe has been regulated since 1999 and has since been subject to further restrictions. In addition, in 2010 a limit of 0.1% was set for ships in port at European docks. In 2015, the so-called Sulphur emission control areas (SECAs) were introduced in the North Sea and the Baltic Sea, areas within which the maximum sulphur content of the fuels used by ships must be less than 0.1%. This has led to a significant reduction in sulphur dioxide emissions in Europe between 2014 and 2019 (STEAM, 2021).

In 2020, a further step was taken to globally reduce sulphur emissions from ships with the entry into force of IMO2020 by the MARPOL Convention, the main international convention on the regulation of pollution by the shipping sector, which sets a sulphur content of 0.5% as the maximum limit for ships operating outside the SECAs. As of 2019, the percentage of ships powered by high-sulphur fuels has progressively decreased, from 23.8% in September 2019 to 1.1% in February 2020. Consequently, the proportion of ships powered by low-sulphur fuels has increased (from 0.1% to 0.5%) and in February 2020 reached the 98.9% (European Maritime Transport Environmental Report, 2021).

Nitrogen oxide emissions from ships that called ports in the European Economic Area in 2019 amounted to 4.46 million tons, or 22% of global nitrogen oxide emissions from international shipping. Like sulphur oxides, nitrogen oxides are also gases harmful to human health and, in addition, contribute to the formation of acid rain and the eutrophication process, which can cause serious damage to terrestrial and marine ecosystems. Emissions of nitrogen oxides are regulated internationally in Annex VI of the MARPOL Convention. These regulations have the limit of applicability only on ships built after 1st January 2021 and operating in the Nitrogen Emission Control Areas (NECAs) in the North Sea and the Baltic Sea.

Finally, the emissions of particulate matters by ships that touched the ports of the European Economic Area in 2019 amounted to about 0.27 million tons, or 18% of the global particulate emissions of international shipping. There is a direct relationship between the emission of sulphur and nitrogen oxides and the particulate matter generated by ships; only a part of SO_2 emitted by the engine converts into SO_3, which almost immediately forms particulate matter. For this reason, regulations on the sulphur content of ships' fuel and on emissions of nitrogen oxides also impact on particulate emissions: in particular, the use of low-sulphur fuel should also reduce particulate emissions.

2.1.2 Water pollution

The direct impact of the shipping sector in water contamination is difficult to estimate, due to the presence of other activities that contribute to the release of polluting factors. Despite this, the reduction of contamination of the seas surrounding the territories of the European Union continues to be a very important large-scale challenge (EEA, 2019), and further commitments are necessary to reduce water pollution, also by the shipping sector.

Three categories of water pollutants are identified by European Maritime Transport Environmental Report (STEAM, 2021): oil spills and other harmful substances, water discharges and the use of antifouling paints.

2.1.2.1 Oil spills and other harmful substances

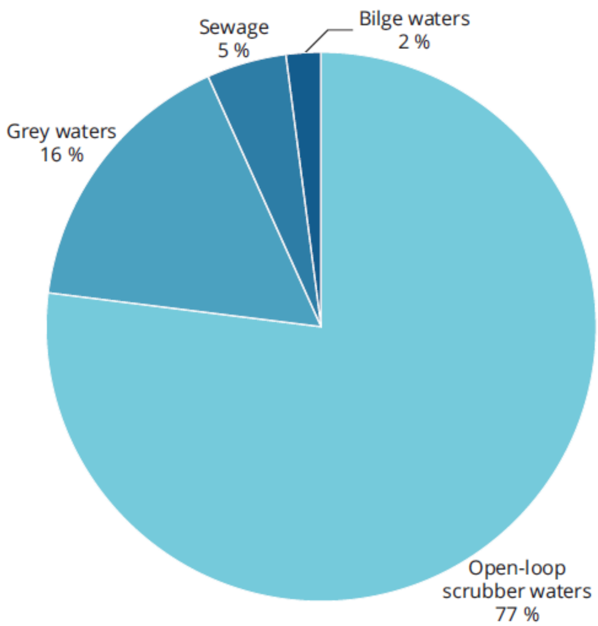
Oil spills are one of the most concerning sources of marine pollution, as they are difficult to clean up and can last for long periods of time in the marine environment. They can severely pollute marine and coastal habitats, causing damage to the natural environment and the economy. Oil spills can originate from deliberate operational discharges, from negligence, such as poor maintenance of equipment, or from the consequences of an accident or incident, such as a vessel collision or grounding, or a pipeline rupture (STEAM, 2021). The MARPOL Convention on the prevention of pollution from ships requires ships to develop and maintain a ship oil pollution emergency plan (SOPEP) and to immediately notify the nearest coastal state of any pollution incident. The growing innovative technologies and the increasingly stringent IMO regulation has meant that, despite the increasing of the amount of oil transported by sea in the last 30 years that increase the risk of spillage, the amount of oil spilled into the sea has steadily decreased (HELCOM, 2018).

2.1.2.2 Water discharges

Water pollution from ship operations is generated by various subsystems on board of ships, which produce discharges that may contain several pollutants (e.g., discharge of black and grey waters, bilge water and tank cleaning water or discharges from the operation of Exhaust Gas Cleaning Systems (EGCSs, as knowns also as “scrubber”). An analysis of data on ship movements in European waters reveals that, excluding ballast water, in terms of volume the largest water discharges from ships come from open-loop EGCSs (77 %), followed by grey waters (16 %) and to a lesser extent by sewage, bilge waters and other discharges (

Figure 6).

Figure 6. Share of estimated water discharges from ships in 2019.



Source: STEAM, 2021.

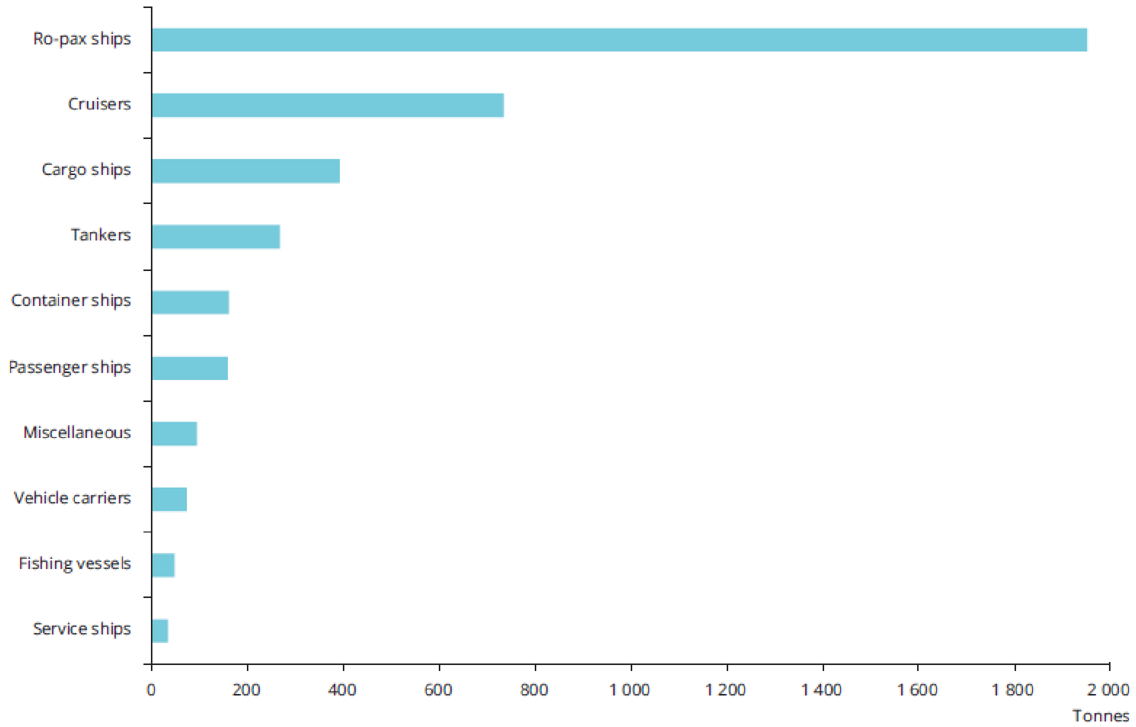
The discharge of waters from open-loop EGCSs installed on ships increased significantly after 2015, as a result of the new standards on the use of low-sulphur fuels (0.10%) in SECAs and also from 1 January 2020, with the introduction of further reductions in the sulphur limits in fuels used in non-SECAs (0.50%). With open-loop scrubbers, the wash water used for the cleaning of the exhaust gases from the ship's engines is discharged into the sea. This discharge water can contain heavy metals and aromatic hydrocarbons and could therefore be potentially harmful to marine organisms. This can be especially concerning in high traffic density areas, as well as in ports and in areas already exposed to high concentrations of hazardous substances.

Nitrogen discharges, which mainly derive from sewage, can also have a significant impact in eutrophic environments (e.g., the Baltic Sea). Ro-Pax sector is responsible for the greatest discharges of nitrogen from sewage (

Figure 7) and this trend has been increasing in recent years and in particular during the summer period (

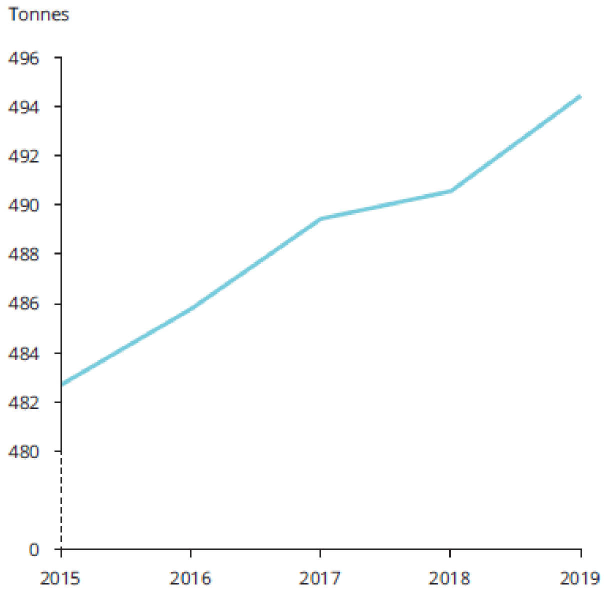
Figure *8*), which is consistent with the high season in maritime transport of passengers (STEAM, 2021).

Figure 7. Estimated nitrogen discharges in sewage by ship type in 2019.



Source: STEAM, 2021.

Figure 8. Estimated nitrogen discharges in sewage from Ro-Pax ships in summer period 2015-2019.



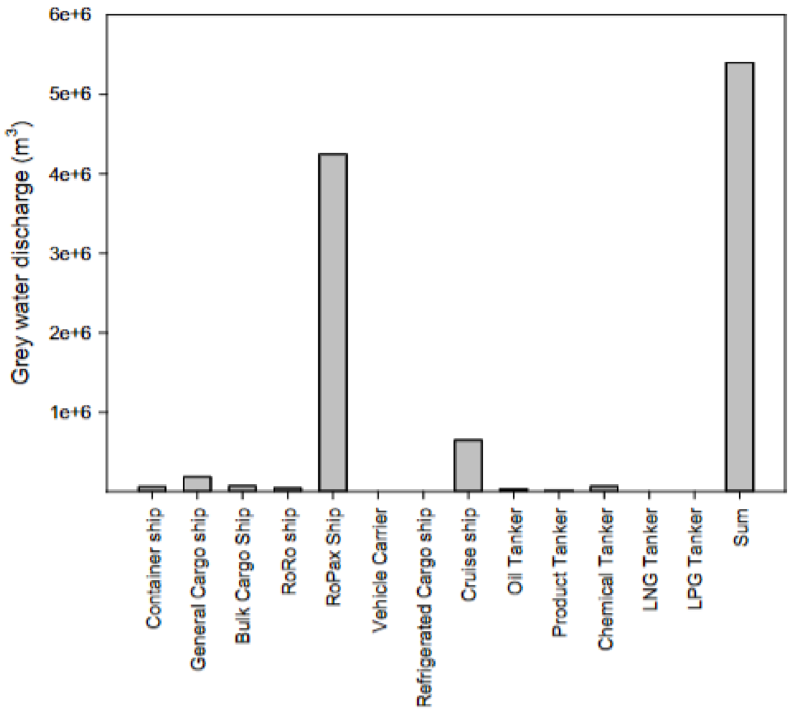
Source: STEAM, 2021.

Furthermore, greywater (or grey water) refers to domestic wastewater generated from streams without faecal contamination, i.e., all streams except for the wastewater from toilets. So, sources of greywater include sinks, showers, baths, washing machines or dishwashers. The discharge of grey water is not regulated by the IMO although representing a significant threat to the marine environment as they contain bacteria, chemical contaminants and nutrients that lead to eutrophication.

A recent study about the discharge of grey water in Baltic Sea context, highlights how most of the grey water is discharged by Ro-Pax ships (4,250,000 m^3), followed by the cruise sector (650,000 m^3), representing the 90% of the total generation of greywater (Ytreberg et al., 2020) (

Figure 9). This demonstrates the extreme relevance of this issue in the Ferry, Ro-Ro and Ro-Pax sector, under analysis in this this PhD thesis.

Figure 9. Volume of grey water discharge in Baltic Sea in a year.



Source: Ytreberg et al., 2020.

2.1.2.3. Use of antifouling paints

Leaching from the antifouling paints used to prevent biofouling on ships' hulls represents another source of water pollution. The antifouling paints may contain biocides that are harmful to the marine environment. The pollutant effect of antifouling paints during the operation of a ship depends on the leaching rate of the biocide from the ship's hull to water and the area of the hull in contact with the water (STEAM, 2021).

Antifouling paints are considered a source of pollution for the marine ecosystem as they are mainly made up of copper and cibutrin, two substances potentially toxic to the marine environment: copper if present in high quantities can be harmful to marine algae (Voulvoulis et al., 1999), while cibutrin is potentially toxic to organisms such as corals and other organisms on which many marine species feed. Alternative technologies include hard coatings, ultrasonic systems, self-cleaning and repellent surfaces, and surfaces with spines that prevent organisms from attaching themselves to the ship (STEAM, 2021). However, more independent information on the costs and effectiveness of the alternatives is needed (ECHA, 2019).

2.1.3 Marine litter

Marine litter refers to persistent, manufactured or processed solid materials that are discarded or abandoned in marine and coastal environments. While the majority of marine litter originates from land-based sources, important contributions come from fishing and aquaculture activities, shipping (commercial and recreational), dredging operations, offshore mining and extraction, ships' sewage sludge and illegal dumping at sea of waste streams containing, for example, plastics and microplastics (Wang et al., 2016).

Referring to marine litter generated by the shipping sector, there are different types of waste that can be generated on board the ship, such as cargo residues, operational waste, waste generated by crew and onboard passenger, oily residues.

However, for most of the waste generated onboard, there are methods that allow waste to be disposed of on board the ship and contribute to its treatment in a sustainable way. The empirical evidence gathered through studies shows that ships use different treatment methods and often only treat part of a waste stream (CE Delft, 2017). Waste that cannot be reused on board or legally discharged at sea under international MARPOL standards must be delivered to port reception facilities (PRFs), available in ports.

Although initiatives have been taken to monitor marine litter, there are gaps in the literature regarding the amount of waste present at sea and its origin. More in-depth knowledge is needed to be able to understand, and then try to mitigate, the impact of the shipping industry on the generation of marine litter.

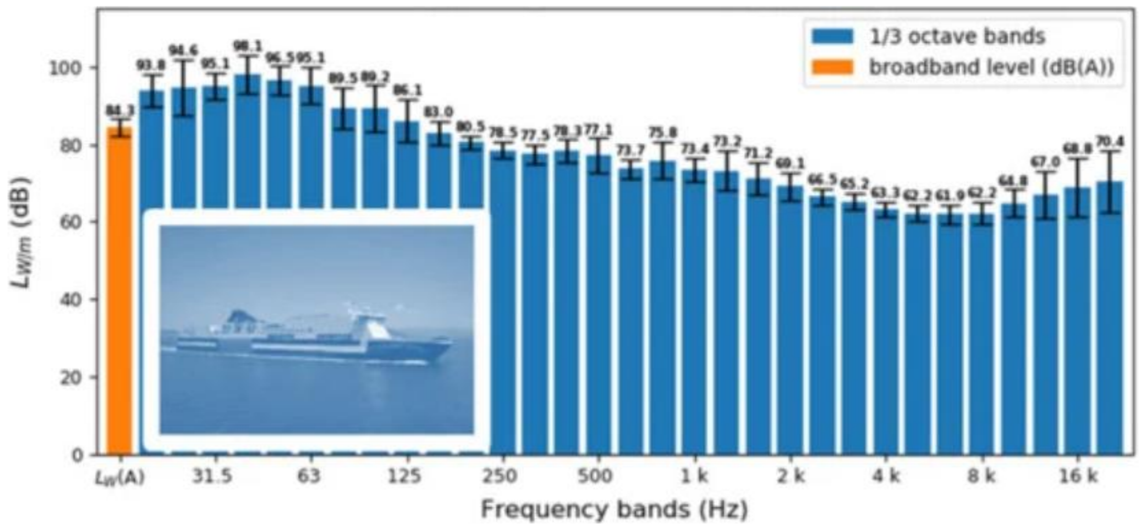
2.1.4 Underwater radiated noise

Underwater noise from shipping is increasingly recognized as a significant and pervasive pollutant, affecting marine ecosystems on a global scale. Measurements in the last 50 years have shown that noise in the oceans is rapidly increasing (Southall et al., 2017). There is also documented scientific evidence linking noise exposure to a range of harmful effects on marine mammals, sea turtles, fish and invertebrates (Williams et al., 2015).

The main underwater noise emitted by ships comes from the propeller when operating under cavitation. Several research projects and studies have been launched to further understand the propeller's cavitation mechanism and noise generated and to find technical solutions to mitigate its negative consequences (AQUO project, 2012-2015; SONIC project, 2012-2015; LIFE-PIAQUO project, 2019-2022; Vard Marine Inc., 2019).

Recently a study was carried out in the industrial canal of the port of Livorno, where noise pollution levels were continuously measured from 24th May 2018 to 5th September 2018 for five types of ships (Fredianelli et al., 2020), including Ro-Ro and Ferry ships. According to the study, for all the ships, the highest noise corresponds with the ventilation close to the chimney and other eventual smaller spikes are given by other ventilation systems present on the hull. Furthermore, due to use tugboats for ships entering and exiting the port (generally, Ro-Ro and container ships have two while oil tankers and chemical tankers have one), the tugs noise is included in the measured sound level of each ship category, and therefore also in the characterization of their category, because the two transits are connected and inseparable. Furthermore, this study carried out a specific analysis for the Ferry sector, calculating the average noise level emitted and the third-octave bands (Figure 10).

Figure 10. Sound power spectrum in Ferry segment.



Source: Fredianelli et al., 2020.

At an international level, the IMO has been working on the adverse effects caused by underwater noise generated by merchant vessels on the marine environment since 2008.

Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life were published in 2014. To this extent the IMO Member States, supported by the EU Member States and the Commission, are now pursuing more stringent mitigation measures, and are proposing a new guideline specifically aimed at reducing continuous underwater noise originating from ships (IMO, 2014).

2.1.5 Non-indigenous species

The Convention on Biological Diversity defines non-native organisms, also known as non-indigenous species (NIS), as those species introduced into a habitat that is not their natural habitat. These species, once introduced into the new habitat, can become "invasive" and have quite marked impacts on the ecosystem in which they have been introduced.

Maritime transport accounts for up to 49% of NIS introductions in the seas around the EU since records began in 1949. Organisms are transported mainly through ballast water (up to 25.5%) and hull fouling (up to 21.2%) (EEA, 2019).

The Mediterranean Sea is the European sea basin with the highest number of NIS introduced by maritime transport, while the Celtic Sea (Atlantic subregion) and the Baltic Sea are those with the lowest introductions. Although the number of introduced NIS has increased overall at the European level over the past century, it seems that the rate of new introductions has slowed down since 2005, also thanks to the increased awareness of the problem, effective policies and new legislation.

2.2 Drivers for greening shipping

Main drivers at the basis of the competitive advantage in shipping industry have suffered dramatic changes in the last decades, and the competitive positioning of companies operating in the sector increasingly depends on different factors and variables from those of the past (Albrecht, 2013; Pace, 2016). According to part of the literature, in recent years there has been an increasing attention towards elements such as environmental sustainability, the reduction of emissions (CO_2, SOx, NOx) and all those concerning the natural environment and its preservation.

With a specific focus on shipping industry, as recognized in academic and scientific literature (Breiltling, 2010), companies have had to adapt their strategies and investment projects also to the changed regulatory framework on environment and to the expressed requests by stakeholders because of the problems related to negative externalities attributable to their activities.

Indeed, issues related to climate change and air pollution, for example, have gained a lot of space in the research agenda of both academics and practitioners, especially due to the intrinsic characteristics and specificities of the business, characterized by high energy-intensiveness and a strong environmental impact. Also, the management of various companies operating in the Ferry, Ro-Ro and Ro-Pax sector has understood the importance of issues related to the reduction of environmental impacts and the pursuit of greater energy efficiency and environmental sustainability. This to the point of defining a series of strategic objectives relevant to its success and competitive positioning:

- the improvement of the company reputation and image towards customers, who have become increasingly sensitive to "green" issues (Green or Environmental or Ecological marketing[23]);
- the need to comply with increasingly stringent regulations on environmental sustainability ("Low Sulphur Cap", "Fit for 55", etc.);
- the continuous research of new and green technological options and solutions to be adopted in order to mitigate the impact of the operations on the environment;
- the new market opportunities related to B2B and B2C customers that are more focused on the environment and sustainability thematic (Wang, et al., 2016);
- the pursuit "green" and sustainable corporate objectives through the implementation of green strategies.

[23] The concept of green, environmental or ecological marketing, referring to the practice of developing and advertising products based on their real or perceived environmental sustainability., appears in the 70s, during the first theoretical discussion on this phenomenon (Omkareshwar, 2013), while, in Europe, it develops only from the 80s (European Commission, 2013) thanks to the environmental movement by citizens and institutions. In 1994, the scholar Polonsky states that the first definition of green marketing was devised by the American Marketing Association (AMA) in 1975; almost at the same time Henon and Kinnear (1976), by means of in-depth research on the issue, have provided the definition of ecological marketing. Later, Mintu and Lozada (1993), Coddington (1993) and Fuller (1999) also analysed the concepts of green marketing, ecological marketing and sustainable marketing, respectively. In the following years, there have also been numerous revisions of these theoretical concepts, for example the authors Dujak and Ham (2008) reworked the first definition of green marketing (Stanton and Futrell 1987).

2.2.1 The United Nations Framework Convention on Climate Change (UNFCCC)

Since several years ago, numerous studies confirm that also in the shipping industry, an enterprise that acts in socially responsible way obtains positive results with reference to the value of the actions and the revenues in the long period (Knoepfel 2001). In this context, we are therefore witnessing the development of new socio-economic, business and government models, which require companies in the sector to recalibrate their role and responsibility towards civil society and future generations. They face a new challenge of dual scope: on the internal front they are called to adopt policies of Corporate Social Responsibility (CSR), while on the external front to implement projects and development plans that are configured as Social Responsible Investments (SRI).

In addition, it is important to highlight how companies that promote sustainability and care about their environmental, social and economic impact, achieve more reliable and safe results for their stakeholders. So, investors tend to concentrate their investments on companies with a high level of sustainability, and this is particularly relevant for those economic sectors that need substantial forms of financing, including the shipping industry.

Because of shipping’s role in guaranteeing the total sustainability, numerous regulations have been introduced, and many of them are today under negotiation, both at international and Community level to control and reduce emissions in the sector. In particular, in the international context, reference is made to three regulations: the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Paris Agreement.

The United Nations Framework Convention on Climate Change (UNFCCC) established an international environmental treaty to combat “dangerous human interference with the climate system”, also by stabilizing GHG concentrations in the atmosphere. It was signed by 154 states at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro in 1992. There are no mandatory limits for GHG emissions to nations, but periodic updates, i.e., “protocols”, are planned to achieve emission reduction targets (ISPRA, 2022). By 2022 the UNFCCC had 198 signatory nations as parties and every year a meeting is held, called the Conference of Parties (COP), during which progress in dealing with climate change is assessed and the necessary decisions are taken to achieve the objectives of the Convention.

One of the achievements of the UNFCCC has been to establish a reporting framework which provides information on GHG emissions and removals using common categorisation and definitions: this framework encourages reporting of data from most of the countries that are party to the Convention. On the contrary, the UNFCCC process has not been effective (enough) in catalysing mitigation action compatible with a below 2°C trajectory because its historical focus on emission targets has been too narrow.

2.2.2 The Kyoto Protocol and the Paris Agreement

The Kyoto Protocol, which was signed in 1997 and ran from 2005 to 2020, was the first implementation of measures under the UNFCCC. The Kyoto Protocol sets out quantified and binding GHG emission reduction targets for the acceding countries, which together add to an average emission reduction of at least 5% compared to 1990 levels in the five-year period 2008-2012. With the definition of the overall objective, this was then divided among the various states adhering to the protocol into national objectives and each state has been assigned a Quantified Commitment of Limitation and Reduction of Emissions, Quantified Emission Limitation and Reduction Commitment (QELRC), defined as a percentage of the country’s emissions level in 1990. The GHG covered by the reduction targets are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Each of these gases has its own Global Warming Potential (GWP), which essentially corresponds to its “greenhouse capacity” in relation to that one of CO_2 which is conventionally set equal to 1 over a time interval that is conventionally set at 100 years. Therefore, when talking about the emission reduction targets, reference is made to values expressed in terms of CO_{2eq}.

The Kyoto Protocol makes it possible to reduce GHG emissions through market-based mechanisms, the so-called “Flexible Mechanisms”. These mechanisms allow Protocol countries to meet their emission reduction commitments by initiating mitigation processes outside their national borders. Specifically, these mechanisms are the Emission Trading System (ETS), the Clean Development Mechanism (CDM) and the Joint Implementation (JI).

- The Emission Trading System allows the exchange of emission credits on specific markets between industrialized countries and economies in transition. This allows countries that have achieved a reduction in their emissions above their target to sell these credits to countries that have not met their targets.
- The Clean Development Mechanism (CDM) allows industrialized countries to launch projects in developing countries in order to produce environmental benefits in terms of GHG reduction and socio-economic development of host countries, and, at the

same time, to generate emission credits (Certified Emission Reductions-CER) for countries that promote projects in order to comply with their QELRCs.

- The Joint Implementation allows industrialized countries to carry out projects to reduce GHG emissions in another industrialized country and to use derived credits (Emission Reduction Units) to comply with their QELRCs.

The Kyoto Protocol was superseded by the Paris Agreement, which was adopted by 196 Parties at COP 21 in Paris and entered into force in 2016. Its goals are i) to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels; ii) to achieve this long-term temperature goal, countries aim to reach global peaking of GHG emissions as soon as possible to achieve a climate neutral world by mid-century; iii) to achieve rapid solutions based on the best available scientific knowledge in order to balance emissions and removals in the second half of the century. In this context, the Parties meet every 5 years to assess collective progress towards the long-term goals and inform the Parties to improve their national contributions, and to report on progress towards the commitments singed under the Agreement through a robust system based on transparency and accountability.

By 2020, countries submitted their plans for climate action known as nationally determined contributions (NDCs). These contributions are negotiated between the Parties as is the Kyoto Protocol but are established unilaterally by each state and subsequently communicated to the UNFCCC. By 2020 the EU, acting jointly with its member states, presented its updated and strengthened NDCs, and set the target of reducing its GHG emissions by at least 55% by 2030 compared to 1990 levels.

Simultaneously with the Paris Agreements, in the same year, the United Nations General Assembly on the adoption of the 2030 Agenda for Sustainable Development announced the 17 Sustainable Development Goals, called Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They represent the objectives to be pursued with reference to a wide range of issues that characterize modern society, and whose aim is to promote the sustainability of social, economic and environmental activities (UN, 2015). In such context, supporting the international commerce and favouring the global economy, the shipping industry is associated to each of the SDGs (Wang et al., 2020), specifically to the SDG 14 that is aimed to conserve and sustainably use the oceans, seas and marine resources for sustainable development (IMO, 2021).

Because of the specific peculiarities of the shipping industry that make difficult the application of the general international regulations of which it has just been treated, its regulation is entrusted to a specialized international agency, the IMO.

In this context, the International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. Adopted on 2 November 1973, the Convention includes regulations aimed at preventing and minimizing pollution from ships – both accidental pollution and that from routine operations – and currently includes six technical Annexes, representing 155 nations with around 99% of global shipping capacity. The Annexes are at the heart of the measures laid down by the Convention, and in particular:

- Annex I (1983) covers practices and tools for the prevention of pollution by oil from operational measures as well as from accidental discharges; it made it mandatory for new oil tankers to have double hulls and brought in a phase-in schedule for existing tankers to fit double hulls.
- Annex II (1983) details the criteria and measures for the discharging of dangerous liquid substances carried in bulk; a list of 250 dangerous substances is contained and the procedures necessary for their handling are defined, forcing the landfill of cargo residues in appropriate port reception facilities, and prohibiting in any case the dumping at sea within 12 miles from the coast.
- Annex III (1992) contains general requirements for the issuing of detailed standards on packing, marking, labelling, documentation, stowage, quantity limitations, exceptions and notifications; "harmful substances" are those substances which are identified as marine pollutants in the International Maritime Dangerous Goods Code (IMDG Code), or which meet the criteria in the Appendix of Annex III.
- Annex IV (2003) contains requirements to control pollution of the sea by sewage; the discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging shredded and disinfected sewage using an approved system at more than three nautical miles from the nearest land.
- Annex V (1988) deals with different types of garbage and specifies the distances from land and the way they may be disposed of (the most important feature of the Annex is the complete ban imposed on the disposal into the sea of all forms of plastics).
- Annex VI (2005) sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts, prohibits deliberate emissions of ozone depleting substances and designates Emission Control Areas (ECAs) with more stringent standards for SOx, NOx and particulate matter; a chapter adopted in 2011 covers mandatory technical and operational energy efficiency measures aimed at reducing greenhouse gas emissions

from ships (such as the Energy Efficiency Design Index and the Energy Efficiency Operating Index).

Among its Pros, the Kyoto Protocol is a global collaborative effort aimed at reducing the effects of climate change, putting into place a range of market mechanisms that would help rich countries offset emissions (also investing in low carbon projects in poor areas around the world). On the contrary, according to the Kyoto Protocol, only requires wealthy nations to cut emissions and while participating countries reported that they have indeed lessened their release of harmful gases into the atmosphere, data is not so encouraging.

Because of the peculiarities that distinguish the maritime transport sector and the consequent difficulty of its regulation, in 2011, through an amendment to Annex VI (limiting sulphur and nitrogen emissions and establishing appropriate ECAs), the IMO introduced some mandatory requirements relating to the energy efficiency performance of ships, called Energy Efficiency Design Index (EEDI), Energy Efficiency Operating Index (EEOI) and Ship Energy Efficiency Management Plan (SEEMP).

The EEDI is a technical indicator for the propulsion systems of ships under construction and it establishes a minimum level of energy efficiency for each type and size of ship (tankers, bulk carriers, gas carriers, general cargo, containership, reefer, Ro-Ro, Ro-Pax[24] and LNG carriers). The EEDI is expressed in grams of CO_2 per ton-mile, so the lower the EEDI and the greater the energy efficiency of a specific ship. It is calculated by a formula based on the technical design parameters for a given ship. Based on existing fleet statistics over a certain period, the maximum values for EEDI for each type of ship have been developed, depending on the GT of the ship. These EEDI upper limits are revised and made more stringent every 5 years, until reaching in 2025 a reduction of 30% of the value of the index compared to the value of phase 0 (IMO, 2014). In the Ferry, Ro-Ro and Ro-Pax segment several studies show that the EEDI in its current form is not able to give a real representation of the energetic efficiency of the ship (Ancic et al., 2014; Ancic et al., 2015; Ancic et al., 2018). This because of the frequent use in these types of ships of non-conventional propulsion systems such as the Integrated Power System (IPS) or the Hybrid Power System that do not allow a true analysis of the energy efficiency of the ship based on the EEDI only.

[24] In the 2011 EEDI was reported to the emissions of CO_2 related to ship as tankers, bulk carriers, general cargo, containership, but with an amendment of 2014 by the Marine Environment Protection Committee (MEPC) the application of the EEDI was extended to ships Ro-Ro, Ro-Pax and LNG carriers.

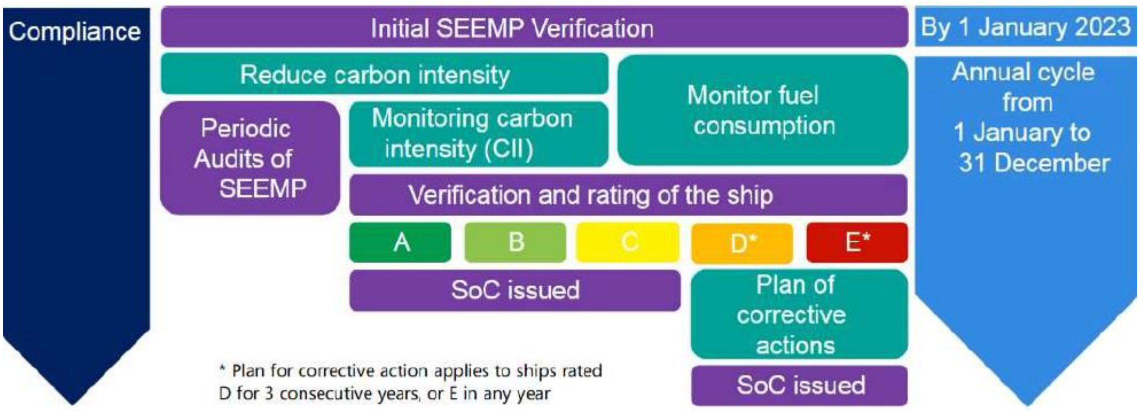
The EEOI is an indicator of an operational nature aimed at measuring and monitoring fuel efficiency (Chou et al., 2021). It can be identified as the average annual carbon intensity of a ship considering the many variables that influence its operation; for example, speed, draft, rate of use of the hold, miles travelled, state of deterioration of the hull, weather and sea conditions. The EEOI enables operators to measure the fuel efficiency of a ship in operation and to gauge the effect of any changes in operation. Although the EEOI is referred to as an energy efficiency indicator, it is technically more accurate to refer to the EEOI as a carbon intensity measure, being calculated in grams of CO_2 released per tons-miles travelled (UCL Energy Institute, 2015). While EEDI is a technical indicator for the propulsion systems of ships under construction, the EEOI is an indicator related to the operational nature of the ships in navigation and is applied not only to the new ships, but also to those ships already operating before the introduction of the index. Therefore, an improvement in the management of the energy, the logistics and the optimization of the trips and in all ship operations, will have a positive impact on the EEOI while it will not be visible in the EEDI.

Due to the growing need to ensure a high level of sustainability by companies around the world, the European Union and the IMO aim to pursue full sustainability within the maritime sector and, to this end, since 2012 they have made SEEMP mandatory (Ship Energy Efficiency Management Plan). It consists of a plan of procedures and operations for energy efficiency to be adopted for the operational management of the fleet. The SEEMP urges the ship owner and operator at each stage of the plan to consider new technologies and practices when seeking to optimize the performance of a ship. It consists of 4 processes: 1) planning to define, based on the specific technical and operational characteristics of the fleet, the procedures, timing and objectives of the company; 2) implementation, i.e., the identification of the internal energy flow of the ships to identify the best operations for energy efficiency; 3) continuous and consistent monitoring of data (the IMO recommends using the EEOI as monitoring tool); 4) evaluation of data to implement an overall assessment of SEEMP to make the shipping company able to streamline operations that were less efficient.

Amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI entered into force on 1st November 2022. As a stimulus to reduce carbon intensity of all ships by 40% by 2030 compared to 2008 baseline, from 1st January 2023 ships will be required to calculate two ratings: their attained Energy Efficiency Existing Ship Index (EEXI) to determine their energy efficiency, and their annual operational Carbon Intensity Indicator (CII) (and associated CII rating) that links the GHG emissions to the amount of cargo carried over distance travelled. Based on a ship's CII, its carbon intensity will be rated "A", "B", "C", "D" or "E", where "A" corresponds to the highest rating level. Ships rated "D" for three consecutive years, or “E” for one year, will have to submit a corrective action plan to show how the required index of “C” or above will be achieved (

Figure *11*). If a vessel gets a rating of “D” for three consecutive years or a rating “E” in any year, it is required to develop and implement corrective actions to achieve rating “C” or better. Administrations, port authorities and other stakeholders and entities as appropriate, are encouraged to provide incentives to ships rated as “A” or “B”. For example, a ship can run on a low-carbon fuel clearly to get a higher rating than one running on fossil fuel, but there are many things a ship can do to improve its rating, for instance through measures, such as hull cleaning (to reduce drag), speed and routeing optimization, installation of low energy light bulbs and/or solar/wind auxiliary power for accommodation services. The rating indicates a major superior, minor superior, moderate, minor inferior, or inferior performance level. The performance level will be recorded in a “Statement of Compliance” to be further elaborated in the ship’s SEEMP. While EEXI generally applies to every ship of 400 gross tonnage and above, CII applies to ships with a tonnage of 5,000 and above. Ships at or above 400 GT will need to be surveyed and issued with the appropriate certificates.

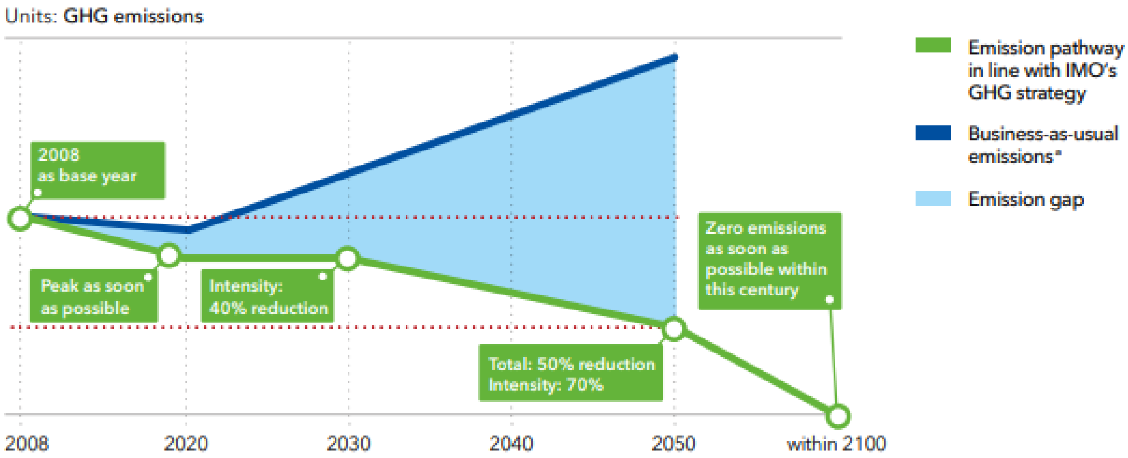
Figure 11. Phases related to the ships carbon intensity rating.



Source: eMarina, 2021.

In response to the objectives set out in the Paris Agreement, such as keeping the average increase in global temperatures below 2 degrees Celsius above pre-industrial levels and to fall below 1.5 degrees Celsius, the IMO defined specific objectives for the shipping industry on proposal of the Marine Environment Protection Committee (MEPC). The answer is in the Initial IMO GHG Strategy adopted in April 2018: with 2008 as a baseline year, this strategy aims to at least halve total GHG emissions from shipping by 2050, and to reduce the average carbon intensity (CO_2 per tonne-mile) by a minimum 40% by 2030, and 70% before mid-century (Figure 12). The IMO's ultimate vision is to phase out GHG emissions as soon as possible within this century.

Figure 12. IMO strategy for major reductions in GHG emissions from shipping,

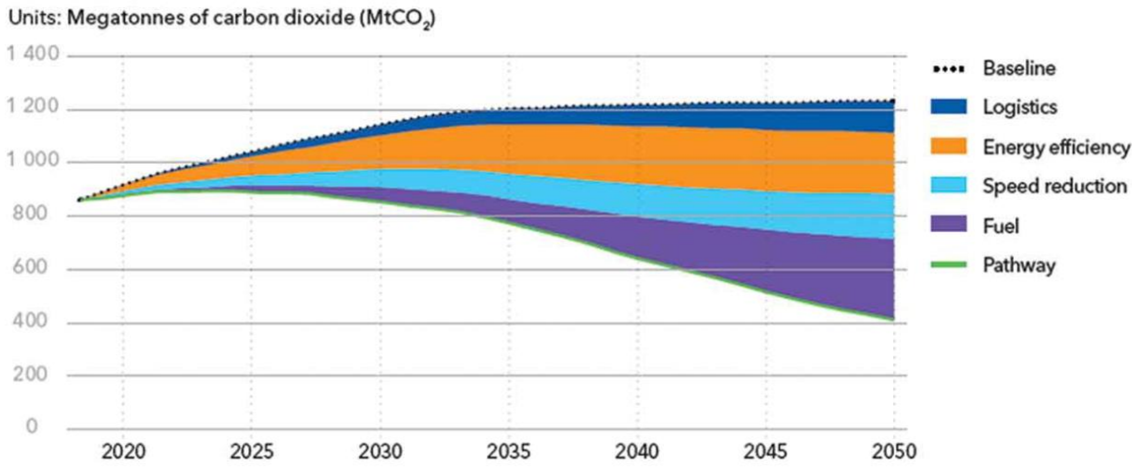


Source: DNV-GL[25]*, 2019.*

Figure 13 shows the scenario hypothesized by DNV-GL, according to which there are three categories of measures to achieve the objectives set by the Initial IMO GHG strategy: in the short and medium term, the energy efficiency of the existing fleet and the reduction of cruise speed; while, in the long term, the use of alternative fuels will be predominant. The impact of energy-efficiency measures and speed reduction can be achieved to full effect early in the period up to 2035, as they can be implemented without renewing the fleet. In these pathways, carbon emissions from international shipping will be around 410 $MtCO_2$ in 2050. A 10% of the emission reduction will be due to logistical improvements in the supply chain; 18% from technical and operational energy-efficiency measures; 14% from speed reduction, considering the additional ships needed to cover the "transport work"; and a further 22% because of carbon-neutral fuels.

Figure 13. Shipping emissions reduction by measure (2018–2050) for the 'design requirements' (DR) pathway.

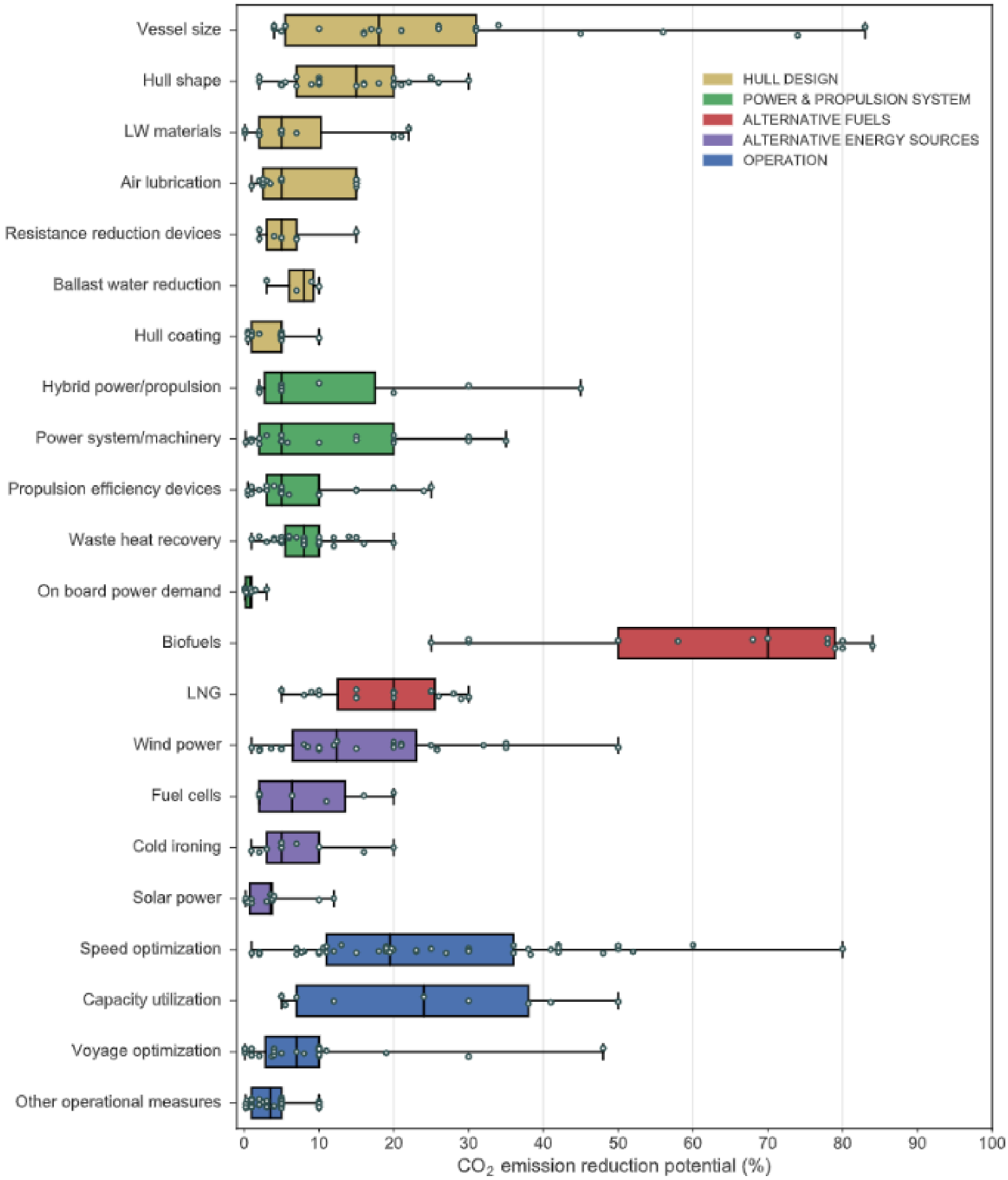
[25] DNV (formerly DNV-GL) is an international accredited registrar and classification society.



Source: DNV-GL, 2019.

An interesting study by Bouman et al. in 2017 shows an analysis by 150 researchers on technologies to pursue the objectives of the Initial IMO GHG Strategy. Through a comparison between the various investment options, they found the differences between the alternative options in terms of potential emission reductions. The various technologies and investment options have been classified into five macro-categories that can contribute to the decarbonization of the sector (Figure 14): hull design, power and propulsion, alternative fuels, alternative energy sources, and operations. None of these options alone is sufficient to achieve the objectives set by the IMO, but a combination of different measures will be needed to achieve decarbonization.

Figure 14. CO_2 emission reduction potential from individual measures, classified in 5 main categories of measures.



Source: Bouman et al., 2017.

Summarizing this paragraph 2.2.3, design indicators like Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI) and Existing Vessel Design Index (EVDI) are difference ways to measure how efficiently a vessel is designed, referring to the theoretical carbon intensity of the vessel. The design indices are calculated based on the design specifications of a vessel, e.g., ME MCR (Maximum Continuous Rating of Main Engine), AE MCR (Maximum

Continuous Rating of Auxiliaries Engine) in the nominator and design capacity, design speed in the denominator: EEDI, EEXI and EVDI rating are fixed when a vessel is designed and built, these values will not change during its lifespan unless the design specifications are modified.

Operational indices like Energy Efficiency Operational Indicator (EEOI) and Annual Efficiency Ratio (AER) are parameters that refer to the actual carbon intensity of a vessel which are the prime concern of the CII, Poseidon Principles and Sea Cargo Charter. These operational indicators measure how well a vessel is operated or managed and may not necessarily determined by its design indices. Both the nominator in the EEOI and AER equations are identical which represents the actual annual carbon emission; while the denominator in the EEOI equation utilizes actual transport work (actual cargo weight carried and distance travelled) and in the AER equation utilizes approximate transport work (deadweight and distance travelled). In the EEOI equation, the determination factor is the actual cargo weight carried. If a vessel is on a ballast voyage (i.e., without cargo/passengers), the denominator in the EEOI equation will always be equals to zero which makes the EEOI value infinite. This result is independent of EEDI, EEXI and EVDI which means that a good design index result does not necessarily guarantee a good EEOI result. In the real world, the carriage of cargo and its weight are not always under the owners' or managers' control: in this vein the AER equation seems to be fairer for the owners or managers. Likewise, a good EEDI, EEXI or EVDI result does not necessarily guarantee a good AER result: for examples, two sister vessels, one always fully loaded, sailing at full speed with more exposure to bad weather and heavy hull fouling, it would most likely get a worse AER than the other one that is always partly loaded with less exposure to bad weather conditions and hull fouling and operates at a slower speed).

2.2.3 The EU Emissions Trading System (ETS)

Considering regulation drivers that are described above in the previous paragraphs, the European Union has always been at the forefront in the fight against climate change, ensuring the sustainability of economic activities taking place within the Union. EU joints to all the international conventions, such as the UNFCCC, the Kyoto Protocol and the Paris Agreements. In the European context, it is possible to mention the European Green Deal, the implementation by the European Commission of the 2030 Agenda of the United Nations, and three regulations part of the package of proposals known as "Fit for 55" that will go to impact the field of the shipping.

The European Green Deal, approved 2020, is a set of policy initiatives by the European Commission with the overarching aim of making the EU climate neutral in 2050. Since this project is ambitious and difficult to implement, all possible policy levers, including regulation and standardisation, investment and innovation, will be used jointly to national reforms, dialogue with the social partners and international cooperation. This articulated structure is managed both by the European Commission, the EU's executive body led by Frans Timmermans, and by the European Parliament and the European Council, with legislative power. In order to achieve climate neutrality by 2050, the EC has set intermediate targets to get by 2030, including a reduction of at least 50-55% of GHG emissions compared to 1990 levels, an annual share of at least 32% of energy generated from renewable sources and an energy efficiency of at least 32.5%.

Among all sectors affected by the Green Deal, the transport segment is of considerable importance, as it alone accounts for about a quarter of GHG emissions with a growth trend. To achieve climate neutrality by 2050, the European Commission has therefore set a sectoral target for transport segment that must reduce emissions by 90% by 2050. In this way, the Green Deal provides for the possibility of extending the system for emissions trading (Emission Tradin– System - ETS) also to the shipping sector.

Objectives set by the European Green Deal are transformed into law through the European Climate Law, according to which all EU countries and economic sectors must contribute to achieving zero CO_2 emissions. The entry into force of the European Climate Act on 29th July 2021 has prompt Member States to take all necessary measures to pursue the Commission's objectives (that became legally binding). This legislative measure also provides for the monitoring of progress during five years and, if necessary, the development of appropriate corrective action programs.

Directive 2003/87/EC of the European Parliament and of the European Council was adopted by Parliament and the European Council by anticipating by three years the date set by the UNFCCC for the commencement of international trade in emissions before the entry into force of the Kyoto Protocol. Adopted with this Directive by the European Commission, the EU Emission Trading System (EU - ETS) is an emission trading scheme whose operation is based on a cap-and-trade mechanism[26], i.e., a system in which an upper limit of emissions allowed on the European territory in the sectors concerned is fixed (cap), which corresponds to an equivalent number of "quotas" (1 ton of CO_{2eq} = 1 quote) that can be bought and sold on a special market (trade). In this way, each operator must "offset" on an annual basis its actual emissions (verified

[26] The term "cap" represents an overall maximum limit on the emissions allowed on the European territory, which is reduced over time, to reduce overall pollution.

by an independent third party) with a corresponding number of quotes. In 2021, the EC adopted a series of proposals to transform EU climate, energy and transport policies in order to reduce GHG emissions by 55% by 2030 compared to 1990 levels and make the continent climate-neutral by 2050. Through the cap-and-trade mechanism, the competent authority defines criteria for the implementation of polluting activities based on a maximum emission limit (cap) which depends on several parameters, such as the geographical coverage, the time interval, the types of gas, etc. (scheme's coverage). After the quotas distribution among the subjects covered by the emission trading system, the sale and purchase of shares is allowed: operators choose whether to implement emission mitigation measures or whether to acquire on the market a quantity of allowances equal to the established limits. In this way the carbon price (price of emissions) is shaped by supply and demand forces: on the supply side, the competent authority shall determine the desired level of pollution (that is the cap) while on the demand side the polluting economic subjects carry out their activities within the limits assigned to them. The demand for quotas (allowances) depends on the cap, but also on the level of emissions released into the atmosphere by economic subjects. Once the cap is fixed and the allowances have been traded in the market, companies monitor their performance in line with the limits imposed and as soon as requested, hand over their emission allowances to the competent authority. Finally, the regulatory authority establishes the penalties for those who don't respect the limits imposed and do not proceed with the compensation through the purchase of a sufficient number of allowances.

The ETS sets a fixed cap on the electricity and heat generation industries, the energy-intensive industry sectors (including oil refineries, steel works, and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals) and the commercial aviation sector within the European Economic Area.

The ETS was designed in four phases (Figure 15) which corresponds to different reduction in emissions levels (-22% in 2017, up to -55% in 2030):

- the first phase was a learning phase,
- the second one slowly introduced the auctioning of allowances,
- the goal of third phase, in which the aviation sector is added to the system, was the European harmonization and implementation of an annual linear reduction of the cap,
- the third phases' cap was slightly increased in phase four.

Figure 15. The four phases of the EU ETS.

EU Emissions Trading System Phases Sustaim

	I	II	III	IV
Goals	• Pilot Phase • Learning by doing	• Stabilisation • First commitment period under the Kyoto Protocol	• European harmonization and consolidation	• At least 40% cuts in greenhouse gas emissions (from 1990 levels) • At least 32% share for renewable energySearch for available translations of the preceding link • At least 32.5% improvement in energy efficiency • Search for available translations of the preceding
Allowances	• Almost 100% free	• 10 % auctioning	• 15% auctioning for aviation	• 15% auctioning for aviation
Reduction		• 6,5% compared to Phase 1	• 1,74% annually	• 2,2% annually
Penalty	• 40€/t CO2	• 100€/t CO2	• 100 €/t CO2 increasing with Inflation	
Geographical scope	• EU	• EU • Iceland, Liechtenstein, Norway	• EU • Iceland, Liechtenstein, Norway	• EU • Iceland, Liechtenstein, Norway

Source: Sustaim.earth[27], 2020.

This Directive consists of five main elements aimed at encouraging the decarbonization in Europe:

1) a reduced cap and more ambitious linear reduction factor for GHG emissions in the Eurozone for each year;
2) revised rules for free allocation of European Union Alliance (EUA) certificates and the market stability reserve;
3) an extension of the ETS to maritime transport;
4) a separate new ETS for buildings and road transport;
5) an increase of the Innovation and Modernization Funds and new rules on use of ETS revenues.

Annually, the EU defines the amount of CO_2 that each involved company can emit into the atmosphere: every year a certain quantity of CO_2 tons is attributed and distributed to the various companies in equal number of European Union Alliance certificates.

When companies emit less CO_2 emissions, they generate a portfolio deficit of certificates that can be monetized in the market; on the contrary, in case of increased CO_2 emissions,

[27] Sustaim.earth helps companies to achieve Net-Zero by providing access to highly qualitative and transparent CO_2 offsetting projects via our marketplace.

companies will have to buy “missing” certificates on the market by companies with excess shares, generating economic profit for them.

Each year, the month of April is the deadline for companies to deliver their emissions to the EU. The structure of the Directive deadlines in the industrial and aviation sector allows companies to receive free of charge by February of each year a certain number of allowances / certificates. For example, by February 2023 each company received the certificates allocation for 2023 and by March 2023, each company must report and verify the emissions related to the previous year (2022) to return the corresponding number of allowances by April 2023. Instead, allowances received in February 2023 should be retained by the companies for their use in the 2023.

There are also other methods of supplying allowances, as well as exchanges between companies, i.e., the possibility to access to government auctions, i.e., European mechanisms for those sectors that do not receive free allocation (such as, the shipping sector, the energy production sector, etc.).

Referring to the shipping sector, to date the inclusion in the ETS Directive is expected from 2024, as confirmed by the trialogue (European Commission, Parliament and Council) in December 2022:

- to September 2020 the European Parliament votes in order to include the shipping industry in the EU ETS, from January 2022;
- in July 2021 the EU Commission proposes the inclusion of the marine transport sector beginning from the next year (2023), supplying more details on the modalities for such inclusion;
- in December 2022 a provisionally based agreement is reached during the negotiations of the trialogue, confirming the inclusion of the shipping sector in the ETS, from 2024;
- the next step is to convert the text into law.

In the shipping industry the entity responsible for the EU ETS system is not yet very clear and the EC will provide more information: the shipowner will always be responsible for the management of certificates but if he was not responsible for the operation of the ship, the cost of the allowances would fall on the charterer / ship manager.

The EU ETS will also have an extraterritorial effect, that is, not only European operators will be subject to the obligations. The EU ETS will apply to all ships with “port call” in EU ports, regardless of the flag of the ship and the registered office of the shipowner. In this vein, the reporting obligations include:

- 50% of emissions for routes starting or finishing within the EU;
- 100% of emissions from intra-European routes;
- 100% of emissions in EU ports.

Each shipping company will be under the responsibility of a Member State, in reason of the shipowner registered office or its main routes: shipping companies based outside the EU will consider the country with the highest number of port calls in the last 2 years, otherwise, in case of absence of travel in the last 2 years, the first destination country below the scope EU ETS.

In this vein, to align the EU ETS Directive with the increased GHG emission reduction targets set in the European Climate Law, the Commission proposed to reduce the emissions from the EU ETS sectors (including the extension to the maritime sector) by 61 % by 2030, compared to 2005 levels. To achieve this target, the proposal increases the linear emissions reduction factor from 2.2 % per year to 4.2 %. The proposal would extend the EU ETS to cover CO_2 emissions from maritime transport, specifically from ships with more than 5,000 GT. The requirement to surrender allowances would be gradually phased-in during 2023-2025. Protection against carbon leakage will still be in place through allocation of free allowances. However, the number of the free allowances will gradually be reduced with a decreasing emissions cap and the proposed introduction of a Carbon Border Adjustment Mechanism (CBAM).

The annual calculation and verification of the emissions will follow the logics defined from the Monitoring Reporting Verification (MRV), in vigour for the shipping from 2018 (

Table 4). The shipping industry will add permission / certificates demand to the mechanism ETS for beyond 83 million allowances/year, which corresponded to about 15% of the market size of the industrial sector.

Table 4. MRV emission factors.

Type of Fuel	Emission factors ($t\ CO_2$ / t fuel)
Heavy Fuel Oil	3.114
Light Fuel Oil	3.151
Diesel/Gas Oil	3.206
Liquefied Petroleum Gas (Propane)	3.000
Liquefied Petroleum Gas (Butane)	3.030
Liquefied Natural Gas	2.750
Methanol	1.375
Ethanol	1.913

Source: Verifavia[28], 2018.

For the EU ETS system, the non-delivery of allowances and, therefore, the default to the system entails a penalty for "non-compliance" until any orders to stop or expulsion:

- the non-delivery of the quotas involves a fine of 100 euro/ton and the obligation of delivery does not lapse;
- when a shipping company has not delivered the shares for two or more consecutive periods may be issued an expulsion order against the ship under the responsibility of the shipping company;

[28] Verifavia, part of the Normec Group, is a worldwide independent environmental accredited verification, certification and auditing body for aviation, airports and maritime transport.

- an expulsion order may lead to a detention of the vessel at the Member State responsible and a ban on entering any port under the jurisdiction of another Member State.

This situation leads to a crucial alignment of interests between the shipowner and the ship manager: as the penalties follow the ship, the ship manager defaulting on the shipowner and/or the shipowner defaulting on the EU generates a loss of competitiveness and potential exit from the market, as well as the probable tightening of the due diligence on the charterer and of the increase of the patentability of the fulfilling shipowner.

This set of proposals (European Green Deal) revises the Non-Financial Reporting Directive (NFRD[29]) to make it more efficient and stimulate more sustainable investments and, in 2021, proposes the Corporate Sustainability Reporting Directive (CSRD). Specifically, one of the proposals concerns the Emission Trading System and the changes made should allow a reduction in emissions of the analysed sectors by 61% by 2030 compared to the level of 2005 (European Council, 2021). In this context, the committee's proposal to include the shipping sector within the EU ETS should be mentioned.

The carbon intensity reduction targets set by the IMO can be achieved by exploiting existing technologies thanks to a combination of short and medium-term measures: to achieve the overall goals of 2050, a greater use and efficiency of technological investment options is considered necessary, as well as a transition towards alternative fuels and energy sources (European Parliament, 2022). To achieve the 2050 objectives, a greater use and efficiency of technological investment options is considered necessary, as well as a transition towards alternative fuels and energy sources (European Parliament, 2022).

2.2.4 The Energy Taxation Directive (ETD)

Within the regulation package Fit for 55, a revision of the Energy Taxation Directive (ETD), would involve great implications for the shipping industry. ETD is the European Union's framework for the taxation of energy products including electricity, motor and most heating fuels. As well as setting out structural rules to avoid potential distortions of competition across the EU, the ETD sets minimum rates of excise duty with the intention of encouraging a low-carbon and

[29] In 2014, the European Commission adopted the NFRD, which further increases the corporate relevance of socio-environmental information by leading investors to consider these values in their investment decisions.

energy efficient economy. Member states design their own taxes within the framework of the ETD and can determine domestic rates if they meet the ETD minimum. The ETD took more than a decade to develop and involved lengthy negotiations across the EU. It may seem that the mechanisms introduced by the ETD to encourage a low carbon economy are primitive and insufficient. However, once it was put in place, it was quickly realized that the new directive incentivized behaviours that were not necessarily conducive to reducing carbon emissions. Criticism of the ETD has grown over the years, with particular emphasis on its failure both to discourage the use of fossil fuels or to encourage intensive consumers of energy to adopt new energy efficient technologies (for example, at the moment shipping remain fully exempt).

As long ago as 2008, the European Council asked the European Commission to consider ways to align the ETD with the EU's climate change objectives. At present, the primary focus of the ETD is on the internal market objectives, while in the proposed review there would be a change of focus on environmental sustainability: the EC, with the revision of the ETD, aims to align the energy taxation system with EU policies on sustainability by promoting the use of green technologies and removing exemptions and reductions of anachronistic taxes that encourage the use of fossil fuels. It introduces a new tax structure based on the energy content and environmental performance of fuels and electricity and extends the application of the tax system to sectors that are not included today (such as aviation and shipping). The reforms announced in July 2021 include:

- taxation of fuels based on their energy content and their environmental performance, rather than in proportion to their volumes, pushing towards cleaner and climate-friendly choices;
- product categorisation for taxation purposes in a simplified way, to ensure that fuels that are most harmful to the environment are taxed higher;
- removal of exemptions for certain products and for domestic heating (it will no longer be possible to tax fossil fuels below the minimum rate);
- removal of exemptions from the EU energy tax on the use of fossil fuels by the aviation, shipping and fisheries sector;
- recognition of new energy products, such as hydrogen (European Parliament, 2021).

The ETD review is currently under consultation, but being based on Article 113 TFEU, it is subject to a special legislative procedure whereby the decision is taken by unanimity of the Council, after consultation with Parliament and the European Economic and Social Committee-EESC.

In this second Chapter, an in deep analysis on impacts and drivers related to the shipping sector, with a specific focus on the Ferry, Ro-Ro and Ro-Pax industry. Specifically, a taxonomy of environmental impacts has been provided. Moreover, a classification of environmental impacts from the shipping industry have been proposed, comparing the classification provided by the EMSA in the European Environmental Report on Maritime Transport of 2021 with other environmental impacts classifications (Jägerbrand et al., 2019; Walker et al., 2019; Joumard et al., 2011; OECD, 2011).

Furthermore, an analysis of main drivers at the basis of the competitive advantage in shipping industry has been proposed, with a specific focus on the increasing attention towards elements such as environmental sustainability, the reduction of emissions and all those concerning the natural environment and its preservation. In this way, the management of various shipping companies also operating in the Ferry, Ro-Ro and Ro-Pax sector has understood the importance of issues related to the reduction of environmental impacts and the pursuit of greater energy efficiency and environmental sustainability. In this line, a series of strategic objectives relevant to its success and competitive positioning are summarize.

In the next third Chapter, an overview of theoretical constructs that are at the basis of the strategic objective of major Ferry, Ro-Ro and Ro-Pax companies is proposed, in order to analyse the reactions of such shipping firms to the environmental challenges and to identify how reductions in energy consumption and air emissions can be pursued by implementing a variety of voluntary initiatives as part of a comprehensive Corporate Social Responsibility (CSR).

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CHAPTER 3

THEORETICAL CONSTRUCT

3. Theoretical construct

According to the aim of this PhD thesis, an analysis of theoretical constructs that are at the basis of the strategic objective of major Ferry, Ro-Ro and Ro-Pax companies is necessary to analyse the reactions of such shipping firms to the environmental challenges. This is also necessary to identify how reductions in energy consumption and air emissions can be pursued by implementing a variety of voluntary initiatives as part of a comprehensive Corporate Social Responsibility (CSR) strategy or while making the business compliant with new regulations applicable to the business (Christodoulou and Cullinane, 2021).

As a result of the evolution of the maritime regulatory framework and the need for shipping companies to respond to their corporate social responsibilities, green shipping practices have been rooted into the corporate actions of maritime companies, mainly in order to improve their energy performance and to reduce associated air emissions (Wong and Fryxell 2004; Dummett 2006; Yang et al. 2010; Lee et al. 2012; Yliskylä-Peuralahti and Gritsenko 2014). Through the application of stakeholder theory, Wong et al. (2009) showed the impact of institutional pressures on the adoption of sustainable practices and the trend of firms to integrate sustainability into their day-by-day activities and operations. Nevertheless, according to Lai et al. (2011), green shipping practices can also be motivated by their alignment with the firm's competitive strategies that fundamentally rely upon the reduction of their production costs or the differentiation of their services (Christodoulou and Cullinane, 2021).

Yuen and Lim (2016) examined the challenges shipping companies face during the implementation of strategic CSR actions, and identified the related barriers in the shipping industry, including a lack of resources (including finances, human capital, knowledge, and expertise), strategic vision, a measurement system, and high regulatory standards, and a low willingness to pay for CSR. To identify the main drivers behind green shipping practices, different theories are analysed below. The motivation of companies to address sustainability issues due to institutional pressures is highlighted in stakeholder theory (Freeman, 2010). Stakeholder theory is a view of capitalism that stresses the interconnected relationship between a business and its customers, suppliers, employees, investors, communities and others who have a stake in the organization; so, the theory argues that a firm should create value for all stakeholders, not just shareholders. The shipping industry is heavily impacted by international and regional institutions that affect the actions and decisions of companies and could provide an explanation as to what motivates a firm towards sustainable practices (Meixell and Luoma 2015). Additionally, CSR can complement command-and-control regulations in a co-governance system to increase transparency and improve quality in shipping and that collaboration between these two forms of regulation is essential for effective maritime governance (Yliskylä-Peuralahti and Gritsenko, 2014).

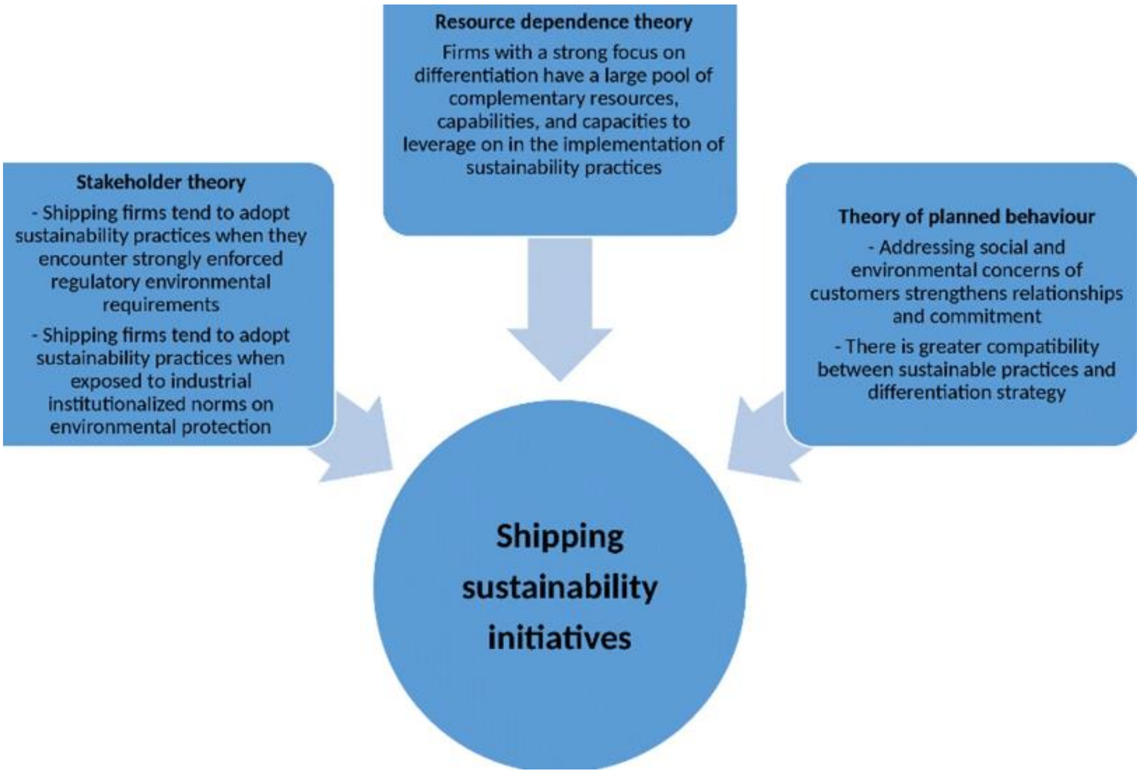
Regardless of institutional pressures, the theory of planned behaviour (Hardeman et al., 2002; Ajzen, 2011) explains that shipping companies may adopt sustainability initiatives only if they believe that such initiatives are aligned with their competitive strategies (Wolf, 2014). The theory of planned behaviour (TPB) is a psychological theory that links strategic behaviour to beliefs. TPB was elaborated by Icek Ajzen to improve the predictive power of the theory of reasoned action (TRA), including also the perceived behavioural control. Perceived behaviour control was not a component of TRA; therefore, TPB has been applied to studies of the relations among attitudes, behavioural intentions and behaviours in various human domains (including, but not limited to, public relations, advertising campaigns, healthcare, sport management, sustainability, etc.). Since the TPB argues that three core components, i.e., attitude, subjective norms, and perceived behavioural control, together form an individual’s behavioural intentions, the TPB suggests that an individual's decisions and behaviour depend on three main factors: attitude towards behaviour, subjective norm and perceptual control. These factors can be applied in the context of Ferry, Ro-Ro and Ro-Pax companies and in the world of investments in green technologies. In the Ferry, Ro-Ro and Ro-Pax industry, attitude towards investments in green technologies, such as the installation of cleaner engines or the adoption of renewable energy sources, could be assessed. Companies could be influenced by factors such as operational efficiency, fuel cost reduction, compliance with environmental regulations and public image. Attitude analysis can provide information on the degree to which operators favour or disfavour green technologies and may influence their investment decisions. In this industry subjective norms might be influenced by relevant stakeholders, such as ship owners, customers, regulators and the general public. If operators perceive a strong social pressure or expectation to adopt green technologies, they might be more inclined to make investment decisions in these technologies. On the other hand, if social norms still favour the use of traditional technologies, this might negatively influence investment decisions in green technologies. Since perceptual control refers to an individual's perception of his or her ability to successfully perform the considered behaviour, in the Ferry, Ro-Ro and Ro-Pax industry, perceptual control may be related to the availability of financial resources, the technical knowledge required to implement green technologies, and the ability to manage any associated risks. If operators feel they have adequate control over these factors, they may be more inclined to adopt green technologies through investment decisions. In this vein, the TBP in this context can therefore constitute a valid theoretical construct on which to base the definition of a system aimed to support and monitor the decision-making processes of companies operating in the Ferry, Ro-Ro and Ro-Pax sector.

Another relevant perspective for this research, embedded within strategic management studies, is represented by the resource-dependence theory, whereby companies need to collect and retain from their external environment the essential resources for their activities to ensure their survival and improve their strategic position (Pfeffer and Salancik, 1978; Drees and Heugens, 2013). Resource-dependence theory has implications with regards to the optimal divisional structure of organizations and companies, the recruitment of board members and employees, the production strategies, the contract structure, the external organizational links, and many other aspects of organizational strategy. For example, Lun et al. (2016) considers sustainable practices in shipping industry as effective tools for strengthening relationships with stakeholders, ensuring access to vital resources. On the basis of those assumptions, the interest of this PhD thesis consists in the research of sustainable initiatives and practices with less environmental impact than the companies operating in the Ferry, Ro-Ro and Ro-Pax industry, also in order to strengthening relationships with stakeholders and other external entities. Resource-dependence theory can be applied also in the analysis of investment decisions in green technologies in the Ferry, Ro-Ro and Ro-Pax sector, as it offers an analytical lens to understand how organisations depend on external resources and how this dependence affects their investment choices. Since resource-dependence theory suggests that organisations seek to ensure access to the resources they need to function and survive, these resources may include financial capital, technology, expertise, information and stakeholder relationships. When analysing investment decisions in green technologies by Ferry, Ro-Ro and Ro-Pax operators, resource-dependence theory can be applied in several ways.

- Dependence on environmental resources: Ferry, Ro-Ro and Ro-Pax operators depend on environmental resources, such as fuel, energy and port infrastructure, for their operation. The adoption of green technologies can influence the dependence on these environmental resources, e.g., by reducing dependence on fossil fuels or by enabling the use of renewable energy sources. Analysis based on resource-dependence theory can help assess how the adoption of green technologies affects environmental resource dependence and how this can influence investment decisions.
- Dependence on stakeholder relationships: Ferry, Ro-Ro and Ro-Pax companies depend on relationships with various stakeholders, such as port service providers, customers, regulators and environmental organisations. The adoption of green technologies can be influenced by dependence on these relationships. For example, if customers demand more sustainable shipping services or if regulators impose stricter environmental regulations, operators may be driven to invest in green technologies to maintain and strengthen relationships with these stakeholders. Analysis based on resource-dependence theory can help assess how dependence on stakeholder relationships may influence investment decisions.
- Dependence on technical and financial resources: Ferry, Ro-Ro and Ro-Pax operators may depend on technical and financial resources to implement green technologies. These resources may include specialised knowledge, research and development capabilities, access to finance or strategic partnerships with technology providers. Analysis based on resource-dependence theory can help assess how dependence on these technical and financial resources affects investment decisions in green technologies. For example, if operators are limited in their technical or financial resources, they may be less likely to invest in green technologies.

These above-mentioned theories are complementary and together represent the foundation for the adoption of sustainable shipping initiatives (Christodoulou and Cullinane, 2021). In this vein, a conceptual framework was developed to identify the most relevant drivers for the implementation of sustainable initiatives within the shipping industry (Lai et al., 2011). According to the results of Lai et al. (2011) and Yuen et al. (2017), a conceptual model is developed on the drivers and the potentialities of the performance of sustainable initiatives in the shipping industry and on the parameters that influence the integration of the CSR in the shipping companies. As shown in Figure 16, the use of this model facilitates the analysis of the drivers that motivate the adoption of green shipping practices, including the impact of both institutional pressures and subjective attitudes towards a firm’s sustainability practices.

Figure 16. Conceptual model of shipping sustainability initiative.



Source: Christodoulou and Cullinane (2021) elaboration from Lai et al. (2011) and Yuen et al. (2017).

In line with the above-mentioned theories the concept of Corporate Social Responsibility (CSR). CSR is a managerial theory developed simultaneously with the concept of stakeholder management. Indeed, academic literature does not provide a uniform and commonly accepted definition of CSR, which still represents a theory in continuous evolution. Several authors and contributions have addressed and analysed the concept of CSR over the years. Bowen (1953), who is still consider the father of CSR, defines Corporate Social Responsibility as the obligation *"to pursue those policies, to make those decisions, or to follow those lines of action which are desirable in terms of the objectives and values of our society"*. In 1960, Davis define CSR: as a *"businessmen's decisions and actions taken for reasons at least partially beyond the firm's direct economic or technical interest"*. McGuire (1963) supposes that *"the corporation has not only economic and legal obligations but also certain responsibilities to society that extend beyond these obligations"*. According to Davis and Blomstrom (1966) social responsibility refers to the *"obligation to consider the effects of decisions and actions on the whole social system, … looking beyond firm's narrow economic and technical interests"*. According to the CSR definition by Johnson (1971), *"business takes place within a socio-cultural system that outlines through norms* *and business roles particular ways of responding to particular situations and sets out in some detail the prescribed ways of conducting business affairs".*

Especially between the 1960s and the 1970s, the Authors analysing CSR theory and related issues received several criticisms. The most famous antagonist of this school of thought is Friedman, who compared social responsibility to "hypocritical window dressing" (Friedman, 1970). He argues that the only responsibility of the firm is to maximise profits to satisfy shareholders, defining CSR as a "Stockholder Theory", i.e., the view that the only duty of a corporation is to maximize the profits accruing to its shareholders, because only economic responsibilities should concern firms' management focused on corporate profitability for rewarding shareholders. This approach was later considered too simplistic and outdated by scholar and academics which, conversely, supported the growing CSR theory.

Steiner (1971) and Davis (1973) defined the CSR as "*more of an attitude*". Steiner (1971) describes CSR as "*a philosophy that looks at the social interest and the enlightened self-interest of business over the long run as compared with the old, narrow, unrestrained short-run self-interest*".

According to Votaw (1973), CSR means something, but not always the same thing, to everybody: the idea of legal responsibility or liability; a socially responsible behaviour in an ethical sense; the issue of "responsible for", in a causal mode; etc. According to Davis (1973) and also to Eells and Walton (1974), CSR also refers to issues beyond the narrow economic, technical and legal requirements. An innovative model to analyse the economic and non-economic profiles of the firm's responsibilities was proposed by the Committee for Economic Development (CED[30]) in 1971. This approach, namely "three concentric circles" approach, is made of three levels of responsibilities ordered by relevance:

- the inner circle concerns basic responsibilities about corporate economic functions,
- the intermediate circle reports the responsibilities related to the course of the business (e.g., environmental conservation, hiring, and relations with employees, etc.),
- the outer circle outlines the emerging responsibilities of the firm regarding social issues.

Sethi (1975) was the first author who explicitly addressed the concept of CSR, providing an analytical framework to assess corporate social performance and making a distinction between

[30] The CED of The Conference Board is an American nonprofit and nonpartisan public policy think tank. The board of trustees consist primarily of senior corporate executives from a range of U.S. industries and sectors.

social obligations, social responsibilities, and social responsiveness. On the same line, Backman (1975) tried to improve the broad *umbrella* of social responsibility.

Fitch (1976) defines CSR as *"the serious attempt to solve social problems caused wholly or in part by the corporation"*. Jones (1979) describes CSR as an obligation for companies (voluntarily adopted and not influenced by the coercive forces of law or union contract) towards social groups other than stockholders (not only customers, employees, suppliers, and neighbouring communities) and beyond what is prescribed by law and union contract.

In 1979 Carrol developed a three-dimensional conceptual model of corporate performance which was rapidly adopted by several authors: according to him, *"the responsibility of business encompasses the economic, legal, ethical, and discretionary expectations that society has of organizations at a given point in time"*. So, in 1991, Carrol argued that the establishment of new government bodies by the USA, such as the Environment Protection Agency, the Equal Employment Opportunity Commission, the Occupational Safety and Health Administration and the Consumer Product Safety Commission, explains that public policy officially recognized environment, employees and consumers as legitimate stakeholders of companies, putting the CSR concept in the limelight. In recent years, the definition of CSR by Carrol has been enriched with a fourth level: economic, legal, ethical and voluntary or philanthropic. This definition is depicted with the Pyramid of Corporate Social Responsibility or pyramid metaphor that is made of the four levels in the following order: economic, legal (two levels that are mandatory to carry out the business), ethical and, on the top, philanthropic responsibilities (

Figure *17*).

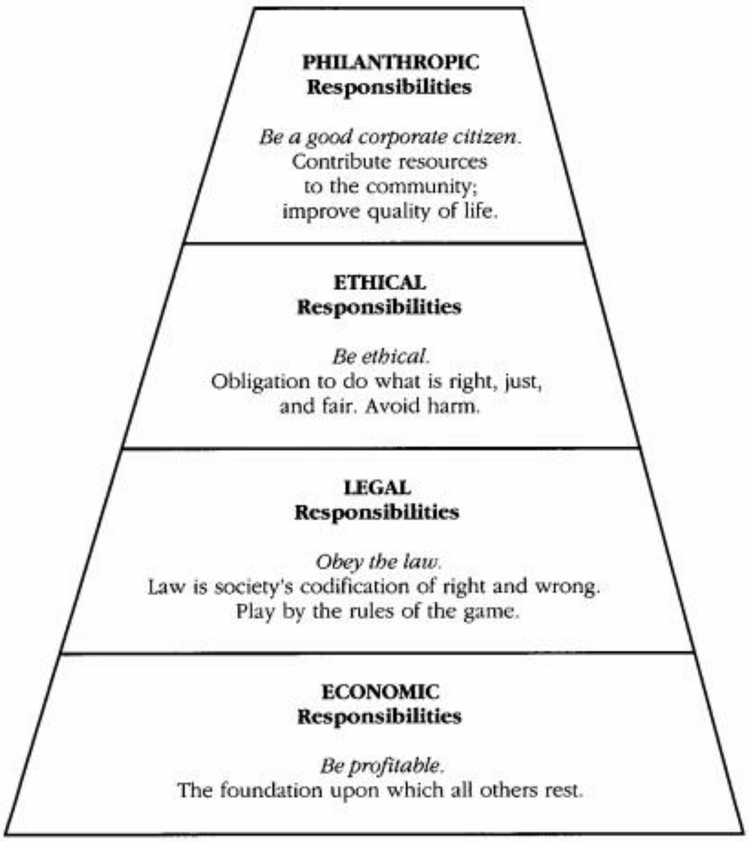
- The economic components lie at the base of the pyramid since profitability is a precondition to the survival and success of enterprises. Indeed, the company represents the basic economic unit in any society, by reason of its responsibility to provide the goods and services required by the economic system (Carroll, 1979).
- Legal responsibilities are at the second level of the pyramid. In fact, enterprises are expected to comply with the law in their business management. The goods and services offered must in fact meet the minimum legal requirements established by the reference standards and regulations.
- Ethical responsibilities are non-compulsory business activities and practices that go beyond the legal requirements but are required by the company (Carroll, 1979). These consist in rules of conduct and ethical norms aimed at satisfying and respecting the moral rights of stakeholders, such as measures regarding environmental protection, civil rights and, in general, social values to improve the quality of life of stakeholders.

Ethical responsibilities can be interpreted as new emerging social values that in the future will be converted into a corporate performance standard established by law (Carroll, 1991).

- Philanthropic responsibilities represent the "icing on the cake" and are less important than the other three layers of the pyramid which are the main components of CSR (Carroll, 1991). Philanthropic responsibilities promote charitable activities within local communities, assistance to educational institutions and any project aimed at improving the quality of life and well-being of stakeholders, especially the community (Carroll, 1979; 1991). Philanthropic responsibilities are distinguished from ethical responsibilities by their voluntary and discretionary nature (Carroll, 1991).

Since responsibilities change over time (especially ethical ones), reflecting the expectations of the company only at a given moment, the management is called not only to listen to the requests of stakeholders (stakeholder theory) but also to monitor changing regulations and societal values which affect the social responsibilities of the company.

Figure 17. Pyramid of Corporate Social Responsibility.



Source: Carroll, 1991.

Schwartz and Carroll (2003) were forced by the numerous criticisms received to reduce the number of CSR levels, by combining philanthropic and ethical responsibilities. With a clear reference to the stakeholder theory, since CSR strategies aim to meet the needs and interests of all stakeholders, the authors sustain that managers should develop programs, actions and initiatives that meet all three categories of responsibility. The concept of CSR was addressed by Freeman (1984) in stakeholder theory, according to which managers should consider all stakeholders during decision-making, including social interests.

Subsequently, according to Hopkins (1998) the normative correctness of the products of corporate action has been the main focus of corporate social responsibility. CSR deals with treating stakeholders, both within and outside the company, in an ethical or socially responsible manner to increase their human development. As a result, CSR is deeply rooted in the stakeholder theory as the main objective is to meet stakeholders' needs and requirements in a socially responsible manner.

Another significant contribution to the CSR theory comes from Elkington in 1994 with the concept of Triple Bottom Line (TBL), according to which companies should address equally economic, environmental and social values. In this way, the promotion of environmental and social values also has a positive impact on business performance. While it may be thought that the adoption of TBL principles favours the company's CSR practices, it has been argued (e.g., McWilliams et al. 2016) that the objectives included in the TBL are not equally important for companies. Indeed, Carroll's Pyramid of CSR identifies the economic responsibilities at the foundation of the model, highlighting their superiority over ethical and philanthropic goals.

Subsequently, in the early 2000s, empirical research incorporated theoretical knowledge, also involving companies and universities in research activities (Carroll, 2008). In the same period, CSR also received more political attention: the Green Paper on CSR of European Commission (2001) reports that, according to the main CSR definitions, companies integrate social and environmental concerns both in their business operations and in their interaction with stakeholders on a voluntary basis. Since then, the concept of CSR has kept evolving in its different definitions. Several studies and contributions (e.g., Carrol, 2008) have recently revised the main extant literature concerning stakeholders and CSR to provide a complete definition of the concept. Along these lines, in 2011, the European Commission published "A renewed EU strategy for corporate social responsibility 2011-2014" providing a modern and overarching interpretation of CSR, making companies accountable for their impact on society. Therefore, companies and enterprises need a process to integrate social, environmental, ethical, human rights and consumer concerns into their business operations and core strategy in close cooperation with their stakeholders. In this way, companies can fully meet their corporate social responsibility, maximizing the creation of shared value not only for their owners and shareholders but also for their stakeholders and for society as a whole aiming to identify, prevent and mitigate their possible negative impacts (European Commission, 2011). According to the Non-financial Relations Directive (NFRD), i.e., the EU Directive 2014/95, large EU companies are required to publish their information on environmental and social issues, the treatment of employees, respect for human rights, the fight against corruption, diversity on boards of directors in terms of age, gender, education and vocational training. In this way, civil society, policymakers, investors and other stakeholders can assess the non-financial performance of large European companies, encouraging them to develop a more responsible and sustainable approach to business.

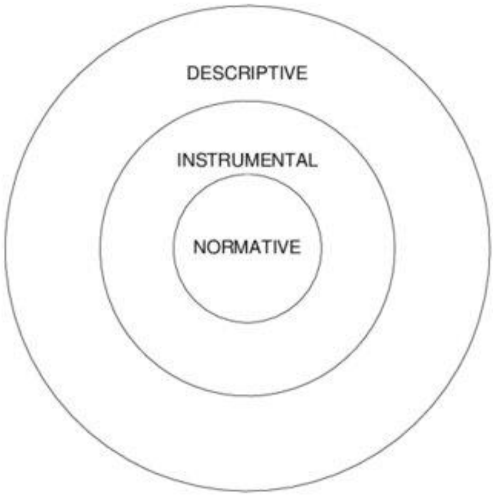
According to the above-mentioned academic studies, normative directives, and business practices, CSR goes far beyond the full compliance with the law, consisting of voluntary practices aimed to meet social, environmental and ethical issues related to companies' stakeholders.

The limits of traditional approaches to strategic management have become evident with the growing pressure from stakeholders (both internal and external to the company) on business performance and with the increasingly changing market rules and conditions (Freeman, 1984). Over time, the interests of key stakeholders have been integrated into the company's objectives and the Stakeholder Relationship Management (SRM) has become one of the cornerstones of strategic management.

The management of the relationships between stakeholders and the integration of their interests to ensure a fair distribution of the benefits and the long-term success of the firm is the central task of SRM (Freeman, 1984). In this perspective, due to the existence of two-way relationships between the firm and the stakeholders (mutual exchange of benefits between them), the stakeholder model recognises not only investors, customers, employees and suppliers as the main stakeholders, but also those groups with a legitimate interest in the firm, including governments, political groups, communities and trade associations (Donaldson and Preston, 1995).

Since the publication of Freeman's book in 1984, the extension of key stakeholders and the increasing attention towards their interests have driven academics (Buysse and Verbeke, 2003; Freeman et al., 2010) to further develop the stakeholder theory. For a decade, diverging criteria and implications arising from the variety of approaches adopted by academics made it difficult to understand the core nature and purpose of stakeholder theory. Then, in 1995 Donaldson and Preston identified three critical perspectives (i.e., descriptive or empirical, instrumental and normative) aimed at analysing the main contributions to stakeholder theory (Figure 18). The firm is seen as a group of cooperating and conflicting interests (Donaldson and Preston, 1995); therefore, the descriptive or empirical perspective analyses its characteristics and behaviours (e.g., the nature of the firm, the managerial practices, corporate internal organisation and objectives, etc.) to identify and evaluate the main relationships with stakeholders. The instrumental perspective investigates the links existing between relationships with stakeholders and corporate objectives: stakeholder theory is used to study to what extent stakeholder management can strengthen corporate performance (e.g., profitability, stability, growth, etc.) compared to classic managerial approaches. In this regard, the adoption of stakeholder principles and practices turns out to rise corporate performance more effectively compared to alternative managerial strategies (see among others: Aupperle et al., 1985; Cornell and Shapiro, 1987). As in Figure 18, the descriptive perspective (external level) deals with the existing relationships between the firm and the economic system; the instrumental perspective (middle level) aims to evaluate these connections and their impact on corporate performance; the normative perspective of stakeholder theory located at the heart (internal level) focuses on stakeholders' interests and expectations (Donaldson and Preston, 1995).

Figure 18. The conceptualisation of stakeholder theory perspectives.



Source: Donaldson e Preston (1995).

Moreover, Donaldson and Preston (1995) explain that the theory should be accepted or preferred over alternative managerial approaches, both in theory and practice because of the distinctive objectives pursued by the stakeholder theory, according to the adopted theoretical perspective (i.e., descriptive, instrumental, or normative).

Donaldson and Preston (1995) outline a fourth additional perspective to stakeholder theory, i.e., an overarching managerial approach that combines the main aspects emerging from the three previous perspectives. This managerial perspective is based on the interests and expectations of stakeholders (which are thus included in the strategic decision-making process by the company) and outlines behaviours, policies, organisational structures and managerial practices to face both internal and external stakeholders. In this context, stakeholder management includes communicating, negotiating, contracting, managing relationships and motivating stakeholders (Strategic Management of Organisation and Stakeholder, 1994). Due to even more collaborative behaviours and strategic partnerships, ethics becomes a major factor of stakeholder management because it provides the principles and codes of conduct to develop fruitful relationships of trust (Freeman et al., 2010).

Stakeholder theory can be applied in the analysis of investment decisions in green technologies by Ferry, Ro-Ro and Ro-Pax operators by providing a broader perspective on the network of influential and interested stakeholders in investment choices. Since stakeholder theory suggests that organisations should not make decisions based solely on shareholder interests but should also consider the interests and influences of all stakeholders involved in their business, when analysing investment decisions in green technologies by shipping companies, stakeholder theory can help identify and understand the key stakeholders that may influence or be influenced by such decisions. Stakeholder theory can also provide a useful framework for understanding how green investment decisions meet stakeholder expectations. Theis PhD thesis relies also on the main European Ferry, Ro-Ro and Ro-Pax companies' sustainability reports as a source of information: by this way it is firstly possible to identify the most relevant stakeholders for each investigated company. Sustainability reports often include a stakeholder section, which lists the interest groups with which Ferry, Ro-Ro and Ro-Pax companies engage or relate. This may include customers, suppliers, regulators, local communities, investors and environmental organisations. By analysing sustainability reports, it is possible to examine how Ferry, Ro-Ro and Ro-Pax companies address stakeholder interests related to green investments. For example, companies can highlight their sustainability goals, emission reduction strategies, energy efficiency, waste management and other green initiatives. Furthermore, sustainability reports can indicate the stakeholder engagement mechanisms used by companies, such as dialogue, public consultations or collaboration with external organisations. The analysis of sustainability reports based on stakeholder theory allows for an assessment of how Ferry, Ro-Ro and Ro-Pax companies recognise and respond to stakeholder interests regarding green investments. This approach can provide a clear and structured overview of the actions taken by companies and their response to relevant aspects for the stakeholders involved.

According to the Corporate social responsibility, a business's performance is measured not only in terms of profit, but in how well it addresses its social and environmental impacts. In this vein, the role of the environment and the sustainability takes on a particularly important and central role in the definition of CSR. Environmental responsibility, as a pillar of corporate social responsibility, focuses in preserving the environment.

Through optimal operations and support of related causes, a company can ensure it leaves natural resources better than before its operations. In this vein, companies often pursue green strategies to preserve the environment through reducing pollution, waste, natural resource consumption, and emissions through its manufacturing process; the recycling goods and materials; the replenishing natural resources or supporting causes that can help neutralize the company's impact; etc. Considering the high negative impact on the environment of the transport sector, the Ferry, Ro-Ro and Ro-Pax industry also contributes to increasing the risk of high environmental impact. In this vein, to identify the behaviours and strategies implemented by Ferry, Ro-Ro and Ro-Pax companies, in the next fourth Chapter a systematic literature review has been carried out to investigate data and findings of authors and academics concerning green, sustainability and environment-related issues and to energy efficiency, emission and environmental impact reduction in the Ferry, Ro-Ro and Ro-Pax industry.

In this second Chapter, an analysis of theoretical constructs that are at the basis of the strategic objective of major Ferry, Ro-Ro and Ro-Pax companies has been deepened in order to analyse the reactions of such shipping firms to the environmental challenges. This is also necessary to identify how reductions in energy consumption and air emissions can be pursued by implementing a variety of voluntary initiatives as part of a comprehensive CSR strategy or while making the business compliant with new regulations applicable to the business.

In the second second, some theoretical constructs have been presented, referring to the topics and issues that are studied by this PhD thesis. For example, the theory of planned behaviour (Hardeman et al., 2002; Ajzen, 2011) has presented because it explains that shipping companies may adopt sustainability initiatives only if they believe that such initiatives are aligned with their competitive strategies (Wolf, 2014). Also the Conceptual model of shipping sustainability initiative (Christodoulou and Cullinane, 2021) has been presented in order to facilitate the analysis of the drivers that motivate the adoption of green shipping practices, including the impact of both institutional pressures and subjective attitudes towards a firm's sustainability practices.

In the third Chapter a systematic literature review has been carried out, in order to analyse the growing importance assumed by green investment options that shipping companies operating in Ferry, Ro-Ro and Ro-Pax sector can implement to contain environmental impacts and ensure the sustainable growth of the sector.

CHAPTER 4

GREEN STRATEGIES: LITERATURE REVIEW

4. Green strategies: literature review

Although the existing green-shipping literature has analysed the potential of international and regional policies for the reduction of shipping emissions to air, the environmental outcomes derived from local private voluntary initiatives that have been implemented by individual shipping companies have not received the same attention in the academic literature (Christodoulou and Cullinane, 2021). These voluntary initiatives vary widely and include but are not limited to the use of alternative fuels, the electrification of ships, the construction of larger ship where emissions per passenger/mile and per tonne or linear metres/mile would be reduced due to economies of scale and slow steaming, etc. (Christodoulou and Cullinane, 2021).

In order to analyse the growing importance assumed by green investment options that shipping companies operating in Ferry, Ro-Ro and Ro-Pax sector can implement to contain environmental impacts and ensure the sustainable growth of the sector, a systematic literature review has been carried out.

4.1 Method: a systematic literature review

For the purpose of this PhD thesis, a systematic literature review has been carried out on around 350 academic contributions, aiming at investigating data and findings of other authors and academics concerning green, sustainability and environment-related issues and to energy efficiency, emission and environmental impact reduction in the Ferry, Ro-Ro and Ro-Pax industry.

For this purpose, a three-stage procedure has been performed, i.e. (i) planning, (ii) execution, (iii) reporting, in line with Tranfield et al. (2003). In the planning stage (i), papers published on international specialized journals or conferences have been extracted from the Elsevier' Scopus database, i.e., the largest abstract and citation database of peer-reviewed papers and contributions, which includes scientific journals, books and conference proceedings. By this way, performing different queries[31] with specific keywords, several academic papers consistent with the object and the range of the research were found. The second stage, the execution stage (ii) was split into three steps in line with Crossan and Apaydin (2003): a) definition of initial selection criteria; b) grouping publications by pertinence; c) analysis and synthesis.

a) Initial selection criteria

The Scopus database has been examined throughout ad hoc-queries using different keywords coherently with the focus of the study, i.e., green investment options in Ferry, Ro-Ro and Ro-Pax sector. The following query was executed: TITLE-ABS-KEY[32] ("green" OR "sustainability" OR "environment") AND TITLE-ABS-KEY ("ferry" OR "ro-ro" OR "ro-pax" OR "roro" OR "ropax" OR "transport passenger") AND TITLE-ABS-KEY ("emission" OR "energy" OR "impact"). As a result, 350 academic papers were identified as eligible. The selected contributions are published in several international journals, including among others Quality and Reliability Engineering International, International Journal of Hydrogen Energy, Journal of Cleaner Production, etc.

b) Grouping publications by pertinence

The initial dataset has been then scrutinized to exclude from the sample academic articles published before 2005 to focus the research on the most updated publications, eliminating 54 outdated studies (at this phase the sample included 296 contributions). Then, non-pertinent studies have been excluded from the sample. For this purpose, the abstract of each paper has been analysed, and those that were found to be non-relevant with regards to the focus and the specific sector of the study have been discarded. Furthermore, for some papers it was not possible to find

[31] Instruction that allows access to the data contained in a database through an appropriate search.
[32] In Elsevier' Scopus database, this returns documents where the terms appear in the title, keywords, or abstract.

the whole text, hence they were deleted from the sample. As a result, a shortlist of 98 potentially relevant papers was obtained.

The 98 relevant contributions and articles were then classified by topic category: "impact" (n. 21 contributions), "drivers" (n. 6 contributions), "investments and technologies" (n. 45 contributions), "green strategies" (n. 1 contribution) and, where appropriate, combinations thereof: "impact/drivers" (n. 1 contribution), "green strategies/investments and technologies" (n. 3 contributions), "investments and technologies/drivers" (n. 7 contributions), "investments and technologies/impact" (n. 14 contributions).

For the purposes of this report, special attention has been paid exclusively on the 69 articles falling within the "investments and technologies" category (also including combined categories of "green strategies/investments and technologies", "investments and technologies/drivers", "investments and technologies/impact"), which constitute the final sample.

c) Analysis and synthesis

Each article belonging to the final sample has been deeply scrutinized in accordance with a number of analytical dimensions, which include:

- authors name;
- year of publication (2005-2022);
- source title;
- keywords selected by authors;
- type of document (article, conference paper, book chapter, business article, note, review);
- paper type (literature review paper, conceptual paper, qualitative and/or quantitative research paper, specifying the research method used by the authors and the main research outcomes);
- operational sector area (general shipping, Ferry, Ro-Ro, Ro-Pax, etc.);
- main sub-category related to the category "Investments and technologies", i.e., technical solutions for energy and environmental efficiency, ship propulsion system and alternative fuels, Ballast Water Treatment System (BWTS);
- specific treated investment options such as renewable energy sources, ship/hull/propeller design, alternative fuel (LNG, hydrogen, low sulphur), electrification, hybrid, fuel cell, battery, Exhaust Gas Cleaning System (EGCS), ballast tank and water injection system;

- if any geographical area of reference (no geographical reference in 24 contributions).

The outcome of the analysis is reported in the next paragraph 4.2.

4.2 Results

This section provides in-depth insights concerning the main findings of the systematic literature review performed on the analysed academic papers (third stage, i.e., reporting).

Table 5 shows the main results deriving from the analysis of the systematic literature review: for each of 69 academic papers under examination, the table shows the related year of publication, source title, type of document, type of paper, the operational sector area, the main sub-category related to the category "Investments and technologies", the specific treated investment options and if any geographical area of reference.

Table 5. Literature review.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
1	Aboud L., Massoud O.M., Tawfik A.A.	Zero Emissions Ferries Utilizing PV/ Shore Connection Hybrid Power System	2021	21st Annual General Assembly, IAMU AGA 2021 – Proceedings of the International Association of Maritime Universities, IAMU Conference	Conference Paper	Research (qualitative-quantitative)	Ro-Ro; Ro-Pax	Investments and technologies	Ship propulsion system and alternative fuels	Renewable energy sources	Africa
2	Aijjou A., Bahatti L., Raihani A.	Influence of keel coolers use on ship energy efficiency: A case study and evaluation	2018	Proceedings of the 2018 International Conference on Optimization and Applications, ICOA 2018	Conference Paper	Conceptual	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Ship/hull/propeller design	Africa
3	Alcaide J.I., García Llave R., Piniella F., Querol A.	New passenger maritime transport system for gulf of Cadiz (ESPOmar PROJECT)	2019	Advances in Marine Navigation and Safety of Sea Transportation – 13th International Conference on Marine Navigation and Safety of Sea Transportation, TransNav 2019	Conference Paper	Research (qualitative-quantitative)	Ferry	Investments and technologies/Impact	Ship propulsion system and alternative fuels/Technical solutions for energy and environmental efficiency	Renewable energy sources	Southern Europe
4	Ančić I., Šestan A., Vladimir N., Klisarić V.	Influence of new power sources on the attained EEDI	2014	RINA, Royal Institution of Naval Architects – Influence of EEDI on Ship Design 2014	Conference Paper	Research (qualitative-quantitative)	Ro-Pax	Investments and technologies/Drivers	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	n.a.
5	Ang J.H., Goh C., Li Y.	Key challenges and opportunities in hull form design optimisation for	2015	2015 21st International Conference on	Conference Paper	Literature review	Ferry	Investments and technologies	Technical solutions for energy and	Ship/hull/propeller design	n.a.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
		marine and offshore applications		Automation and Computing: Automation, Computing and Manufacturing for New Economic Growth, ICAC 2015					environmental efficiency		
6	Anwar S., Zia M.Y.I., Rashid M., De Rubens G.Z., Enevoldsen P.	Towards ferry electrification in the maritime sector	2020	Energies	Article	Literature review	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	n.a.
7	Banaei M., Rafiei M., Boudjadar J., Khooban M.-H.	A Comparative Analysis of Optimal Operation Scenarios in Hybrid Emission-Free Ferry Ships	2020	IEEE Transactions on Transportation Electrification	Article	Research (qualitative-quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Northern Europe
8	Bassam A.M., Phillips A.B., Turnock S.R., Wilson P.A.	Design, modelling and Simulation of a hybrid fuel cell propulsion system for a domestic ferry	2016	PRADS 2016 – Proceedings of the 13th International Symposium on PRActical Design of Ships and Other Floating Structures	Conference Paper	Research (qualitative-quantitative)	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	Northern Europe
9	Berntsen A., Sæther S., Røyrvik J., Biresselioglu M.E., Demir M.H.	The Significance of Enabling Human Consideration in Policymaking: How to Get the E-Ferry That You Want	2021	Frontiers in Psychology	Article	Literature review	Ferry	Green strategies/Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	Northern Europe
10	Bosich D., Vicenzutti A., Sulligoi G.	Environment-friendliness in Maritime Transport: Designing Smart	2020	2020 15th International Conference on Ecological Vehicles	Conference Paper	Research (qualitative-quantitative)	Ferry; port	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	Southern Europe

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
		Recharging Stations in North Adriatic Sea		and Renewable Energies, EVER 2020							
11	Buitelaar H.	Thinking green: Smart automation helps captain to save fuel	2014	Maritime by Holland	Article	Research (qualitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Western Europe
12	Burel F., Taccani R., Zuliani N.	Improving sustainability of maritime transport through utilization of Liquefied Natural Gas (LNG) for propulsion	2013	Energy	Article	Research (qualitative-quantitative)	Tanker; Ro-Ro	Investments and technologies	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	ECA area
13	Cai W., Wu W., Chen K.	Study on the application of all electric vehicle carriers in upper Yangtze River of China	2008	Proceedings of the International Offshore and Polar Engineering Conference	Conference Paper	Research (qualitative-quantitative)	Ro-Pax	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	Eastern Asia
14	Chou C.-C., Hsu H.-P., Wang C.-N., Yang T.-L.	Analysis of energy efficiencies of in-port ferries and island passenger-ships and improvement policies to reduce CO_2 emissions	2021	Marine Pollution Bulletin	Article	Research (quantitative)	Ferry	Investments and technologies/Impact	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Eastern Asia
15	Contessi C.	From tugs to FPSO: Gas as the green solution for offshore applications	2015	Offshore Mediterranean Conference and Exhibition, OMC 2015	Conference Paper	Conceptual	Shippin g	Investments and technologies/Drivers	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	n.a.
16	Cucinotta F., Raffaele M., Salmeri F., Sfravara F.	A comparative Life Cycle Assessment of two sister cruise ferries with Diesel and Liquefied Natural Gas machinery systems	2021	Applied Ocean Research	Article	Research (quantitative)	Ferry	Green strategies/Investments and technologies	Technical solutions for energy and environmental efficiency	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Northern Europe

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
17	de Baere K., Verstraelen H., Willemen R., Meskens R., Potters G.	Taking care of ballast tank coatings = green ballast tanks coatings	2014	SNAME Maritime Convention 2014, SMC 2014	Conference Paper	Research (quantitative)	Shipping	Investments and technologies	Ballast water treatment systems	Ballast tank and water injection system	n.a.
18	Dong Z.	Modelling and optimization of green ships using diesel/natural gas/fuel cell hybrid or pure electric propulsions	2020	Proceedings of the International Offshore and Polar Engineering Conference	Conference Paper	Research (quantitative)	Shipping	Green strategies/Investments and technologies	Ship propulsion system and alternative fuels/Technical solutions for energy and environmental efficiency	Alternative fuel (LNG, hydrogen, low sulphur, biofuel); Electrification, hybrid, fuel cell, battery	n.a.
19	Doulgeris G., Korakianitis T., Pilidis P., Tsoudis E.	Techno-economic and environmental risk analysis for advanced marine propulsion systems	2012	Applied Energy	Article	Research (qualitative)	Ro-Pax	Investments and technologies/Impact	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	n.a.
20	Durmaz M., Kalender S.S., Ergin S.	Experimental study on the effects of ultra-low sulfur diesel fuel to the exhaust emissions of a ferry	2017	Fresenius Environmental Bulletin	Article	Research (quantitative)	Ferry	Investments and technologies/Impact	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Western Asia
21	Erto P., Lepore A., Palumbo B., Vitiello L.	A Procedure for Predicting and Controlling the Ship Fuel Consumption: Its Implementation and Test	2015	Quality and Reliability Engineering International	Conference Paper	Research (quantitative)	Ro-Pax	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	n.a.
22	Faturachman D., Yandri E., Pujiastuti E.T., Anne O., Setyobudi R.H., Yani Y., Susanto	Techno-Economic analysis of photovoltaic utilization for lighting and cooling system of ferry Ro/Ro ship 500 GT	2021	E3S Web of Conferences	Conference Paper	Research (quantitative)	Ferry	Investments and technologies	Ship propulsion system and alternative fuels/Technical solutions for energy and environmental efficiency	Renewable energy sources	Southeast Asia

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
	H., Purba W., Wahono S.K.										
23	Fu S., Yan X., Zhang D., Shi J., Wan C., Song Z.	Use of FMECA method for leakage analysis of LNG fuelled vessels	2014	Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering – OMAE	Conference Paper	Research (quantitative)	Shippin g	Investments and technologies	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Western Asia
24	Gełesz P., Karczewski A., Kozak J., Litwin W., Piątek Ł.	Design Methodology for Small Passenger Ships on the Example of the Ferryboat Motława 2 Driven by Hybrid Propulsion System	2017	Polish Maritime Research	Article	Conceptual	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Renewable energy sources; Electrification, hybrid, fuel cell, battery; Ship/hull/propel ler design	Central Europe
25	Jang H., Jeong B., Zhou P., Ha S., Nam D., Kim J., Lee J.-U.	Development of Parametric Trend Life Cycle Assessment for marine SOx reduction scrubber systems	2020	Journal of Cleaner Production	Article	Research (qualitative-quantitative)	Ro-Ro	Investments and technologies	Technical solutions for energy and environmental efficiency	EGCS	n.a.
26	Karatzas V., Hjørnet N.K., Kristensen H.O., Berggreen C., Jensen J.J.	The effects on the operating condition of a passenger ship retrofitted with a composite superstructure	2016	PRADS 2016 – Proceedings of the 13th International Symposium on PRActical Design of Ships and Other Floating Structures	Conference Paper	Research (qualitative-quantitative)	Ro-Pax	Investments and technologies	Technical solutions for energy and environmental efficiency	Ship/hull/propel ler design	Northern Europe
27	Kawanami Y., Kudo T., Kawashima H.	Contra-rotating podded propulsor and its full-scale model tests	2005	Proceedings of the 12th International Congress of the International Maritime Association of the Mediterranean,	Conference Paper	Research (qualitative)	Shippin g	Investments and technologies	Technical solutions for energy and environmental efficiency	Ship/hull/propel ler design	n.a.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
				IMAM 2005 – Maritime Transportation and Exploitation of Ocean and Coastal Resources							
28	Khresna R., Yanuar	Installation of hybrid power system in ro-ro passenger vessel	2019	2nd IEEE International Conference on Innovative Research and Development, ICIRD 2019	Conference Paper	Research (quantitative)	Ro-Pax	Investments and technologies	Technical solutions for energy and environmental efficiency	Renewable energy sources	Southeast Asia
29	Koumentakos A.G.	Developments in electric and green marine ships	2019	Applied System Innovation	Review	Conceptual	Shipping	Investments and technologies/Drivers	Technical solutions for energy and environmental efficiency	Renewable energy sources; Electrification, hybrid, fuel cell, battery; EGCS	n.a.
30	Kunicka M., Litwin W.	Energy Efficient Small Inland Passenger Shuttle Ferry with Hybrid Propulsion – Concept Design, Calculations and Model Tests	2019	Polish Maritime Research	Article	Research (qualitative-quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Ship/hull/propeller design	Central Europe
31	Lepistö V., Lappalainen J., Sillanpää K., Ahtila P.	Dynamic process simulation promotes energy efficient ship design	2016	Ocean Engineering	Article	Research (quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Northern Europe
32	Letafat A., Rafiei M., Ardeshiri M., Sheikh M., Banaei M., Boudjadar J., Khooban M.H.	An Efficient and Cost-Effective Power Scheduling in Zero-Emission Ferry Ships	2020	Complexity	Article	Research (quantitative)	Ferry	Investments and technologies/Impact	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	n.a.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
33	Lipman T.E., Lidicker J.	Wind-assist marine demonstration for ferries: Prospects for saving diesel fuel with wind power	2019	International Journal of Environmental Technology and Management	Article	Research (qualitative-quantitative)	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Renewable energy sources	United States
34	Lümmen N., Nygård E., Koch P.E., Nerheim L.M.	Comparison of organic Rankine cycle concepts for recovering waste heat in a hybrid powertrain on a fast passenger ferry	2018	Energy Conversion and Management	Article	Research (qualitative-quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Northern Europe
35	Lutful Kabir S.M., Alam I., Rezwan Khan M., Hossain M.S., Rahman K.S., Amin N.	Solar powered ferry boat for the rural area of Bangladesh	2017	2016 International Conference on Advances in Electrical, Electronic and Systems Engineering, ICAEES 2016	Conference Paper	Research (qualitative)	Boat	Investments and technologies	Technical solutions for energy and environmental efficiency	Renewable energy sources	Southern Asia
36	MacPherson D.M., Bakas I.	Design-side innovation to minimize the environmental footprint of a RO/PAX ferry	2017	RINA, Royal Institution of Naval Architects – Power and Propulsion Alternatives for Ships 2017, Papers	Conference Paper	Research (qualitative-quantitative)	Ro-Pax	Investments and technologies/Impact	Technical solutions for energy and environmental efficiency	Ship/hull/propeller design; Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	n.a.
37	Martínez-López A., Romero A., Orosa J.A.	Assessment of cold ironing and LNG as mitigation tools of short sea shipping emissions in port: A Spanish case study	2021	Applied Sciences (Switzerland)	Article	Research (quantitative)	Ro-Pax	Investments and technologies	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Western Europe
38	Mutarraf M.U., Terriche Y., Nasir M., Guan Y., Su C.-	A Decentralized Control Scheme for Adaptive Power-Sharing in Ships based Seaport Microgrid.	2020	IECON Proceedings (Industrial Electronics Conference)	Conference Paper	Research (qualitative-quantitative)	Ferry; port	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	n.a.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
	L., Vasquez J.C., Guerrero J.M.										
39	Ozdemir H., Guldorum H.C., Erdinc O., Sengor I.	Energy management of a port serving fuel cell and battery based hybrid green ferries	2021	SEST 2021 – 4th International Conference on Smart Energy Systems and Technologies	Conference Paper	Research (quantitative)	Ferry; port	Investments and technologies	Ship propulsion system and alternative fuels	Renewable energy sources; Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Western Asia
40	PACE – Process and Control Engineering	Drive technology for a Green ferry	2007	Trade Journal	Article	Conceptual	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Renewable energy sources	Australia
41	Palconit E.V., Abundo M.L.S.	Mapping of the potential sites for electric ferry operation using geographic information system (GIS) for green inter-island transport	2020	40th Asian Conference on Remote Sensing, ACRS 2019: Progress of Remote Sensing Technology for Smart Future	Conference Paper	Research (qualitative-quantitative)	Ferry	Investments and technologies/Impact	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Southeast Asia
42	Pamucar D., Deveci M., Gokasar I., Popovic M.	Fuzzy Hamacher WASPAS decision-making model for advantage prioritization of sustainable supply chain of electric ferry implementation in public transportation	2021	Environment, Development and Sustainability	Article	Literature review	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	Eastern Europe
43	Peder Kavli H., Oguz E., Tezdogan T.	A comparative study on the design of an environmentally friendly RoPax ferry using CFD	2017	Ocean Engineering	Article	Research (qualitative)	Ro-Pax	Investments and technologies/Impact	Ship propulsion system and alternative fuels	Ship/hull/propeller design; Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	n.a.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
44	Philipp R.	Blockchain for LBG Maritime Energy Contracting and Value Chain Management: A Green Shipping Business Model for Seaports	2020	Environmental and Climate Technologies	Article	Research (qualitative)	Ro-Pax	Investments and technologies	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Northern Europe
45	Plessas T., Kanellopoulou A., Zaraphonitis G., Papanikolaou A., Shigunov V.	Exploration of design space and optimisation of RoPax vessels and containerships in view of EEDI and safe operation in adverse sea conditions	2018	Ocean Engineering	Article	Research (qualitative)	Ro-Pax	Investments and technologies/Drivers	Technical solutions for energy and environmental efficiency	Ship/hull/propel ler design	Southeast Europe
46	Qiu Y., Yuan C., Sun Y., Tang X., Yan X.	Impact of photovoltaic penetration factor on the power quality of the photovoltaic system of ships	2018	Harbin Gongcheng Daxue Xuebao/Journal of Harbin Engineering University	Article	Research (qualitative)	Ro-Ro	Investments and technologies	Ship propulsion system and alternative fuels/Technical solutions for energy and environmental efficiency	Renewable energy sources	n.a.
47	Radloff E.	NOx emissions reduction through water injection	2006	Naval Engineers Journal	Article	Research (quantitative)	Ro-Ro	Investments and technologies/Impact	Technical solutions for energy and environmental efficiency	Ballast tank and water injection system	Canada
48	Radloff E., Gautier C.	Engine NOx reduction using charge air water injection	2005	2005 Fall Technical Conference of the ASME Internal Combustion Engine Division	Conference Paper	Research (quantitative)	Shippin g	Investments and technologies/Impact	Technical solutions for energy and environmental efficiency	Ballast tank and water injection system	Canada
49	Rafiei M., Boudjadar J., Khooban M.-H.	Energy Management of a Zero-Emission Ferry Boat with a Fuel-Cell-Based Hybrid Energy System: Feasibility Assessment	2021	IEEE Transactions on Industrial Electronics	Article	Research (quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	n.a.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
50	Ruggiero V.	New approach to the fire risk and firefighting in small ships, as consequence of latest developments in Industry 4.0 for the use of hybrid propulsion.	2021	Procedia Computer Science	Conference Paper	Conceptual	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	n.a.
51	Sæther S.R., Moe E.	A green maritime shift: Lessons from the electrification of ferries in Norway	2021	Energy Research and Social Science	Article	Research (qualitative)	Ferry	Investments and technologies/Drivers	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Northern Europe
52	Sargada P.K., Katara R., Suman L.	Reductions in Fuel Consumption by Implementation of Solar Energy on Watercraft	2017	Journal of Environmental Science and Engineering	Article	Research (quantitative)	Shippin g	Investments and technologies/Impact	Ship propulsion system and alternative fuels	Renewable energy sources	n.a.
53	Symington W.P., Belle A., Nguyen H.D., Binns J.R.	Emerging technologies in marine electric propulsion	2016	Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment	Review	Literature review	Shippin g	Investments and technologies	Technical solutions for energy and environmental efficiency	Renewable energy sources; Electrification, hybrid, fuel cell, battery	n.a.
54	Tang R., Fang Y., Kong Z.	Research on Topological Structure and MPPT Algorithm of Photovoltaic Array in Large Green Ship	2017	Hunan Daxue Xuebao/Journal of Hunan University Natural Sciences	Article	Research (quantitative)	Ro-Ro	Investments and technologies/Drivers	Ship propulsion system and alternative fuels/Technical solutions for energy and environmental efficiency	Renewable energy sources	n.a.
55	Tarkowski M.	Towards a More Sustainable Transport Future—The Cases of Ferry Shipping Electrification in	2021	World Sustainability Series	Book Chapter	Research (qualitative)	Ferry	Investments and technologies/Drivers	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Northern Europe

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
		Denmark, Netherland, Norway and Sweden									
56	Temiz M., Dincer I.	Techno-economic analysis of green hydrogen ferries with a floating photovoltaic based marine fuelling station	2021	Energy Conversion and Management	Article	Research (quantitative)	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Renewable energy sources; Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Canada
57	Tinsley D.	Hydrogen ferry fits Norwegian green agenda	2021	Motor Ship	Article	Research (qualitative-quantitative)	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	Northern Europe
58	Tzannatos E., Papadimitriou S., Koliousis I.	A Techno-Economic Analysis of Oil vs. Natural Gas Operation for Greek Island Ferries	2015	International Journal of Sustainable Transportation	Article	Research (quantitative)	Ferry	Investments and technologies/Impact	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel)	Southeast Europe
59	Vicenzutti A., Mauro F., Bucci V., Bosich D., Sulligoi G., Furlan S., Brigati L.	Environmental and operative impact of the electrification of a double-ended ferry	2020	2020 15th International Conference on Ecological Vehicles and Renewable Energies, EVER 2020	Conference Paper	Research (quantitative)	Ferry	Investments and technologies/Impact	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	Southern Europe
60	Vukić L., Guidi G., Jugović T.P., Oblak R.	Comparison of external costs of diesel, LNG, and electric drive on a ro-ro ferry route	2021	Promet – Traffic – Traffico	Article	Research (quantitative)	Ro-Ro, ferry	Investments and technologies	Ship propulsion system and alternative fuels	Alternative fuel (LNG, hydrogen, low sulphur, biofuel); Electrification, hybrid, fuel cell, battery	Southeast Europe
61	Wang H., Oguz E., Jeong B., Zhou P.	Life cycle and cost performance analysis on ship structural	2018	Progress in Maritime Technology and Engineering – Proceedings of the 4th	Conference Paper	Research (qualitative-quantitative)	Ferry	Investments and technologies/Impact	Technical solutions for energy and environmental efficiency	Ship/hull/propeller design	Western Europe

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
		maintenance strategy of a short route hybrid		International Conference on Maritime Technology and Engineering, MARTECH 2018							
62	Wang H., Oguz E., Jeong B., Zhou P.	Life cycle and economic assessment of a solar panel array applied to a short route ferry	2019	Journal of Cleaner Production	Article	Research (qualitative-quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Renewable energy sources	Western Asia
63	Wang H., Oguz E., Jeong B., Zhou P.	Optimisation of operational modes of short-route hybrid ferry: A life cycle assessment case study	2018	Maritime Transportation and Harvesting of Sea Resources	Conference Paper	Research (quantitative)	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	Western Europe
64	Wang S.	Research on Marine Photovoltaic Grid-connected System Based on Super Capacitor	2021	IOP Conference Series: Earth and Environmental Science	Conference Paper	Conceptual	Ro-Ro	Investments and technologies	Ship propulsion system and alternative fuels	Renewable energy sources	Eastern Asia
65	Winebrake J.J., Wang C.	Optimal fleetwide emissions reductions for passenger ferries: An application of a mixed-integer nonlinear programming model for the New York–New Jersey Harbor	2005	Journal of the Air and Waste Management Association	Article	Research (qualitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Alternative fuel (LNG, hydrogen, low sulphur, biofuel); EGCS	United States
66	Wu J., Xie J.	The Assessment of Fuel Cell for a 100-Seat Ferry Power Application	2021	2021 3rd Asia Energy and Electrical Engineering Symposium, AEEES 2021	Conference Paper	Research (quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	n.a.

#	Authors	Title	Year	Source title	Document Type	Typology	Sector	Category	Sub-category	Specific options	Geographical area
67	Wu P., Partridge J., Anderlini E., Liu Y., Bucknall R.	Near-optimal energy management for plug-in hybrid fuel cell and battery propulsion using deep reinforcement learning	2021	International Journal of Hydrogen Energy	Article	Research (quantitative)	Ferry	Investments and technologies	Technical solutions for energy and environmental efficiency	Electrification, hybrid, fuel cell, battery	n.a.
68	Yadav S., Van Der Blii N.H., Bauer P.	Modelling and Stability Analysis of Radial and Zonal Architectures of a Bipolar DC Ferry Ship	2021	2021 IEEE Electric Ship Technologies Symposium, ESTS 2021	Conference Paper	Research (qualitative-quantitative)	Ferry	Investments and technologies	Ship propulsion system and alternative fuels	Electrification, hybrid, fuel cell, battery	n.a.
69	Zapałowicz Z., Zeńczak W.	The possibilities to improve ship's energy efficiency through the application of PV installation including cooled modules	2021	Renewable and Sustainable Energy Reviews	Article	Research (quantitative)	Ro-Pax	Investments and technologies	Ship propulsion system and alternative fuels/Technical solutions for energy and environmental efficiency	Renewable energy sources	Northern Europe

Source: Author's elaboration.

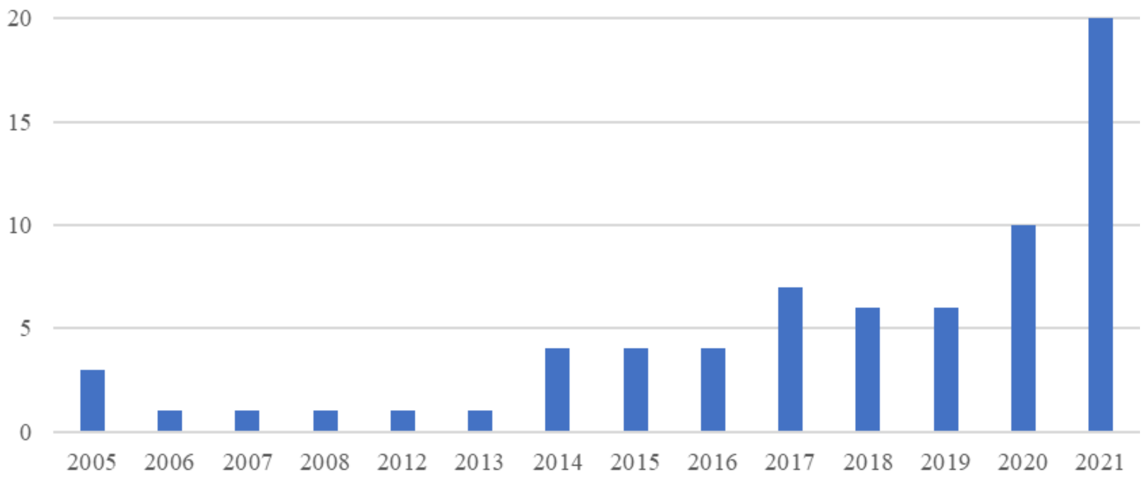
In the next three paragraphs, a discussion of major outcomes and results related to the following issues will be presented:

- spatial and temporal dimensions (Par. 4.2.1), i.e., the most investigated geographical area in the articles, and the temporal distribution of the sample papers (from 2005 to 2021);
- paper type and method applied (Par. 4.2.2), i.e., research papers, conceptual studies and literature reviews;
- sub-category distribution in term of investments and technologies treated (Par. 4.2.3), i.e., technical solutions for energy and environmental efficiency, ship propulsion system and alternative fuels and ballast water treatment systems.

4.2.1 Spatial and temporal dimensions

As concerns the timing of academic publications on green investments and technologies in Ferry, Ro-Ro and Ro-Pax domain, Figure 19 shows the increasing importance assumed by the topic over the recent years. In fact, the attention the issues awarded by academics and scholars has been increasing exponentially over the last 5 years; 49 of the 69 sample studies (71% of the sample), in fact, have been published within the 2017-2021 timeframe and 20 of them (41% of recent studies) in 2021.

Figure 19. Temporal distribution of the sample papers.

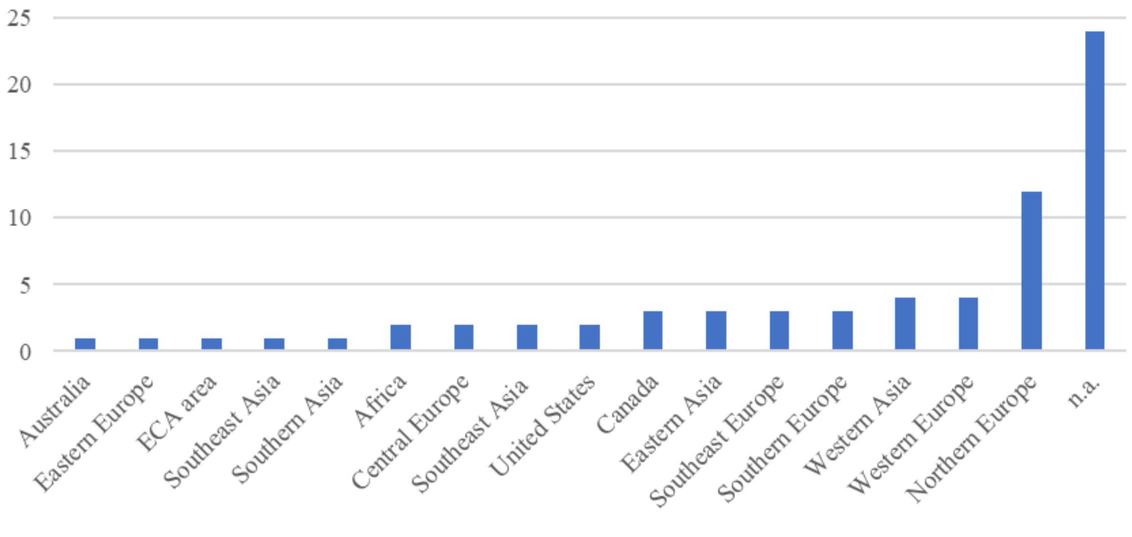


Source: Author's elaboration.

When it comes to the geographic coverage of the analysis, a substantial part of the articles does not consider a specific geographical area (24 of the 69 articles of the sample). Among the remaining 45 articles, the most investigated geographical area was Northern Europe with 12 articles. This result is not surprising as Northern European countries are worldwide recognized as extremely advanced when it comes to environmental sustainability issues. Grouping the geographical areas examined, 25 articles investigate Europe as a geographical area, 12 articles concern Asia area and only 5 articles are related to America. There is also a contribution in which the ECA area constitutes the geographic coverage of the analysis, specifically. The geographical areas examined by the sample and their weight within the study can be appreciated in Figure 20 and in

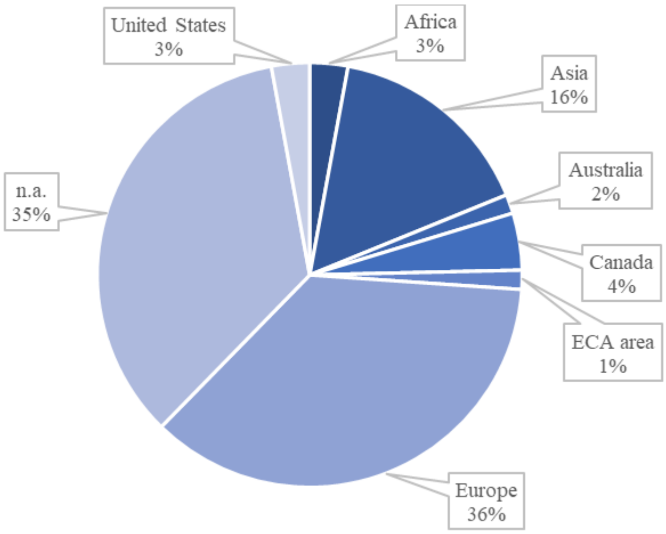
Figure 21 (grouping geographical areas into macro-categories).

Figure 20. Geographical distribution of the sample papers.



Source: Author's elaboration.

Figure 21. Geographical distribution of the sample papers (macro-categories).



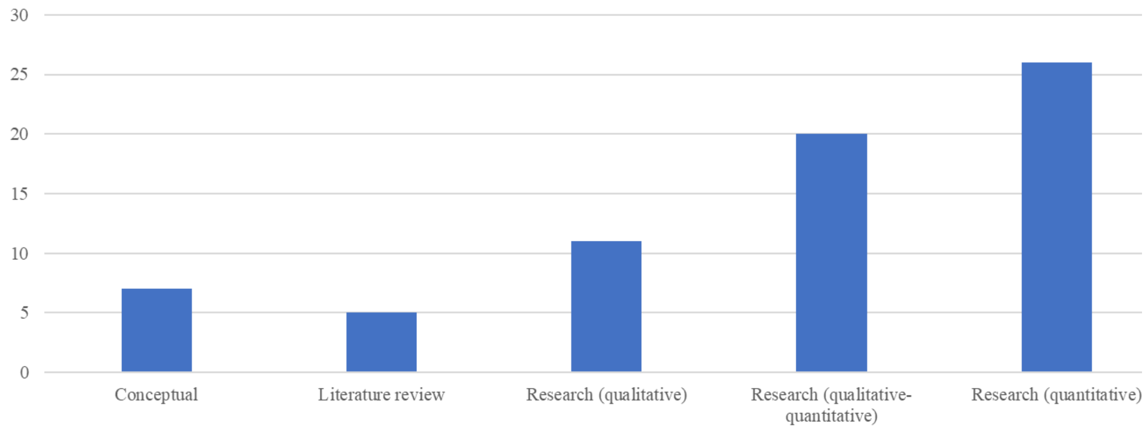
Source: Author's elaboration.

4.2.2 Paper type

As regards the paper type predominantly used by academics and scholars in the sample manuscripts (Figure 22), research papers clearly dominate the scene (83% of the sample), whereas both conceptual studies (10%) and literature reviews (7%) constitute only a residual proportion of the whole sample. Unsurprisingly, pure quantitative research papers outnumber pure qualitative ones (38% vs. 16% of research papers): in 20 cases in research papers (29%), the authors combine qualitative and quantitative methods for enriching their investigation. In Table

6 it is possible to identify the research method adopted by the authors as part of the empirical papers under examination.

Figure 22. Paper type distribution.



Source: Author's elaboration.

Table 6. Research method used by the authors.

Research method	***N° of papers***
Research (mixed qualitative-quantitative)	20
Research (quantitative: comparative analysis)	11
Research (qualitative: case study analysis)	9
Conceptual	7
Literature review	5
Research (quantitative: case study analysis)	3
Research (quantitative: feasibility analysis)	2
Research (quantitative: LCA analysis)	2
Research (quantitative: regression analysis)	2
Research (quantitative: simulation analysis)	2
Research (qualitative: comparative study)	1

Research (qualitative: stochastic analysis)	1
Research (quantitative: calculation methodology)	1
Research (quantitative: Data Driven Design approach)	1
Research (quantitative: Dynamic process simulation model)	1

Source: Author's elaboration.

Within this PhD thesis, the main outcomes related to empirical contributions are examined. About 60% of the research papers provides concrete results regarding the impacts of one or more examined technologies, especially in terms of reduction of operational costs, emissions and bunker consumption. About 12% of the empirical contributions focus their research on the main insights useful for comparing different technologies and investment options that are treated along the paper, to select the most suitable one for the study. Moreover, about 9% of empirical studies provides an exhaustive list of elements and issues that can affect and influence the development of the technology and investment options that are examined in the contribution. On the other hand, many studies focus on practices and tools for optimizing the use and the impact deriving from the adoption of the investment options and technologies analysed in the papers.

4.2.3 Sub-category distribution

Referring to the category "investments and technologies", subcategories of investment options and technologies implementable by companies operating in the Ferry, Ro-Ro and Ro-Pax sectors in order to reduce their environmental impact have been mapped.

In this context, it is possible to notice a predominance of the subcategory that gathers the technical solutions for energy and environmental efficiency, representing 53% of the sample. Secondly, the subcategory concerning ship propulsion system and alternative fuels represent the 43% of the "investments and technologies" category. In the sample, six studies (that represent the 9% of the "investments and technologies" category) have been assigned to both subcategories "ship propulsion system and alternative fuels" and "technical solutions for energy and environmental efficiency". Furthermore, those articles focus their studies not on a single technology but provide an overview of multiple technical solutions applicable to the Ferry, Ro-Ro and Ro-Pax sector (Table 7).

Table 7. Investments and technologies discussed in the sample contributions.

Investment and technologies	N° of papers*
Technical solutions for energy and environmental efficiency	39
Ship propulsion system and alternative fuels	32
Ballast water treatment systems	3

* For each paper, more than an investment/technology could be flagged.

Source: Author's elaboration.

Through the systematic literature review that has been performed for the aim of this PhD thesis, it was possible to provide an overview of the main investment options and technologies for pursuing an emission reduction in the Ferry, Ro-Ro and Ro-Pax sector. In fact, in the following paragraphs the subcategories of the abovementioned technologies will be examined, with a specific focus on electrification, hybrid ship, fuel cell, batteries installation onboard (44.93 % of the sample), renewable energy sources (26.09% of the sample) and alternative fuel (23.19% of the sample) because, as resulting from the analysis of the main academic contribution on the issue, together they represent the technical investments options with the greatest activation potential (around 94% of the sample) for the Ferry, Ro-Ro and Ro-Pax sectors (Table 8).

Table 8. Specific investments options discussed in the sample contributions.

Specific investments options	N° of papers*
Electrification, hybrid, fuel cell, battery	31
Renewable energy sources	18
Alternative fuel (low sulphur, LNG, biofuel, methanol, hydrogen)	16
Ship/hull/propeller design	10
Water treatment system	3
Exhaust Gas Cleaning System	3

* For each paper, more than an investment/technology could be flagged.

Source: Author's elaboration.

Figure 23 shows a graphical representation of main categories of green investment options (as in the Table 8), that have been defined from case studies in literature and business practices:

- electrification, hybrid, fuel cell, battery (batteries, fuel cell and cold ironing);
- renewable energy sources (solar panel and wind power);
- alternative fuel (LNG, biofuel, methanol, hydrogen);
- ship/hull/propeller design (hull air lubrication, new bulbous bow, antifouling paints);
- water treatment systems (ballast tank and water injection system);
- exhaust gas cleaning system (dry and wet scrubber).

Figure 23. Graphical representation of specific investments options.

Electrification, hybrid, fuel cell, battery	Renewable energy sources	Alternative fuels	Ship / hull / propeller design	Water treatment systems	Exhaust Gas Cleaning Systems
Batteries	Solar panel	LNG	Hull air lubrication	Ballast tank	Dry scrubber
Fuel cell	Wind power	Biofuels	New bulbous bow	Water injection system	Wet scrubber
Cold ironing		Methanol	Anti-fouling paints		
		Hydrogen			

Source: Author's elaboration.

4.2.4 Main current literature gap

The worldwide growing concern about climate change is leading industries to adopt measures to reduce negative externalities. Within this scope, also shipping companies operating in Ferry, Ro-Ro and Ro-Pax industry are increasingly aware of the social and environmental impacts caused by their operations, making the identification of appropriate and sustainable investments and strategies particularly urgent for the industry. Nevertheless, the nature and intensity of the adoption of green and sustainable solutions by Ferry, Ro-Ro and Ro-Pax companies is still scarcely investigated by academics. In this vein, this PhD thesis sets two objectives in order to fill in the existing literature gap. In line with the research objective n. 1, the fifth Chapter of this PhD thesis deepens the technical solutions and investments options that emerged in the literature review as the main opportunities for Ferry, Ro-Ro and Ro-Pax companies. As emerged from the systematic literature review conducted in this PhD thesis, the green investments options most widely analysed in the Ferry, Ro-Ro and Ro-Pax industry by scholars and academics in the sample contributions consist in electrification, hybrid, fuel cell, battery (as emerge by Table 8). Obviously and accordingly to the research objective n. 2, this proposed model, with its gap and lacks from the point of view of the existing literature review on the issues, will be applied to major Ferry, Ro-Ro and Ro-Pax companies, in order to assess the current state of the art in the industry as well as the real commitment of companies in pursuing green strategies.

As emerged by previous paragraph, the systematic literature review that are conducted in this PhD thesis came from through ad hoc queries using different keywords coherently with the focus of the study. Some queries are tested in order to identify the right one, because of the scarcely investigation by academics and scholars on these issues. In addition to identifying in the query the issues related to sustainability ("green", "sustainability", "environment") and the keywords related to aim and the purpose of green strategies ("emission", "energy", "impact"), also the sector covered by this thesis is introduced ("ferry", "ro-ro", "ro-pax", "roro", "ropax"). To this last field it has been necessary to also add the entire sector of the passenger transport as the extracted scientific contributions were scarce.

In this vein, 350 academic papers were identified as eligible as a result. The initial dataset has been then scrutinized and many non-pertinent studies have been excluded from the sample, obtaining only a shortlist of 98 potentially relevant papers. In this specific step the main current literature gap clearly shows that extant literature does not address specific challenged for ferry, Ro-Ro and Ro-Pax industry. This gap is also strengthened following the classification of papers by topic into sub-categories ("impact", "drivers", "investments and technologies", "green strategies" and combinations of them), aiming at identifying which contributions of academics and scholars are focused on green strategies in the industry. Obviously, for this PhD thesis and the related purposes, a special attention has been paid exclusively on articles falling within the "investments and technologies" category, which constitute the final sample.

Indeed, the existing literature on such issues focuses mainly on green practices and sustainable investment options that transport and shipping companies can generally access to pursue sustainable growth and emission reduction goals. In this vein, through in-depth analysis of different green practices and sustainable investment options that Ferry, Ro-Ro and Ro-Pax companies can implement to pursue environmental sustainability and emission reduction objectives, this PhD thesis tries to fix the literature gap on the green, sustainability and environment-related issues and to energy efficiency, emission and environmental impact reduction in the industry. In this vein, this PhD thesis contributes to extant literature by applying a technical and pragmatic approach to bridging some knowledge gaps concerning the role of green strategies in Ferry, Ro-Ro and Ro-Pax industry. The analysis of the most valuable green alternatives for the industry also providing best practices for managers and policy makers, provides useful insights for increasing eco-efficiency levels in shipping operations, thus contributing to improve the relationship between ports, shipping companies and local communities.

This fourth Chapter proposed a systematic literature review aimed to investigating data and findings of other authors and academics concerning green, sustainability and environment-related issues and to energy efficiency, emission and environmental impact reduction in the Ferry, Ro-Ro and Ro-Pax industry. The results (69 academic papers under examination) are commented related to spatial and temporal dimensions, geographical area, paper type and method applied and to sub-category distribution in term of investments and technologies treated. This analysis leads to say that the investments options most widely analysed in the Ferry, Ro-Ro and Ro-Pax industry by academics and scholars in the sample contributions are the electrification, hybrid, fuel cell, battery.

The fifth Chapter deepens the technical solutions and investments options that emerged in the systematic literature review as the main opportunities for Ferry, Ro-Ro and Ro-Pax companies aimed at reducing their environmental impact and pollutant emission. In each next paragraphs, all technical solutions and investments options are extensively deepened, supported both by scholars and academics in the sector, and then by the real feasibility of these technology and investment options in the Ferry, Ro-Ro and Ro-Pax industry, with a specific focus on the European companies.

CHAPTER 5

GREEN INVESTMENT OPTIONS IN FERRY, RO-RO AND RO-PAX INDUSTRY: STATE OF THE ART

5. Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the art

The fifth Chapter of this PhD thesis examines in detail the technical solutions and investments options that emerged from the review of the main extant academic literature (performed in the fourth Chapter) as the main opportunities for shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry in order to pursue the objectives of containment of environmental impacts, thus ensuring the sustainable growth of the segment.

As emerged from the systematic literature review (cf. fourth Chapter) and as reported in Table 8, the technical solutions and investments options most widely adopted by the sector consist in electrification, hybrid, fuel cell, battery. Following, the subcategories related to renewable energy sources and that of alternative fuel (LNG, hydrogen, low sulphur) result to be among the most popular solutions aimed at greening the sector. The topic of ship/hull/propeller design (technologies such as hull air lubrication, the improving the design of bulbous bows, etc.) is addressed in 10 of 69 contribution of the sample. Furthermore, investments options related to ballast tank and water injection systems are outlined in only 3 contributions of the sample, since this technical solution is mainly employed by oil tankers during ballast voyages along their route. Conversely, solutions as Exhaust Gas Cleaning Systems are treated in only 3 contributions within the sample probably because of the widespread use of scrubbers on Ferry, Ro-Ro and Ro-Pax ships, above all, conditioned by the IMO Low Sulphur Cap. However, there are still innovations and cutting-edge technologies recently introduced in the field of Exhaust Gas Cleaning System that are treated in this PhD thesis in the next paragraphs. In Table 9, a summary of the main different drivers and barriers selected for each green investment option in Ferry, Ro-Ro and Ro-Pax industry that is analysed within fifth Chapter of this PhD thesis.

Table 9. Main drivers and barriers for each green investment option

	Drivers	Barriers
Electrification, hybrid, fuel cell, battery		
	Great opportunities to reduce at berth emissions and improve the air quality in port areas, high conversion rates of energy efficiency.	*The voyage distance; the need to recharge batteries in port and use lightweight materials for reducing the weight of electric ships; the energy regulations are not supportive enough to effectively enable the shift towards green energy, in reason of the taxation of green energy; crews require training to familiarize with the technical, operational, and safety issues of the system.*
Renewable energy sources		
	More stringent regulations from IMO to reduce GHG emissions for the global shipping industry.	*Need of a lot of onboard space (limited ship dimensions); higher costs.*
Alternative fuels		
	The improvement of the company reputation and image towards customers, who have become increasingly sensitive to "green" issues.	*Higher price compared to traditional fuels (HFO and MDO) that is even higher for advanced biofuels.*
Ship / hull / propeller design		
	The design of the ship in term of dynamic structure and construction material empathizes the effects on the ship from an operational and environmental impact perspective, contributing to the energy efficiency of the ship as to the reduction of consumption and environmental emissions.	*Actions that alone do not allow significant emission reductions.*
Water treatment systems		
	Growing focus on preserving and protecting the marine ecosystem, adoption of physical disinfection technology for treatment of ballast water.	*Technical solution mainly used for oil tankers during ballast voyages along their route.*
Exhaust Gas Cleaning Systems		
	Sulphur emission and PM reduction 5 times lower than limits required by law.	*All scrubbers emit nitrates, PAHs, and heavy metals that accumulate in the environment and food web and can negatively affect both water quality and marine life.*

Source: Author's elaboration.

5.1 *Electrification, hybrid, fuel cell, battery*

The subcategory "Electrification, hybrid, fuel cell, battery" is treated in 31 of 69 articles and contributions of the sample, it is the most investigated and discussed topic in the sample (cf. fourth Chapter); indeed, it is the most promising technological-technical solution for the future in the Ferry, Ro-Ro and Ro-Pax industry.

According to several studies (Bassam et al., 2016; Banaei et al., 2020), the utilization of green energy sources to provide power to ships has received increasing attention over the last years, where different green resource combinations and control strategies have been discussed and implemented. Specifically, electrification, exploiting advanced technologies and instruments characterized by a very high level of innovation such as batteries, fuel cells, photovoltaic systems and Cold Ironing, allows to drastically reduce harmful emissions attributable to ship operations, qualifying as the most promising solution for the achievement of the zeroing of emissions generated by ships (Bosich et al., 2020).

At present, the examined technologies are still at an embryonic stage and need further research and development to be fully applicable to the shipping industry as a whole. Despite this, for the Ferry, Ro-Ro and Ro-Pax segment, they already represent a concrete solution, due to their distinctive characteristics. In this respect, electricity can be used onboard Ferry, Ro-Ro and Ro-Pax ship units by using hybrid engines that combine traditional diesel propulsion with electric propulsion, or by using electric propulsion alone. However, the mere use of electricity as a source of propulsion is not sufficient to ensure better environmental performance. This stems from the fact that electricity is often produced by diesel generators which, when connected to alternators, produce electricity, generating a substantial negative impact in environmental terms. Therefore, the use of new technologies in electrification is an essential factor to achieve an effective decarbonization of the sector, making it possible to produce and store electricity without the use of fossil fuel and with a consequent mitigation in polluting emissions.

Despite the great importance of the electrification, there are certain challenges that currently hinder the successful implementation of this technology in the Ferry, Ro-Ro and Ro-Pax industry. These barriers are related not only to technical and operational issues, but also to legal and human factors (Anwar et al., 2020). The technical issues are related to the voyage distance (especially in fully electric ferries), the specialized electrical infrastructure needed to recharge batteries in port, the need to use lightweight materials for reducing the weight of electric ships (such as carbon fiber). As regards legal challenges, energy regulations are not supportive enough to effectively enable the shift towards green energy; this in reason of the taxation of green energy while hydro-carbon fuels are exempt, in many EU countries. Finally, Ferry, Ro-Ro and

Ro-Pax crews require training to familiarize with the technical, operational, and safety issues of the new system (Kim et al., 2020).

Several studies refer to ferry electrification (E-ferries) as a great opportunity for potential economic savings and environmental conservation when compared with traditional diesel, diesel-electric and, to a lesser extent, LNG-powered ferries (Berntsen et al., 2021). These studies concern the operative activities of electric ferries in different geographical areas, such as Philippine (Palconit and Abundo, 2020), Norway (Sæther and Moe, 2021), Denmark and Sweden (Tarkowski, 2021).

5.1.1 Batteries

According to several studies and research in the sample, the basic concept of hybrid propulsion is the use of battery packs to store energy and consequentially operate the ship propulsion system for a zero-emission navigation (Ruggiero, 2021). Batteries are devices that transform chemical energy into electricity through an electrochemical reaction of reduction and oxidation (redox[33]). Electric propulsion with energy stored in a battery can originate either from charging from shore connection during a stopover, from charging the battery with the main engines driving a generator, or from generating electricity by recovering thermal energy from on board waste heat sources (Lümmen et al., 2018).

Conventionally, two types of batteries can be distinguished: there are primary batteries, which cannot be recharged electrically, and secondary batteries that, on the contrary, can be charged by electricity. With specific reference to rechargeable batteries, today the most mature technology concerns lead-acid batteries: this type of batteries has the advantage of being economical, but the disadvantage of having low specific energy and energy density. Marine propulsion has some similarity with land vehicle propulsion, but the application has its unique characteristics and challenges (Dong, 2020): the shipping industry needs large and heavy batteries to achieve a sufficient amount of energy to allow the propulsion. (Symington et al., 2016).

For this reason, the batteries with the greatest application potential in the Ferry, Ro-Ro and Ro-Pax industry are lithium-ion batteries. These batteries have technical specifications suitable for application in ship propulsion: a nominal voltage of each cell equal to about 3.7 volts

[33] With redox there is electron transfer: the atom that loses them (acquiring positive charges) is oxidized and constitutes the reducing agent, while the atom that buys them (acquiring negative charges) is reduced and constitutes the oxidizing agent.

(compared to 1.2 volts of Nickel Cadmium batteries), higher specific energy and higher energy density, a number of life cycles of about 5,000 and a particularly high efficiency, ranging between 95% and 98%. Lithium-ion batteries can store high quantities of energy and provide it to the propulsion systems (that usually operate with high voltage – 660 V or more) to guarantee adequate efficiency at the system (Ruggiero, 2021). The main limits related to lithium-ion batteries consist in the high purchase cost, equal to more than 600$/KWh per each battery, as well as some safety problems caused by the instability of the electrodes when exposed to high temperatures (Mutarraf et al., 2020) with the risk of explosion in case of overheating (Ruggiero, 2021).

The use of batteries as a source of energy, especially with additional technologies such as Fuel cell, photovoltaic (PV), Cold Ironing (Buitelaar, 2014; Rafiei et al., 2021, Wu et al., 2021), is already a solution implemented by shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry.

Under this profile, the Norwegian company Fjord1 ASA owns 17 Ro-Pax ships, aged between 3 and 1 year, which entered into service between 2019 and 2021 in North Sea and in Norwegian Sea, equipped of on-board batteries for propulsion, to reduce emissions both in port and during navigation. As verified by this PhD thesis, also another Norwegian company, i.e., Norled AS, holds 9 Ro-Pax ships, entered in operation between 2020 and 2022, with on-board batteries for propulsion. Also Norled AS's ships operates among the North Sea and the Norwegian Sea, as Fjord ASA's fleet. In addition to the above-mentioned Norwegian group owners, the Italian-based Grimaldi Group SpA also owns 6 Ro-Pax ships that have been commissioned and are currently under construction: the technical plans of the 6 commissioned ships include the installation of on-board batteries for propulsion.

5.1.2 Fuel cell

Although the use of batteries is an interesting solution in terms of reducing the ship consumption and related harmful emissions, today their use as the sole source of energy is rather complicated, as it would result in a loss of the overall ship efficiency due to the non-negligible weight of the batteries, and it would also be difficult to guarantee a full recharge of the same duration as the port stops (Banaei et al., 2020). Several studies and research included in the sample sustain that it is fundamental to combine their use with other technologies to satisfy the ship's energy needs while generating of lower environmental impacts. In this perspective, a highly innovative solution is represented by the joint use of batteries and fuel cells (Banaei et al., 2020), also to cover the fast load variations (Anwar et al., 2020). The combined use of the two solutions appears preferable in several respects. First, the use of a single energy resource decreases the reliability of the operation, especially for a ferry ship, which operates as an isolated microgrid during sailing and carries many passengers. Secondly, the energy density and specific energy of fuel cells are higher than the one of batteries. This leads to a considerable increase in weight of the ship if only batteries are used to provide the required energy for the ship (Anwar et al., 2020).

As investigated and discussed in several studies in the sample, among different types of clean energies, FC is an interesting source of power generation to meet the load demand of the Energy Management Strategy (EMS). Furthermore, FCs are widely considered as the electric power supply that causes no emission and GHG (Pamucar et al., 2021). Generally, the system operation of the FCs is based on a transformation process, wherein the chemical energy is converted into electrical power (Letafat ET AL., 2020).

Fuel cells are electrochemical cells capable of converting the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electrical energy, through redox reactions. Fuel cells include Acid Fuel Cells (AFC), Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells (SOFC). With specific reference to Acid Fuel Cells, the Proton-Exchange Membrane Fuel Cell (PEMFC) represents a particularly relevant solution as it is the most suitable type for the propulsion of Ferry, Ro-Ro and Ro-Pax ship (Wu and Xie, 2021). More specifically, PEFMCs have the advantage of operating at low temperatures without electrolytic[34] loss, are characterized by a rather long-life cycle, have a significantly high specific energy and are able of providing up to 500 KW of power (Senčić et al., 2014).

Compared to traditional energy sources, the use of fuel cells has the following advantages (Wu and Xie, 2021).

- High conversion rates of energy efficiency: average efficiency between 40 and 50% with the possibility of reaching 60%.
- Zero emissions of sulphur oxides and nitrogen (it is possible to refer to "zero-emissions"): hydrogen and methanol fuel cells emit only water and carbon monoxide and do not require combustion processes at high temperatures.
- Fuel cells can use different fuel sources, such as hydrogen, methanol and natural gas, so there is no risk of fuel shortages.

[34] The dynamic fuel cell system is a multistage thermodynamic device that converts the energy of chemical reaction directly into electricity and heat, thus producing power efficiently at a finite rate and in an irreversible way (Energy Optimization in Process Systems, 2009).

Despite the above-mentioned benefits and advantages, the use of such technology presents, however, several problems (Wang et al., 2018) which can be overcome through the continuation of scientific studies on the solutions treated and the increase of investments in research and development (Wu and Xie, 2021). These issues concern:

- safety, because the fuel cells system integrates thousands of individual cells to generate energy that is "only" sufficient, even if vibrations and oscillations due to wave motion can cause the internal imbalance of fuel cells;
- technical performance, such as the dynamic response speed of fuel cells which is significantly lower than that of traditional diesel engines, and the useful life of fuel cells, which does not exceed 5,000 hours on average and the need for use in in very low temperature environments, which is currently impossible;
- high supply costs, because of the expensive construction materials, such as platinum.

In 2021, the world's largest liquid hydrogen powered ferry unit entered in service using Proton-Exchange Membrane Fuel Cell (PEMFC); i.e., the MV Hydra, owned by the shipping company Norled A/S. The ship is able to transport up to 300 passengers and 80 cars and will be fed by two fuel cell modules from 200 KW each supplied from the society Ballard Power Systems Inc.

It is important to make a distinction between the various types of methanol potentially usable like fuel from the shipping industry. There is a distinction between green, blue, grey and brown methanol: the green methanol is made from biomass or captured CO_2 and green hydrogen, the blue methanol is made using blue hydrogen in combination with carbon capture technology, the grey methanol is produced using natural gas while the brown methanol is produced using coal. Among them, the green methanol is the most environmentally sustainable. Blue methanol still significantly reduces well-to-tank CO_2 emissions compared to fossil fuels like diesel. Despite this, the most methanol today is either grey or brown, and this is one of the biggest challenges for maritime decarbonisation. All types of methanol could lead to a tank-to-wake CO_2 reduction of about 7% compared to diesel (Wärtsilä). However, considering the well-to-wake approach (from production to utilisation), the CO_2 impact of grey and brown methanol is worse than that of diesel. This is why green and blue methanol are the only real alternatives when targeting well-to-tank GHG reduction. Green methanol combustion reduces emissions compared to diesel and a conversion can help to improve the EEXI and CII ratings. In case of newbuilding vessel, the use of green methanol can help to achieve better EEDI and CII values. The green methanol is one of the best available options to meet current and future emissions targets and will also reduce the overall greenhouse gas emissions of the industry (Wärtsilä).

5.1.3 Cold Ironing

According to the sample of contributions, electrification of the maritime industry is one of the main ways to improve the efficiency of ship operation (Bouman et al., 2017). Several studies sustain that the future electric ship architecture is expected to be based on DC[35] (direct current, i.e., a one-directional flow of electric charge.) (Yadav et al., 2021). This is due to a number of advantages that characterize the aforementioned technology: lower losses due to the absence of reactive power and skin effect in DC; reduced size of passive components because of high frequency power conversion, and easier integration of renewable energy resources since batteries and photovoltaic produce DC power (Kim et al., 2018). Compared to a unipolar DC grid, a bipolar DC grid has many advantages, which can be summarized as follows (Van Den Broeck, 2019):

- an higher power transmission capacity per mm^2, compared to a unipolar grid, since in a bipolar grid three conductors are required instead of four to transfer the same amount of power at the same voltage;
- a single voltage level in the system;
- higher robustness than that of a unipolar grid because the latter can still function with half power capacity when there is a fault on one of the poles.

The implementation of bipolar DC grids on ships is quite limited, also due to the lack of information and commercially available components (Yadav et al., 2021).

According to the sample contributes, for companies operating in the Ferry, Ro-Ro and Ro-Pax industry, one of the most promising solutions to achieve an effective reduction of their consumption and, consequently, of pollutant emissions, is the so-called Cold Ironing. Specifically, the Cold Ironing is an innovative technology that allows the ship to be powered when it is stationary in port, at berth and with the engines switched off. Power is supplied through electricity produced ashore via an electric cable, enabling both the continuation of loading/unloading operations on/from the ship and the maintenance of all on-board services for passengers (Letafat et al., 2020).

Usually, when a ship is berthed, the main engines are switched off and only the auxiliary engines are used to provide the ship with the necessary electricity for lighting, heating, hot water, etc. However, such operations cause significant fuel consumption, and consequently, the production of several amounts of exhaust fumes as well as noise and vibration that are particularly

[35] The DC distribution system has been proposed, as a replacement for the present AC power distribution system for ships with electric propulsion. This represents a new way of distributing energy for low-voltage installations onboard ships. It can be used for any electrical ship application up to 20 megawatts and operates at a nominal voltage of 1000 V DC.

harmful not only to the environment, but also for the health of port workers and the inhabitants of the areas surrounding the port. Through Cold Ironing, it is possible to reduce such pollution factors, causing positive effects on the environment and the health of people living in port areas.

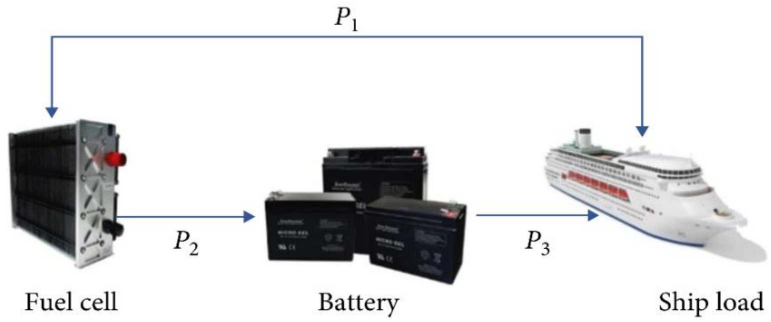
The recharging process of the ship batteries is performed using Cold Ironing (Vukić et al., 2021). The sources of the produced electricity will determine the impact of electrification on the ship emissions and environment: in order to accomplish the complete zero-emission and reach sustainability goals, the power required to operate cold ironing technology should derive from renewable energy sources, which are cleaner when compared to the fossil ones (Davarzani et al., 2016).

In Europe, one of the first infrastructures required for Cold Ironing was installed in the port of Gothenburg (Sweden), where two terminals dedicated to the berthing of Ferry and Ro-Ro ships were equipped with the necessary electrical connections to carry out Cold Ironing operations. The Gothenburg Port Authority reported a reduction of 80 metric tons of NOx, 60 metric tons of SOx and 2 metric tons of PM per year for the ships using Cold Ironing in port (Zis, 2019).

With a specific reference to Italy, the National Recovery and Resilience Plan or Recovery Plan (NRRP) allocated 700 million euros to investments related to Cold Ironing on the national territory. Such financial resources will allow the introduction of Cold Ironing in 34 Italian ports, of which 32 belong to the TEN-T network, such as ports of La Spezia, Civitavecchia, Naples, Salerno, Taranto, Ancona, Ravenna, Venice and Trieste (NRPP, 2021). In this way, it seems opportune to specify how the Port of Genoa has set itself up as a "precursor" and "pilot case", having already provided for the electrification of part of the infrastructures and having also set appropriate plans for the complete electrification of the passenger and cargo terminals.

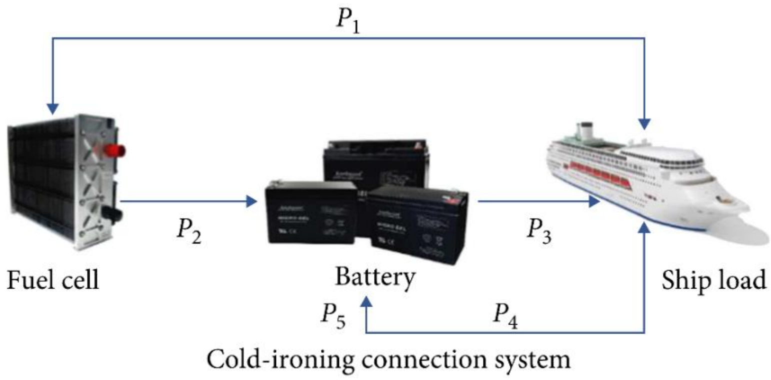
As mentioned by Leftat et al. (2020), the power flow of the ship through batteries, FCs and Cold Ironing are represented separately when the ship is sailing and when it is in port. Figure 24 indicates the power flow of the system when the ship is sailing. P1 is the power generated by the FCs that is consumed by the ship loads. P2 is the power generated by the FCs that is charged in the batteries. The sum of P1 and P2 represents the total power generated by the FCs. Instead, P3 is the power discharged by the batteries to the ship loads. When the ship is at the berth, the Cold Ironing can also be performed (Figure 25). P4 represents the power consumed by the ship loads through the Cold Ironing and P5 represents the stored energy in the batteries through Cold Ironing.

Figure 24. The topology of the fuel cell-battery- ship's load (ship during navigation).



Source: Leftat et al., 2020.

Figure 25. The topology of the fuel cell-battery-cold ironing (ship in port).



Source: Leftat et al., 2020.

5.2 Renewable energy sources

The use of non-clean energy sources such as fossil fuels poses a major threat to the environment and a crucial contributor to climate change. With the quick economic development, the energy demand and conventional fuel consumption steadily increased, generating a growth in the pollution and environmental impacts. For this reason, many worldwide companies are now turning to renewable sources like solar, wind, hydroelectric, biomass, and geothermal energy to produce clean energy and to reduce emissions (Aboud et al., 2021).

Within the maritime industry, that, among all other industries, is being forced to gradually reduce its emissions (Koumentakos, 2019), this trend is confirmed also in the Ferry, Ro-Ro and Ro-Pax sector: the subcategory "Renewable energy sources" is treated in 18 of 69 articles and contributions of the sample. In particular, a further interesting solution for the Ferry, Ro-Ro and Ro-Pax sector consists in the use of wind and solar propulsion.

Both solar and wind energy offer fuel-free power production without any emissions for auxiliary services, while a ship is in operation, both at berth and at sea (DNV, 2012 and IRENA, 2015). They have received quite a bit of interest despite having been implemented only to a limited extent, because of their high level of complexity in terms of design and operation which, in turn, influences implementation cost led to a high abatement cost per ton of CO_2. According to DNV (2012), solar panels and wind generators show the highest cost per tonne of CO_2 averted (i.e., more than USD 200/tonne) and considered for auxiliary power only, they show the lowest contribution to the total CO_2 potential abatement reduction (in millions of CO_2 tonnes/year)[36].

5.2.1 Solar Panel Power

Referring to the use of solar energy as a source of propulsion, several studies in the sample demonstrated that the most mature technology is represented by photovoltaic (PV) systems (Sargada et al., 2017; Faturachman et al., 2021). PV systems are electrical systems with assembly of several photovoltaic modules that exploit solar energy to produce electricity. The production of energy through photovoltaic panels is considered "environmentally friendly" because it is free of polluting emissions, both from an environmental and acoustic point of view (Lutful et al., 2017).

According to several studies and research in the sample (Wang et al., 2019; Wang, 2021). Today, there are two types of integration of photovoltaic systems into the ship's electricity network, namely "off-grid" and "grid-connected". The "off-grid" photovoltaic system is not directly connected to the power grid of the ship since, after capturing solar radiation, it directly transforms solar energy into electricity that is stored in energy storage devices, generally represented by lithium-ion batteries. Conversely, the photovoltaic system "grid-connected" converts solar power into direct current (DC) generated by the system into alternating current, which is directly integrated into the ship's electrical network (Wang, 2021).

Recently, Khresna and Yanuar (2019) carried out an analysis of the costs incurred and the related savings after the substitution of two diesel engines with a photovoltaic-diesel hybrid engine on a Ro-Pax ship operating between the ports of Merak and Bakauheni, Indonesia. The

[36] Research for TRAN Committee – The EU Maritime Transport System: focus on ferries.

photovoltaic system consists of 577 solar panels of 22 kg each for a total of 12,694 kg; each solar panel has a maximum output power of 250 W, and it operates with an efficiency of 18.07%. In this system, in addition to the PV system, a battery is also installed, to store the excess energy generated by the photovoltaic system. The costs incurred for the installation of the system can be appreciated in

Table *10*. As a result of the introduction of the hybrid system and the reduction of maintenance costs, the reduction of annual fuel consumption of the ship and the consequent reduction of costs as well as the return-on-investment time can be appreciated in Table 11. Considering the abundance of solar radiation in the concerned area, the installation of photovoltaic on the ship can generate 0.83 MWh/day and fuel reduction around 638,352 litres annually. This study results in savings of approximately US 3,019,918.76 yearly and identifies the breakeven point in 10.5 years (Khresna and Yanuar, 2019).

Table 10. Installation cost of the PV system.

	Capacity (Watt)	Total Installation Price ($)
PV modules	83,721.92	183,242.62
PV modules Installation	83,721.92	83,721.92
Installation kit, Mounting, and Support System	83,721.92	61,954.22
Battery	16,800	2,691,000
Total Cost		3,019,918.76

Source: Khresna and Yanuar, 2019.

Table 11. Costs and return-on-investment time of the new hybrid system.

	Unit	Cost ($)
Annual Fuel Consumption	1,276,704 L	549,212.4
Engine Maintenance	2 AE	17,438.2
Fuel Reduction by Hybrid System	638,352 L	274,606.2
Engine Maintenance Cost Reduction	1 AE	8,719.1
Total Cost Reduction (Yearly)	1 AE	283,325.3
PV System Installation Cost	557	3,019,918.76
Return Period		10.5 Years

Source: Khresna and Yanuar, 2019.

The Grimaldi Group has recently taken delivery the tenth Grimaldi Green 5th Generation Ro-Ro class, a class comprising the world's largest environmentally friendly Ro-Ro unit for short sea shipping. This ship unit, i.e., the MV Eco Mediterranea, is equipped with an "off-grid" photovoltaic system consisting of 350 square meters of solar panels to recharge the mega lithium batteries for a total power of 5MWh. The combined use of batteries and the photovoltaic system allows for zero-emissions port calls, with obvious positive effects on air quality in port areas, and reduces the overall emissions generated by the unit in its operations.

5.2.2 Wind Power

Among innovative propulsion systems, according to the sample contributes, wind energy is regarded as one of the most promising alternative energy sources in the maritime sector (Rehmatulla et al., 2015; Aboud et al., 2021). Regarding the use of wind energy as a source of marine propulsion, several studies have been carried out with the aim of developing new methods and technologies for the use of wind energy in the specific Ferry, Ro-Ro and Ro-Pax sector. Under this profile, the study conducted by the Transportation Sustainability Research Center of the University of Berkeley is particularly interesting, which installed a carbon fiber wing sail on a 14-metre ferry operating in San Francisco Bay. With a continuous monitoring of data, it emerged that the use of this technology can ensure a reduction in fuel consumption ranging from 25 to 40% (depending on wind conditions), with a direct and proportional reduction of GHG and air pollutants emitted as well as fuel costs (Lipman and Lidicker, 2019).

Among the innovative propulsion systems, wind energy is considered one of the most promising alternative energy sources in the maritime sector. The abatement potential resulting from the application of wind technologies on ships is estimated at around 10-60% (Rehmatulla et al., 2015) and specifically between 1% and 50% in terms of CO_2 reduction (Bouman et al., 2017). In addition, Smith et al. (2016) calculates fuel consumption reductions between 10% at 20 knots and 30% at 10 knots.

Recently, a study conducted by Ozdemir et al. (2021) proposed an energy management algorithm for a port with photovoltaic plant (PVP) and wind power plant (WPP), serving fuel cell/battery hybrid ferries. The power needs of the electrolyser and ferries are supplied by PVP and WPP in the involved port structure.

If supplied power is insufficient to front the power demand, the rest of the demand is provided by grid, and if the power demand is fully met, excess power generated at the port is transmitted to the grid. According to the energy state of battery, electricity price and departure time of the ship, fuel cell of each ferry can supply power for its battery charging and for needs during berthed-in mode within the port. Furthermore, the battery can also be discharged for the power demand during its stay in port. The main objective of the proposed energy management model conducted by the study of Ozdemir et al. (2021) is to minimize the cost.

The Norsepower's wind propulsion technology (Rotor Sail Solution technology)[37] allows at reducing fuel consumptions by 2.6% using a single rotor sail, while the new technology named "Auxiliary Sail Propulsion System" (ASPS), developed by Windship Technology Ltd, uses the rotation of the shafts to develop greater power, allowing the engine to maximize its performances and fuel economy (Parola et al., 2020).

This section 5.2.2 mentions also some of wind-assisted ship propulsion solutions which cover a wide array of technologies, i.e., large rigid sails (wing sails) or soft sails; hull sails; suction wings that create an upward lifting force similar to the wings on airplanes; small rigid sails on deck which can utilize both wind and solar energy; towing sky sails or kites; wind turbines installed on deck; or the installation of rotors which are vertical spinning cylinders utilizing the Magnus Effect for ship propulsion. Below, some of the most famous ship concepts which use or plan to harness wind energy as propulsion power for ships.

As the maritime industry marches through stringent environmental regulations and increasing fuel costs, shipping companies and organizations are spending considerable amount of resources to search for viable alternative green ship technologies. Lloyd's Register provided a set of projects which involved ships successfully using wind power in future. According to the test results of one of the concepts, experts believe that if wind power is utilized in the right way, then fuel savings of up to 50% are possible especially on the windy routes.

For example, using sails for cargo ships is a concept which has been under research for quite some time now: the B9 Windpower Technology revolve around a cargo ship which uses a unique sail propulsion system utilizing wind energy to produce 60% of the power for ship propulsion and the rest from ancillary engines powered by biogas.

Furthermore, Eco Marine Power's EnergySail technology utilizes an array of rigid sails which can utilize both wind and solar energy. The sails can be used with other green ship technologies to reduce fuel consumption and gas emissions. The EnergySail is unlike any other

[37] With the addition of Norsepower's technology, the MV Viking Grace is one of the most environmentally friendly cruise ferries in the global maritime industry. This vessel is reducing its emissions, fuel burn, and fuel costs, carbon emissions by circa 900 tons, equivalent to cutting 300 tons/year of LNG fuel, making it the first-ever global LNG/wind electric propulsion hybrid ship.

sail – it can be used even when a ship is at anchor or in port and has been designed to withstand high winds or even sudden micro-bursts. It can be fitted on a wide variety of ships from large Capesize bulk ore carriers to naval and coastguard patrol ships.

Moreover, the skysail technology uses towing kites to move the ship forward, reducing the load on the engine and lowering fuel consumption. This innovative use of wind energy has been implemented on several types of cargo ships with favourable results. The MV Aghina Marina is the largest bulk carrier ship using skysail technology successfully.

Another technology in this field is the Flettner rotors, that are special vertical spinning cylinders which utilize the Magnus Effect for ship propulsion. This ship concept utilizing such technology are known as rotor or Flettner Ship.

In addition, German Engineer Anton Flettner was the first to build a ship in 1922 using Magnus effect propulsion, using cylindrical vertical bodies for propulsion. With a dream to achieve a Zero Emission Ship by 2030, NYK has designed the futuristic Eco-Ship 2030. This green ship concept has a variety of unique features such as weight reducing structure, optimized hull form for propulsion efficiency, solar and wind power harnessing equipment, and fuel cell utilization to reduce the emission of carbon-dioxide by staggering 69%. The ship concept also utilizes new materials such as extra high tensile steel and alloys, and composites, and carries lighter containers and less fuel for a total reduction of 20% weight and 9% carbon-dioxide.

For example, STX Eoseas is an innovative cruise ship concept developed by STX Europe: this project aims at using marine clean technologies to reduce power consumption by 50%, emissions of CO_2 by 50%, SO2 by 100%, NOx by 90%, and ash by 100%.

The first zero-emission ship concept of the world is the Wallenius Wilhelmsen’s MV E/S Orcelle uses a variety of green technologies to form a system which doesn’t release any emissions in the atmosphere. In design, the Orcelle combines sustainable forms of energy captured through sails, solar panels, and wave energy converters to generate the energy required by the vessel. This is then used to extract hydrogen from water with the aid of fuel cell technology. The resultant fuel is a clean fuel that can then be made use of. In this manner, there are zero emissions from the vessel as such. The subsequent electricity generated, can also be used immediately or stored for times of no wind, sun, or waves.

5.3 Alternative fuel (low sulphur, LNG, biofuel, methanol, hydrogen)

The subcategory "Alternative fuel" is addressed in 16 of 69 articles and contributions of the sample, representing 22% of the sample. According to several studies and research, as regards alternative marine fuels, the easiest way to comply with the IMO2020 "Low Sulphur Cap" requirements consists in the use of low-sulphur fuels, such as very-low sulphur fuel oil (VLSFO), ultra-low sulphur fuel oil (ULSFO) and marine gasoil (MGO). Although these fuels are considerably greener than traditional ones, such as heavy fuel oil (HFO), they contribute to significant atmospheric emissions (especially CO_2). However, these fuels are difficult to find and are significantly more expensive than HFO, so the shipping sector is currently focusing on finding more sustainable alternative fuels, both environmentally and economically. Examples of sustainable alternative fuels can include for example, Liquefied Natural Gas (LNG), biofuels, methanol and hydrogen. In the sample contributions, alternative fuel that are treated and investigated by scholars and academics are LNG, biofuel, methanol, and hydrogen.

5.3.1 Liquefied Natural Gas (LNG)

According to several studies (Contessi, 2015; Lepistö et al., 2016; Cucinotta et al., 2021), to comply with more stringent emission regulations, also including the institution of Emission Control Areas, that increasingly prompted shipowners to choose new-generation engines, LNG has been recognized as the best solution to enter a new era with fewer emissions and a greener profile and as the best alternative to Fuel Oil (Burel et al., 2013). Global LNG production is growing at a rate of 2.1% per year, while its consumption is growing at a rate of 1.7% (Cepeda et al., 2019) and is therefore able to meet the demand for fuel for maritime transport at least for the coming decades.

LNG fuel is expected to have a promising outlook in the green shipping industry with advantages in reducing emissions (Fu et al., 2014): the use of LNG leads to a 100% reduction in SOx emissions, 80-85% of NOx emissions, 95% of PM emissions and 20-30% of CO_2 emissions compared to HFO/MDO (Burel et al., 2013). Numerous empirical evidence also shows that LNG not only leads to a reduction in atmospheric emissions, but also allows a reduction in the operating costs of the ship in the order of 35% (Burel et al., 2013), combining the effects of both lower energy consumption and the positive impact of the LNG's price which is currently low.

Today LNG represents an interesting solution for shipping companies. However, it is considered a transitional fuel and not a definitive solution to limit emissions in the shipping industry (Martínez-López et al., 2021). Indeed, the management and combustion of LNG involve the release of methane (methane slip), a greenhouse gas with a global warming potential 28 times greater than CO_2, considering a period of 100 years and 84 times greater, over a period of 20 years (Anderson et al., 2016), therefore, its release into the atmosphere may reduce the overall environmental benefits deriving from the use of LNG.

Peder et al. (2017) focus their research on diesel engine and LNG-fuelled turbines to be used as main engines, clearly showing that the second one is the most environmentally friendly power option since it causes the least GHG emissions compared to the other configurations. The reasons behind this result can be attributed to the use of clean LNG fuel and the efficiency improvement of employing an extra cycle to the turbines (Peder et al., 2017).

The recent study of Cucinotta et al. (2021) presents the results of a Life Cycle Assessment (LCA)[38], carried out on two sister cruise-ferries with the same ship design but equipped, respectively, with a traditional Diesel and an LNG engine. In this vein, the study compares the environmental impacts of the two motorizations, highlighting the differences, investigating weight and materials, the shipbuilding, ship operations and dismantling of the to two cruise-ferries. The comparison performed within the study shows that the LNG Otto cycle engines are a viable alternative in terms of emission reduction and environmental impact, especially with regard to the effects on human health and fossil resources depletion, however their impact is also important due to the leakage of methane, which has a major impact on climate change, and for the energy necessary for liquefaction (Cucinotta et al., 2021).

Regarding sample studies and articles about alternative studies, 10 of them investigates LNG and contribute to the achievement of the following results and main outcomes:

- reduction of operational costs, emissions and bunker consumption through the use of LNG (Burel et al., 2013; Tzannatos et al., 2015; MacPherson and Bakas, 2017; Cucinotta et al., 2021);
- how to preserve LNG losses (Fu et al., 2014);
- energy efficiency of LNG propelled ferry (Lepistö et al., 2016);
- hybrid LNG turbine as most environmentally friendly power option (Peder et al., 2017);

[38] Life Cycle Assessment (LCA) is an internationally standardized methodology (ISO 14040 ff) that helps to quantify the environmental pressures related to goods and services (products), the environmental benefits, the trade-offs and areas for achieving improvements taking into account the full life cycle of the product.

- higher total fuel cost savings by switching to LNG compared with electric power (Vukić et al., 2021).

Numerous companies operating in the Ferry, Ro-Ro and Ro-Pax industry at a European level have carried out huge investments for the refitting of ships of their own fleet or for the purchase of new LNG-propelled ships. As confirmed by this PhD study, Compagnie Luxembourg de Navigation (CLdN) holds 6 LNG-propelled ships, as a results of both the refitting of existing vessels and new buildings (MV Hermine, MV Laureline, MV Sixtine, MV Ysaline, MV Faustine, MV Seraphine). These ships have and will have a dimension of more than 50,000 GT and operates and will enter in service among English Channel, Biscay Bay and North Sea. Among the most widely used alternative fuels for propulsion (biofuel, LNG, methanol, hydrogen, VLSFO/ULSFO), LNG is the most widely used in Europe. Among European Ferry, Ro-Ro and Ro-Pax ships, many units are dual fuel and some of them are also hybrid ships with LNG propulsion and onboard battery for storing energy to be used for the propulsion (Doeksen G and Seatrans AS, owned by Torghatten Nord AS). With its 9 LNG ship, Balearias invests mainly on LNG propulsion, transitioning towards full decarbonisation, as confirmed by Balearias' Sustainability Report (2021).

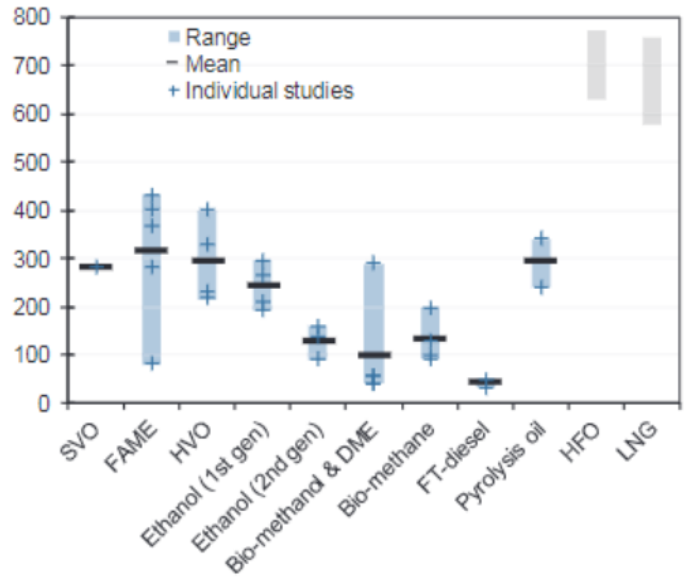
5.3.2 Biofuel

Biofuel are fuels produced from organic material, such as plant materials and animal waste and represent an alternative to conventional fuel. Depending on the quality, type, and way in which the biological raw material is processed, it is estimated that biofuels can achieve the CO_2 emissions (by between 25% and 100%), NOx and SOx emissions reduction target (Philip, 2020). All biofuels contain negligible amounts of sulphur and produce significantly lower NOx and PM emissions than MGO. Furthermore, biofuels are biodegradable, which is a major advantage over fossil fuels in accidental spills.

First-generation biofuels, including straight vegetable oil (SVO), hydrotreated vegetable oil (HVO), fatty acid methyl ester (FAME) and bioethanol, can potentially be produced in large quantities, but their use is limited by international conventions as their production is a threat to biodiversity and the food supply. Instead, advanced biofuels, i.e., those obtained by processing materials such as wood, crops and waste materials, show a higher emission reduction potential than traditional biofuels, without presenting the problems related to first-generation biofuels (

Figure *26*). However, second-generation biofuels, using only degraded land or residual biomass for their production, without damaging agricultural land and forests, are often not yet ready to be used as they are still at a research and development phase. Specifically in shipping industry, the most suitable advanced biofuels are Fischer-Tropsch diesel (FT-Diesel), pyrolysis oil, Ligno-Cellulosic Ethanol (LC Ethanol), biomethane and bio-LNG (Balcombe et al., 2019).

Figure 26. GHG emissions (gCO$_{2eq}$/KWh) related to biofuels and other fuel.



Source: Balcombe et al., 2019.

The great barrier to the use of biofuels is the price differential compared to traditional fuels, such as HFO and MDO. Moreover, the price differential with traditional fuels is even higher for advanced biofuels, due to the complexity and immaturity of the production processes. Nevertheless, it should be noted that in some cases, biofuels can be used as "drop in" fuel, requiring limited alterations to the engine already in use and consequently low conversion costs (IEA, 2017).

Among European companies operating in Ferry, Ro-Ro and Ro-Pax industry, Fjord1 has been using 100% renewable biofuel as an energy source or natural gas propulsion. In the Grimaldi Group Sustainability Report (2021) fuels as methanol, biofuel and LNG are not mentioned as fuels used for the propulsion of ships in operation and those under construction. The largest company within express ferry and boat operators, i.e., Norled AS, invested significantly in new types of vessels and eco-friendly technology and has developed solutions used solely by the company. Some of Norled AS ferries can operate with alternative fuels and the most of them uses biofuel for propulsion and only two ships (MV Hydra and MV Nesvik).

5.3.3 Methanol

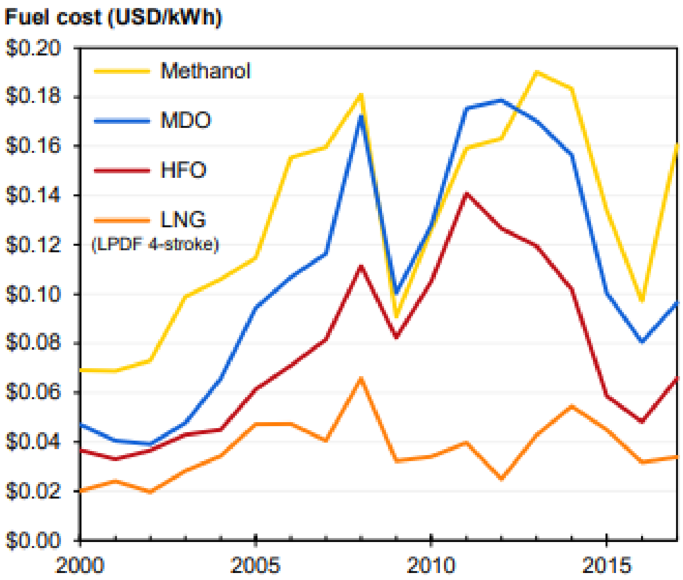
Methanol is considered an interesting solution for the reduction of the negative environmental impact related to the operations of the shipping industry. For this reason, there is currently one marine engine available that may run on methanol as a dual fuel. Specifically, its use as a source of propulsion allows a substantial reduction in CO_2 emissions and other air pollutants compared to traditional fuel such as HFO and MDO (Christodoulou and Cullinane, 2021).

Methanol can be produced from several sources such as natural gas, catalytic hydrogenation of a waste CO_2 stream or biomass. In this context, it is necessary to consider the main criticality related to the use of methanol, that is the emissions generated during its supply chain, which are greater or lesser depending on the production source. In this way, when analysing the harmful emissions generated throughout the entire life cycle of methanol, it can be argued that emissions associated to ship operations are lower than those generated using HFO or MDO, but that emissions produced during the entire methanol life cycle are 10% higher than those deriving from the use of HFO or MDO (Balcombe et al., 2019).

The cost of methanol as a fuel is greater than liquid fossil fuels and LNG, as shown in

Figure 27. Thus, whilst air quality emissions may be significantly reduced, the carbon credentials of methanol fuel must be proven and then incentivized to encourage further uptake.

Figure 27. Average fuel costs for each year for different fuels per KWh of engine output[39].



Source: Balcombe et al., 2019.

Linking ports of Gothenburg and Kiel, Stena Germanica, the world's first methanol-powered sea vessel, is reported to have reduced SOx emissions by 99%, NOx by 60%, particulates by 95% and CO_2 by 25%, comparing with HFO, thus complying with the latest ECA regulations on its Baltic Sea route (Christodoulou and Cullinane, 2021).

Among European companies operating in Ferry, Ro-Ro and Ro-Pax industry, all ships powered by dual-fuel engines are also capable of operating on LNG and some of them are fitted with a propulsion system that can operate on LNG and biogas (LBG) or methanol. Manifold investments in methanol are made by Stena Line for the control of the emissions: both MV Stena Estrid, MV Stena Edda and MV Stena Embla, has a main-propulsion package that can used both methanol both LNG, in addition to distillate fuel. Among the DFDS Climate Action Plan, DFDS introduces small amounts of methanol in the existing propulsion machinery on many of vessels, in the four-stroke engines that make up the most part of DFDS fleet. Together with onsite-

[39] LPDF 4-stroke = low pressure dual fuel 4 stroke run on LNG. Average fuel costs per tonne from [28, 68-74] are converted to engine output using standard engine efficiencies.

produced hydrogen, the company will inject the methanol into combustion chambers, replacing up to 10-15% of the heavy fuel oil needed to fuel the same voyage. With this technology, that is still under development, but the initial testing and the results look promising, DFDS wants to be able to push the market demand for sustainable fuels like green methanol, to have a positive ripple effect on the development of green fuel production nationally and internally.

5.3.4 Hydrogen

Referring to the use of hydrogen (H_2) as an alternative fuel, only 4 studies in the sample demonstrated that this innovative fuel is gaining more and more acceptance, as the environmental impact of hydrocarbons becomes more evident (Koroneos et al., 2004; Dong, 2020). The presence of so few contributions in the sample is due to the current study phase concerning hydrogen as an alternative fuel and its possible application in the maritime field.

This alternative fuel is now under analysis and the subject of numerous studies for its application in the shipping industry (Temiz and Dincer, 2021), as it would allow the zero emission of carbon dioxide (CO_2) and sulphur oxides (SOx) connected to the ship propulsion and would lead to a significant reduction of nitrogen oxides (NOx) and particulate matter (PM) emitted into the atmosphere (Alternative Fuels Data Center, 2022).

The use of hydrogen as a substitute for conventional diesel fuel still requires research and development and now there is currently no standardized procedure for refuelling ships (Tinsley, 2021). More specifically, hydrogen can be used as a fuel through different technologies, such as the above-mentioned fuel cells or through hydrogen combustion engines as a substitute for traditional HFO. As for its use within an electric/hybrid system by means of fuel cells, please refer to what was discussed above (cf. paragraph 5.1.2). As for the use of hydrogen as a replacement for HFO, it is not mature enough to date, and it is therefore necessary to further implement research and development concerning this topic (Temiz and Dincer, 2021).

Whatever the technology it is used with, to evaluate the sustainability of hydrogen as an alternative to traditional fuels, it is necessary to evaluate the production process through which it is obtained (Dong, 2020). Indeed, hydrogen can be produced from natural gas with a production process during which high quantities of carbon dioxide are emitted, through the gasification of coal that also generates significant CO_2 emissions, or through more sustainable methods such as water electrolysis (Koroneos et al., 2004). Specifically, this technique is a more attractive alternative in terms of environmental sustainability, since the electricity required for electrolysis can be generated from renewable energy sources such as solar, wind or hydroelectric plants, improving the green potential of the entire hydrogen production life cycle.

Although hydrogen is generally considered to be a clean fuel, it is important to recognize that its method of production plays a very significant role in the level of environmental impacts. Within the study conducted by Koroneos et al. (2004), the LCA of hydrogen systems indicates that the production pathway using photovoltaic energy has the worst environmental performance compared to all other pathways, due to the manufacturing process of photovoltaic modules that contributes highly to all environmental impact categories of the system. In this context, high equivalent emissions of CO_2 and SO_2 have a negative impact on hydrogen production by steam reforming of natural gas. To reduce the emissions along the entire hydrogen supply chain, hydrogen must be produced using wind, hydroelectric, solar or thermal energy. However, the future of renewable hydrogen energy also depends strongly on reduced costs for renewable energy production (Koroneos et al., 2004).

Two hydrogen-powered ferries, entering in operation in October 2025, are being developed by Norwegian shipowner Torghatten Nord. Both ferries are planned for operation on Norway’s longest ferry route and are designed to use a minimum of 85% “green hydrogen” based fuel. In this way, both hydrogen-powered ferries can eliminate GHG emissions, thanks to the hydrogen storage system that powers the fuel cells, and the fuel cells themselves, providing electric power for the propulsion and all other on-board utilities. As from Balearia Sustainability report (2021), the first 100% electric passenger and cargo ferry in the Mediterranean will produce zero emissions during port stays and approach by using green hydrogen as a test bed for this energy source. DFDS is studying new kinds of fuels and technologies for its fleet and in this vein a partnership aims to develop hydrogen ferry for Oslo-Copenhagen has been established. DFDS and its partners (ABB, Ballard Power Systems Europe, Hexagon Purus, Lloyd’s Register, KNUD E. HANSEN, Ørsted and Danish Ship Finance) have applied for EU support for development of a ferry powered by electricity from a hydrogen fuel cell (100% hydrogen powered ferry) which only emits water. Among European companies, Norled AS fleet is composed also by some ferries that can operate also with alternative fuels: MV Hydra and MV Nesvik are hydrogen-propelled.

5.4 Ship/hull/propeller design

Due to stringent environmental regulations and volatile fuel prices, ships are now expected to be more eco-friendly and fuel efficient. In this context, simulation-based hull form design optimisation, new bulbous bow and antifouling paints are gaining increasing attention and importance (Ang et al., 2015).

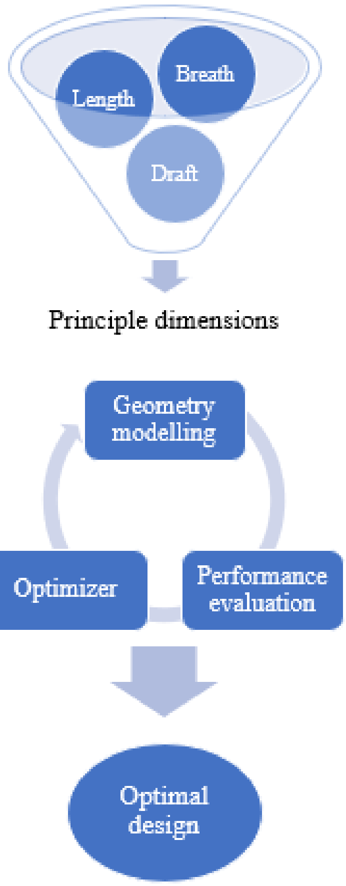
Among others, the development of design variant of ship is based on a set of design parameters that are main particulars (length BP, beam, draught, depth); length of entrance, mid-body and run; variables controlling local hull form details (e.g., shape and size of bulbous bow, transom and duck tail); length and position of engine room(s); ship capacity (linear metres and passengers); service speed, range (Plessas et al., 2018).

The design of the ship in term of dynamic structure and construction material empathizes the effects on the ship from an operational and environmental impact perspective (Karatzas et al., 2016). These green investment options contribute to the energy efficiency of the ship as to the reduction of consumption and environmental emissions, making the ship more hydrodynamic, resistant to friction between the hull and water. Considering the systematic literature review conducted in this PhD thesis, scholars and academics investigates the optimization of Ferry, Ro-Ro and Ro-Pax ships design through the analysis of the hull design, the antifouling paints and new bulbous bow. The subcategory “Ship/hull/propeller design” is treated in 10 of 69 articles and contributions of the sample.

5.4.1 Hull Air Lubrication

New environmental regulations and volatile fuel prices have resulted in an ever-increasing need for reduction in carbon emission and fuel consumption also through the optimization of the designs of the hull. Several studies (Ang et al., 2015) analyse the state-of-the-art of hull form design techniques, with a focus on geometry modelling, shape transformation, optimization and performance evaluation, in order to discuss strengths and weaknesses of existing solutions. In addition, these studies focus their analysis of key challenges of hull form optimization specific to the design of ship, also proposing new technological solutions. The hull form is the largest single component of the ship or floating structure and exerts the greatest influence not only on hydrodynamic performance, but also on operation of the vessel. It is a crucial aspect to achieve maximum gain on the overall design of the ship (Ang et al., 2015).

Figure 28. Simulation-based hull form design optimization framework.



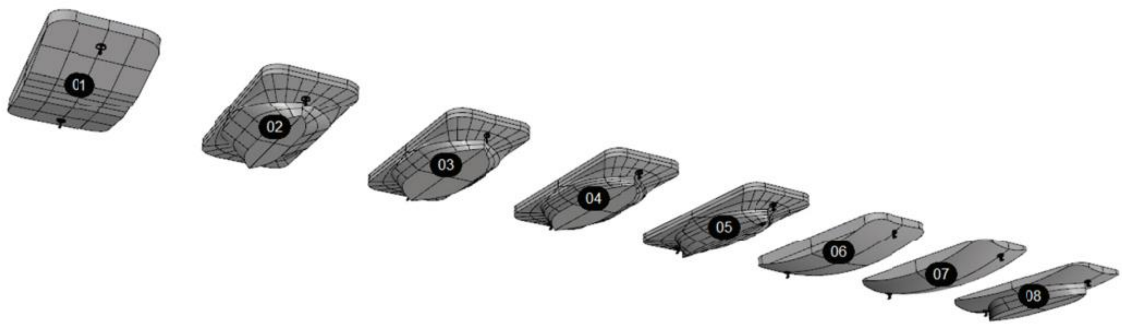
Source: Author's elaboration from Ang et al., 2015.

Key processes in simulation-based hull form design consist of geometry modelling and shape transformation, optimization, and performance evaluation. Main challenges in performing hull form optimization include scepticism due to, among others, for example "black-box" functions, high computational costs, automated optimization loop. Recent developments in advance computation techniques and more powerful computers have presented multiple opportunities such as multi-disciplinary optimization, machine learning, approximation methods, and optimized hull form design based on variable speed or multi-draft. By addressing challenges and further developing prototypes, simulation-based hull form optimization can become more accepted and widely applied in marine and offshore vessel design (Ang et al., 2015).

Another study of the sample conduct by Gełesz et al. (2017) demonstrates that, among others, the CAD software allows to make spatial visualizations and parametric form of the design. During the analysis, the applied software made it possible to carry out graphical programming and to obtain new free shapes of hull by building connections between various geometrical objects, their transformations, and functions. During the design process, several different hull geometry forms can be generated (some of them are reported in

Figure *29*); all of them are longitudinally and transversely symmetrical and free of any appendages at this design stage. According to the research, these hull geometry forms are based on traditional hull forms including flat-bottomed, spheroidal, keel-fitted, and cruiser–stern-ended. In the study conduct by Gełesz et al. (2017), resistance qualities calculated by using the parametric method, are analysed with the use of a spreadsheet program.

Figure 29. Considered variants of underwater part of designed ferry.

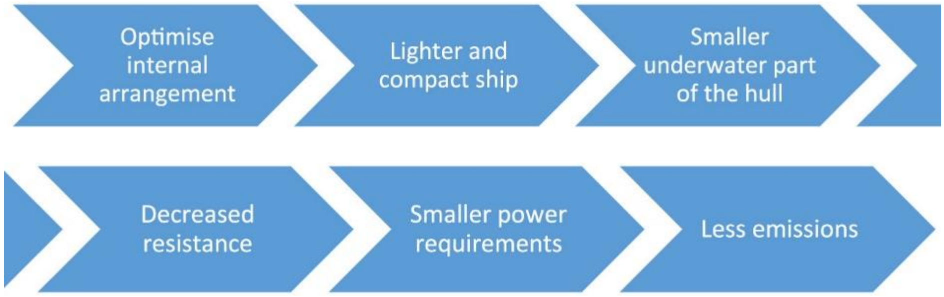


Source: Gełesz et al., 2017.

According to some studies and research of the sample, the goal of the hull design process is to reduce the operational emissions by designing a ship that is compact and can carry many vehicles and passengers relative to its size (Peder et al., 2017). The design process adopted for ship hull is aimed at obtaining a ship with reduced emissions (

Figure *30*).

Figure 30. Reduced emissions by hull optimisation.



Source: Peder et al., 2017.

The Air Lubrication System, also known as Bubble Technology, is an innovative system that reduces the resistance between the hull of the ship and the water through the generation of air bubbles. The distribution of air bubbles along the hull of the ship significantly reduces the friction of the hull with water, resulting in increased hydrodynamics, causing substantial energy savings and a consequent reduction in operating costs and pollutant emissions.

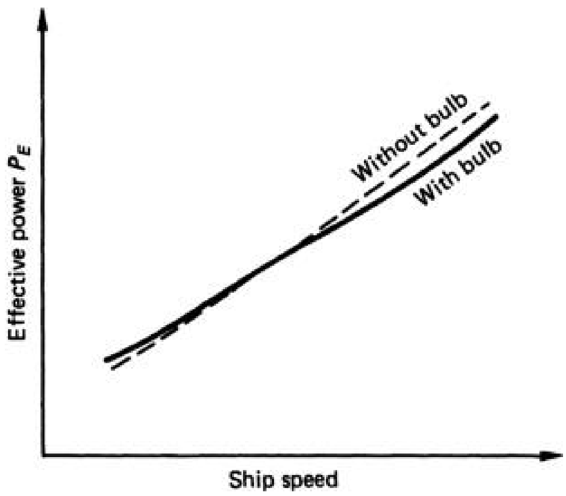
Recently, the shipping company Finnlines has received delivery of a new unit Ro-Ro, i.e., the MV Finneco III, that is equipped with the latest generation technologies, including an innovative system of Hull Air Lubrication, able to ensure high energy efficiency and better environmental performance. This bubble technology will be installed also on MV Finncanopus and MV Finnsirius.

5.4.2 New bulbous bow

The research and development activities related to the new designs and modifications of the ship's bulbous bow, are aimed at the implementation of the current design of the hull to increase the overall hydrodynamics of the ship.

Although its origins are to be sought before the end of the last century, the first application seems to have been in 1912 by the US Navy, while the commercial application seems to have waited until the late 1950s and early 1960s. The basic theoretical work and study of the effectiveness of this solution was carried out by Wigley (1936) who demonstrated that, with a bulbous of almost spherical shape, the acceleration of the flow on the surface would induce a low-pressure region that could be extended. This region of low-pressure reacts with the pressure wave of the bow to cancel or reduce the effect of the bow wave itself. The effect of the bulbous bow, therefore, is to cause a reduction, in most cases, of the power required for the propulsion, being the actual power defined as the product of the ship's resistance to the ship's speed in the absence of the propeller. In addition, as confirmed by Wigley (1936), a bulbous bow is generally advantageous above a certain speed, due to the balance between the effect of reduction of the bow pressure wave and the increase of the friction resistance caused by the presence of the bulbous bow on the hull.

Figure 31. Actual power performance at varying speed per vessel with and without bulb.

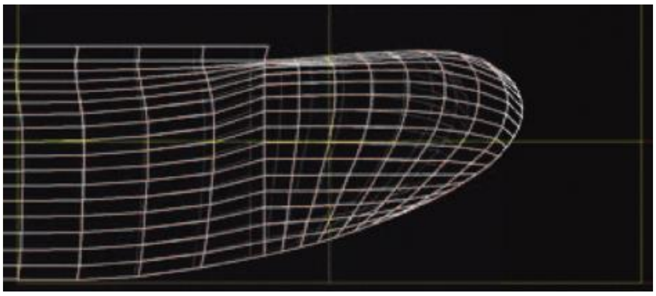


Source: Wigley, 1936.

Through the generation of a wave that cancels what would otherwise be generated by the ship's hull, the bulbous bow allows to strongly reduce the resistance of the ship and the friction with the water during navigation, with strong positive consequences in terms of reducing fuel consumption and reducing operating costs, as well as polluting emissions. The development of innovative design of bulbous bow is carried out mainly from bulk carriers, tanker ships and containerships, as the use of the bulbous bow, to be efficient to the maximum of its potentialities, requires a cruise speed as stable as possible over time. It should be noted, however, that, as shown by the research and studies of the sample, the improvement of the design of the ship has also involved several shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry, especially over recent years.

To illustrate a hull form design optimization, Ang et al. (2015) propose a case study of a 180 meters passenger ferry vessel. The purpose is to modify the shape of an existing bulbous bow design to improve the wave making resistance. Unlike conventional manual method where hull form optimization is carried out individually and manually, the purpose of the study is to demonstrate the practicability and efficiency of a fully automated hull form optimization solution by integrating the different processes into one common environment. In the case study conducted by Ang et al. (2015), for shape transformation of the ship, free-form deformation (FFD) technique was selected: the bulbous bow shape was modified simply by creating a boundary box and extending the length by 3 meters toward forward direction (Figure 32). The study demonstrated that bulbous bow optimization can be applied successfully to improve forward end resistance of ferry vessels.

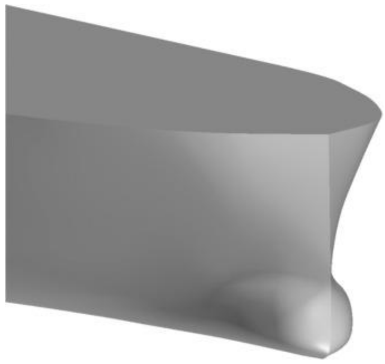
Figure 32. Free form deformation (FFD) of bulbous bow area.



Source: Ang et al., 2015.

As shown in the study conducted by Peder et al. (2017) shows that the bow must be designed with a bow which aims to reduce the wave resistance by piercing through the waves, rather than pushing them away. For this reason, the bulbous bow it is designed to be vertical, with a relatively small flare angle that reduces the amount of reserve buoyancy at the bow. The lack of reserve buoyancy prevents the vessel from reacting with trim motions when penetrating the waves (Peder et al., 2017). Figure 33 shows the results related to the study conducted by Peder et al. (2017). It shows that the bow must be designed with a bow which aims to reduce the wave resistance by piercing through the waves, rather than pushing them away. For this reason, the bulbous bow it is designed to be vertical, with a relatively small flare angle that reduces the amount of reserve buoyancy at the bow. The lack of reserve buoyancy prevents the vessel from reacting with trim motions when penetrating the waves (Peder et al., 2017).

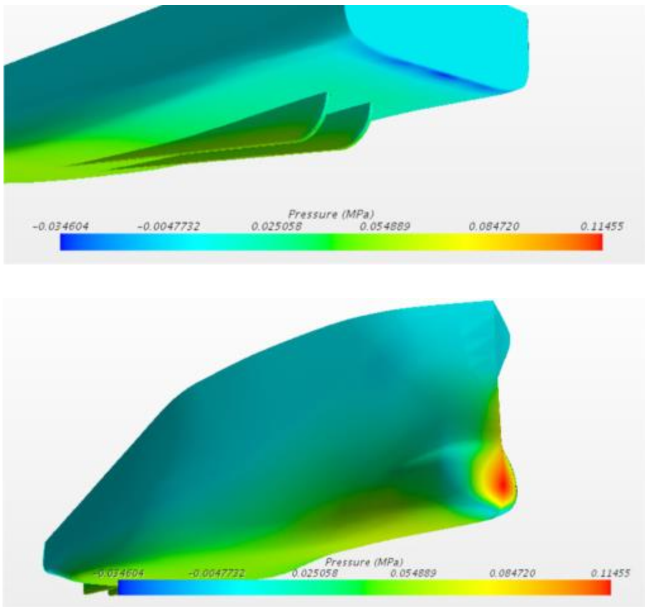
Figure 33. The wave piercing bow of a ship.



Source: Peder et al., 2017.

In this way, the pressure distribution around the ship's hull (Figure 34) is an important tool for naval architects to identify the areas where high pressure and therefore high stress is expected to occur (Peder et al., 2017). Such areas are often prone to cracking or collapsing and therefore must be supported with structural members.

Figure 34. Pressure distribution on the ship's hull at 24 knots (a view from stern and bow).



Source: Peder et al., 2017.

Many investment options made by Grimaldi Group, CLdN and Balearia for the control of the emissions are focused on bulbows bow. The same for Stena Line: vessels as MV Stena Estrid, MV Stena Edda and MV Stena Embla are equipped with bulbous bow to improve the operating efficiency. The MV Salamanca, a new E-Flexer-class vessel that is operated by Brittany Ferries, is equipped with bulbous bow for greater hydrodynamics as well as the MV Santona, a virtual copy of the MV Salamanca. The stern of the MV Côte d'Opale is also especially designed to fit the quayside facilities in ports and equipped with a third bow thruster to facilitate the many daily manoeuvres in port. DFDS manifold investments are focused on the equipment of the ships with bulbous bow (MV Troy Seaways and MV Ephesus Seaways). Aug Bolten Wm Miller's two new Ro-Pax ferries are also equipped with an optimized hull form with a bulbous bow and a special underwater hydrodynamic coating, aiming at reducing emissions and improving operating efficiency. Another vessel, MV Peter Pan, was ordered by shipowner Aug Bolten Wm Miller's at the Chinese shipyards of Jiangsu Jinling, and it will be also equipped with an optimized hull form with a bulbous bow to improve the operating efficiency and reduce the emission of PM, SOx and NOx.

5.4.3 Antifouling paints

Depending on the area of sailing and on several operational conditions, biological fouling can occur (Kunicka and Litwin, 2019): the accumulation of biofouling, i.e., the spontaneous accumulation of microorganisms, algae plants, barnacles, mussels, or animals on the surfaces of the vessel in contact with water, is responsible for a significant decrease in the hydrodynamic performance of the vessel. In this respect, some studies of the sample have shown that the accumulation of biofouling can lead to an increase in the friction of the ship with water by 40%, which determines the need to use more energy to push the ship into the water, resulting in increased fuel consumption and hence operating costs as well as emissions. To prevent this problem different types of antifouling paints are available (Aijjou et al., 2018). For many years the most used biocide in antifouling paints has been tributyltin, but due to its high toxicity to the marine ecosystem its use has been prohibited by the IMO through the International Convention on the Control of Harmful AntiFouling Systems on Ships and, at Community level, through Regulation 782/2003. The shipping industry has therefore, in collaboration with the entire scientific community, developed alternative antifouling paints that could be less toxic but equally effective: currently the most widely used biocides include copper compounds, such as copper oxide or copper thiocyanate, and a biocidal booster (Guardiola et al., 2012).

The regularly removal of biofouling and the application of antifouling paints, contribute to a better ship resistance that leads to a lower fuel cost (Wang et al., 2018). As emerged within the study conduct by Wang et al. (2018), to solve the problem of the attachment of organisms on the ship's hull, a specific maintenance plan of antifouling coating must be planned: a yearly partial coating and every five years a full coating of the ship with antifouling paints. The maintenance practice of partial coating consists in the annual removal of biofouling accumulated on ship external surface and the repainting of the area, thus helping to reduce the roughness of ship's hull and bringing it back to its initial condition so that the increasing of the energy efficiency of the vessel can be achieved. Therefore, for every five years, the ship hull roughness must be returned to its initial condition, causing major changes in fuel consumption. With the principle of applying different maintenance intervals, energy consumptions due to maintenance varies to reach a minimum cost and environmental impact (Wang et al., 2018).

New biofouling control strategies are currently being researched and developed (Kunicka and Litwin, 2019), and a new generation of antifouling paints based on non-toxic and/or non-biocidal substances such as innovative new polymers with properties such as hydrophilic, is now emerging.

The shipping company Stena Line, the leader in Ferry, Ro-Ro and Ro-Pax industry in terms of sustainability, has been working for years on sustainable solutions for the containment of the accumulation of biofouling on ship surfaces. More specifically, the company is currently using biocide-free and environmental-friendly antifouling paints and is developing alternative solutions to counteract the development of biofouling on the hull using ultrasound.

Among the Stena's E-Flexer ferries, the MV Stena Estrid is the first in Stena Line's new line of E-Flexers and has been hailed as the "most efficient ship in Stena's history". The E-Flexer ferries are equipped with energy efficiency innovations and cutting-edge technologies. Singling out other environmentally friendly and energy efficient features, the MV Stena Estrid's hull has an excellent hydrodynamic performance. Furthermore, the ship highlights other energy efficient and innovative solutions used such as antifouling – Selektope, that is bio-repellent, organic and non-metal compound. Among the Grimaldi fleet, the MV Eco Valencia (2020) received the Shippax Ro-Ro technology and environmental award, further demonstrating the innovativeness and efficiency of the entire GG5G class of ships. After the delivery of four GG5G-class of ships in 2021 (MV Eco Barcelona, MV Eco Livorno, MV Eco Savona and MV Eco Catania) and other vessels in 2022, that are operating in Mediterranean Sea (MV Eco Adriatica, MV Eco Italia, MV Eco Malta, MV Eco Mediterranea), Grimaldi Group has also commissioned the building of six new ships to the Korean Hyundai Mipo Dockyard Co. Ltd shipyards. The G5 Hyundai Class ships will feature the adoption of several innovative technological solutions aimed at energy efficiency and reduced environmental impact: among them the hydrodynamic efficiency of the hull with reduced hull friction that will be the result of the application of latest-generation antifouling paints with low roughness and self-cleaning characteristics and the Air Lubrication System.

5.5 Ballast tank and water injection system

Investments options related to ballast tank and water injection system are treated in only 3 out of 69 articles and contributions of the sample, as this technical solution is mainly used for oil tankers during ballast voyages along their route.

In 2004, the IMO formulated the Ballast Water Management Convention (BWM), an international convention requiring ships to develop ballast water management plans and to keep a record of BW on board. The convention aims to minimize, or even eliminate, the transmigration of harmful aquatic microorganisms. To ensure greater stability and trim during navigation, each ship take on seawater (ballast water), and with them also all the microorganisms in the marine ecosystem. Once arrived in the port of destination waiting to be unloaded and loaded, the ship's stability conditions no longer conform to its next configuration, hence the need to discharge ballast water or add additional water and, with it, even the microorganisms within the water. Given the enormous diversity between the fauna and flora in the marine environment globally, harmful events often occur, including the spread of invasive and biological species. Dangerous invasions pose a major threat to the balance of the ecosystems. Most of the micro-species transported do not survive until the arrival at the port of destination (60-70%) while the remaining 40-30% is able to form real viable populations and then become dangerous parasites (Tsolaki and Diamadopoulos, 2010).

Two contributes within the sample explain the research conducted by Transportation Development Centre of Transport Canada, in collaboration with the Environment Research and Measurement Division of Environment Canada, on marine emissions control technologies to lower GHG emissions (Radloff and Gautier, 2005; Radloff, 2006). An initial round of laboratory tests demonstrated the viability of a Water Injection System (WIS) to reduce NOx emissions. The results indicate that the WIS has achieved a 20 to 28% NOx reduction over a 25 to 75% load range with a maximum of 33% water injection (Radloff, 2006). The WIS was optimized during laboratory bench tests and will be installed on a Ro-Ro ship operating between Montreal, Quebec, and St. John's, Newfoundland. In this way, with high water injection ratios above 50 % engine load, WIA reduces NOx (between 10 and 35%) although generating an increase in both particulate matter and carbon monoxide when using intermediate fuel oil, without any negative impacts on fuel consumption or engine operation and performance (Radloff and Gautier, 2005).

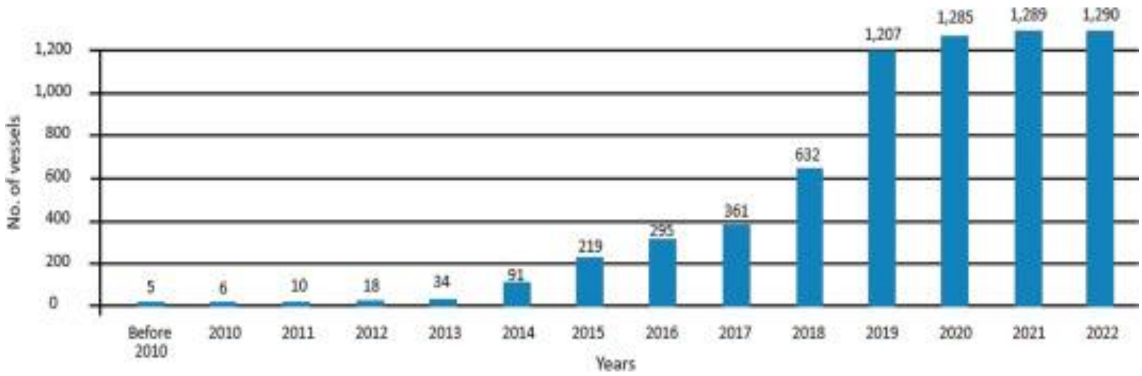
As shown by studies and research conducted in the sample, one element defining the seaworthiness of a ship is also the condition of its ballast tanks (de Baere et al., 2014). These tanks are subject to corrosion and due to the enclosed environment and complex structure, maintenance is very difficult and costly. The study conducts by de Baere et al. (2014) focuses on many types of ships in the database: amongst others also 9 Ro-Ro ships are included. To solve the issue of surface corrosion, the study reveals certain mechanism and procedures such as blasting with shot, grit and vast amounts of water and related rinsing. The reduction of the environmental impact has beneficial economic consequences as it brings down significantly maintenance costs (de Baere et al., 2014).

5.6 Exhaust Gas Cleaning System

The subcategory of Exhaust Gas Cleaning System (ECGS) is treated in 3 of 69 articles and contributions of the sample, because of the widespread use of scrubbers on Ferry, Ro-Ro and Ro-Pax ships as conditioned by the IMO Low Sulphur Cap. The wide use of scrubbers is demonstrated in

Figure *35* which shows the increase in the number of scrubber systems applied to ships over the last decade. In particular, prior to 2010, only 5 scrubber systems were applied to ships, but as of 2018, the cumulative number of ships to be installed or under contract has reached over 1,200 sets of scrubber systems.

Figure 35. Scrubber systems market trend.



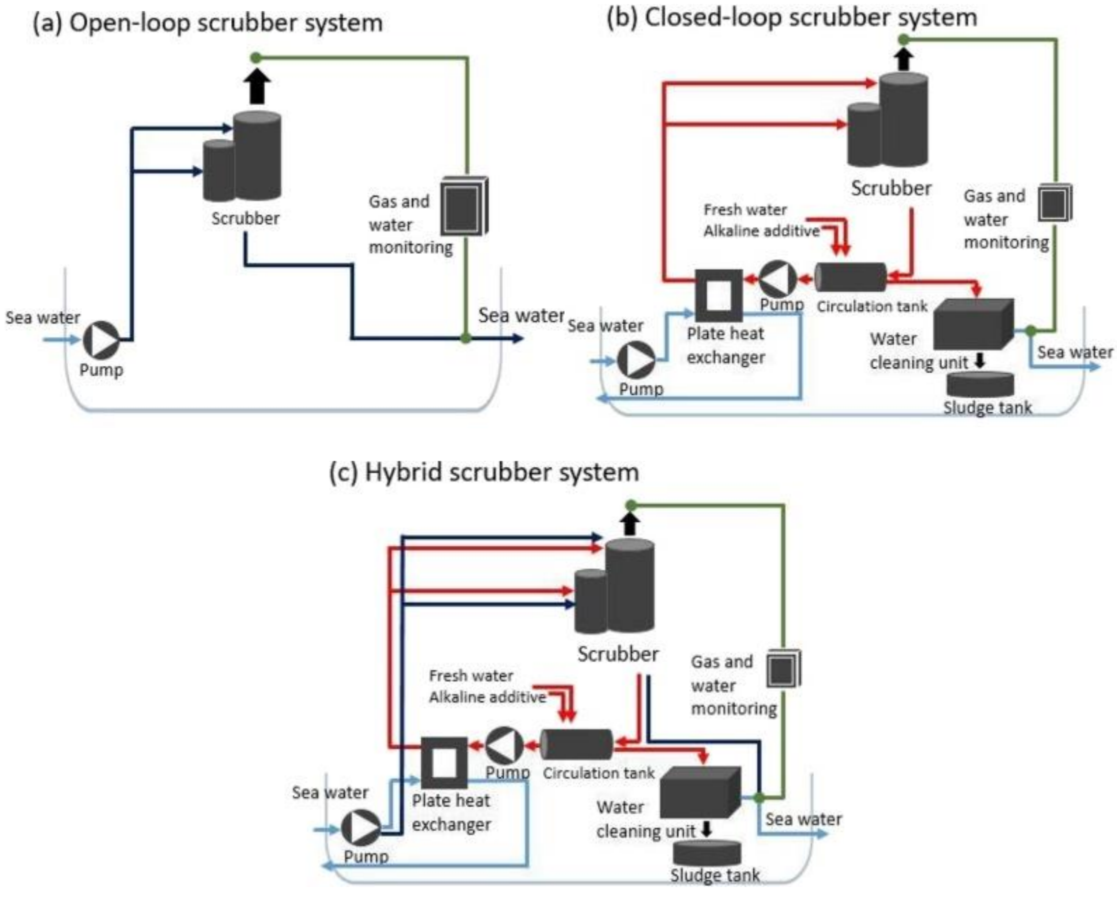
Source: DNV-GL, 2018.

To comply with sulphur restrictions, according to the current technological state of the art, ship-owners have three options for their existing fleet (Winebrake and Wang, 2005): in addition to low sulphur fuels or retrofitting for the usage of alternative fuels (see paragraph 5.3), also the installation of emission abatement technologies, i.e., the Exhaust Gas Cleaning Systems, commonly named scrubbers (Philipp, 2020). These technologies consist in purification systems that allow the removal of sulphur oxides and particulates contained in the exhaust gases of engines and boilers of ships, with a consequent reduction in the emissions of these substances into the atmosphere (Koumentakos, 2019).

In response to the international maritime regulation, MARPOL Annex VI Reg. 14, for the reduction of sulphur oxides arising from shipping activities, Jang et al. (2020) contribute to the extant literature evaluating the environmental impacts of the entire life cycle of three different SOx-reducing scrubber systems. Specifically, scrubbers can be divided into two categories, namely dry scrubbers and wet scrubbers. Dry scrubbers treat the exhaust gases by adding moisture to make it react with the pollutant particles and then make it evaporate, without generating condensation inside the system. Wet scrubbers, on the other hand, treat the exhaust gases by using liquid substances, mainly water: the polluting particles are incorporated into the liquid and then separate the liquid part from the gases.

Wet scrubbers are the most widely used and can in turn be distinguished in (a) wet open-loop, (b) wet closed-loop, and (c) wet hybrid (Jang et al., 2020) (Figure 36). As of 2018, the open-loop scrubber systems accounted for about 64% in the marine scrubber market due to its simplicity and low capital costs; those scrubber systems are designed to directly spray sea water through the exhaust gas so that the natural alkalinity of sea water can neutralize the acid contained in the gas (DNV-GL, 2018). On the other hand, the closed-loop scrubber systems (about 4%) are operated by chemical-controlled fresh water with Sodium Hydroxide (NaOH) as the cleaning solution. This solution is not directly discharged into the sea, but it is neutralised in the process tank with NaOH and becomes reusable. Thus, the discharge of contaminated wash water can be considerably reduced, compared to open-loop scrubber systems. The hybrid scrubber systems (about 28%) are equipped with both open-loop and the closed-loop system functions (Jang et al., 2020).

Figure 36. The configuration of proposed wet scrubber systems.



Source: ABS, 2018.

There are many companies operating in the Ferry, Ro-Ro and Ro-Pax industry at European level that have installed exhaust gas cleaning systems on their ships, and among them also leading companies in the sector such as Grimaldi Group SpA, Finnelines, DFDS Denizcilik ve Tasimacilik, Grandi Navi Veloci SpA, Tirrenia di Navigazione SpA. The group owner Grimaldi Group SpA, in early 2022, in collaboration with Wartsila, presented to the market a highly innovative technology capable of making open-loop scrubbers an instrument aimed not only at protecting the environment and combating climate change, but also at protecting the oceans and marine species. These systems can filter the washing water from waste gas cleaning systems installed on board ships in order to retain microplastics, thus preventing them from being ingested by fish and other marine organisms and entering the food chain. In this way, open loop scrubbers can take seawater for the purification of exhaust gases and, at the same time, collect microplastic in the oceans during their normal operation.

In this fifth Chapter an analysis of technical solutions and investments options most widely adopted by the Ferry, Ro-Ro and Ro-Pax industry is proposed. As emerged from the systematic literature review (cf. fourth Chapter), electrification, hybrid, fuel cell, battery result to be among the most popular solutions aimed at greening the sector, also with the use of renewable energy sources, alternative fuel (LNG, hydrogen, low sulphur) and the review of ship/hull/propeller design (technologies such as hull air lubrication, the improving the design of bulbous bows, etc.). Conversely, solutions as EGCS are treated in only 3 contributions within the sample probably because of the imposition of the IMO Low Sulphur Cap and the widespread use of scrubbers on Ferry, Ro-Ro and Ro-Pax ships. Moreover, a summary of the main different drivers and barriers selected for each green investment option in Ferry, Ro-Ro and Ro-Pax industry is proposed within the fifth chapter of this PhD thesis.

The sixth Chapter of this PhD thesis examines in detail the state of the play of the adoption of technical solutions and investments options from shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry, in order to test the conceptual framework proposed within the fifth Chapter. The sixth Chapter also conducts an analysis aimed to identify the best group owners, basing on the greater incidence of “green” ships respect to the total of the fleet and on their managerial and governance behaviours.

CHAPTER 6

GREEN INVESTMENT OPTIONS IN FERRY, RO-RO AND RO-PAX INDUSTRY: STATE OF THE PLAY

6. Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the play

The sixth Chapter of this PhD thesis tests the conceptual framework proposed within the fifth Chapter, examining examines in detail the state of the play of the adoption of technical solutions and investments options from shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry.

In this vein, the Paragraph 6.1 deepens the methodology for empirical investigation conduct by this PhD thesis, testing by empirically investigation the profitability and feasibility of green investments pursued by European Ferry, Ro-Ro and Ro-Pax companies.

Then, the Paragraph 6.2 examines how the “overall” sample is constructed and the results from the analysis of the first sample that is considered as extended or “overall” sample. The analysis that is conduct in this Paragraph is about ship type distribution (Par. 6.2.1), fleet dimension (Par. 6.2.2), ship dimension and ship capacity (Par. 6.2.3), ship age distribution (Par. 6.2.4), ship status (Par. 6.2.5), Ferry, Ro-Ro and Ro-Pax operators, group owner and ship manager (Par. 6.2.6), maritime flag and ship classification society distribution (Par. 6.2.7), shipbuilders’ distribution (Par. 6.2.8) and fuel type (Par. 6.2.9).

Finally in Paragraph 6.3, this PhD thesis proposes an in deep analysis of the sample with a construction of a new “green” sample (Par. 6.3.1), in order to scrutinize the previous “overall” sample (Par. 6.3.2). A specific analysis is conducted about group owners that own ships belonging to the sample. In this vein best group owners are identified, basing on the greater incidence of “green” ships respect to the total of the fleet, and an in deep analysis of the managerial and governance behaviours of best group owners is conducted in Paragraph 6.3.3: sub-paragraphs from 6.3.3.1 to 6.3.3.10 show an overview of top ten group owners and related managerial and governance behaviours.

6.1 Methodology for empirical investigation

The conceptual framework proposed within the previous chapter of this PhD thesis is tested by empirically investigating the profitability and feasibility of green investments pursued by shipping companies operating in the Ferry, Ro-Ro and Ro-Pax sectors at a European level. In Table 12, this PhD thesis proposes the conceptual framework and related theories, with a potential application in the Ferry, Ro-Ro and Ro-Pax industry.

Table 12. The application of theoretical constructs in the Ferry, Ro-Ro and Ro-Pax industry

Theoretical constructs	Empirical definition and key elements	Application in the Ferry, Ro-Ro and Ro-Pax industry
Theory of Planned Behaviour *Individual's decisions and behaviour depend on three main factors: attitude towards behaviour, subjective norm and perceptual control*	Attitude concerns an individual's subjective evaluations of the behaviour under consideration	Attitude analysis can provide information on the degree to which operators favour or disfavour green technologies and may influence their investment decisions
	Subjective norm refers to an individual's perceptions of the expectations of significant others in their social environment	Subjective norms might be influenced by relevant stakeholders (shipowners, customers, regulators and the general public): if operators perceive a strong social pressure or expectation to adopt green technologies, they might be more inclined to make investment decisions in these technologies; on the other hand, if social norms still favour the use of traditional technologies, this might negatively influence investment decisions in green technologies
	Perceptual control refers to an individual's perception of his or her ability to successfully perform the considered behaviour	Perceptual control may be related to the availability of financial resources, the technical knowledge required to implement green technologies, and the ability to manage any associated risks: if operators feel they have adequate control over these factors, they may be more inclined to adopt green technologies through investment decisions
Resource Dependence Theory *Organisations seek to ensure access to the resources they need to function and survive*	Dependence on environmental resources	Since Ferry, Ro-Ro and Ro-Pax operators depend on environmental resources, such as fuel, energy and port infrastructure, for their operation, analysis based on Resource Dependence Theory can help assess how the adoption of green technologies affects environmental resource dependence and how this can influence investment decisions

Theoretical constructs	Empirical definition and key elements	Application in the Ferry, Ro-Ro and Ro-Pax industry
	Dependence on stakeholder relationships	Since Ferry, Ro-Ro and Ro-Pax operators may depend on technical and financial resources to implement green technologies, including specialised knowledge, research and development capabilities, access to finance or strategic partnerships with technology providers, analysis based on Resource Dependence Theory can help assess how dependence on these technical and financial resources affects investment decisions in green technologies: if operators are limited in their technical or financial resources, they may be less likely to invest in green technologies
	Dependence on technical and financial resources	Since Ferry, Ro-Ro and Ro-Pax operators depend on relationships with various stakeholders, such as port service providers, customers, regulators and environmental organisations, Analysis based on Resource Dependence Theory can help assess how dependence on stakeholder relationships may influence investment decisions: if customers demand more sustainable shipping services or if regulators impose stricter environmental regulations, operators may be driven to invest in green technologies to maintain and strengthen relationships with these stakeholders
Stakeholder Theory *Provides a broader perspective on the network of influential and interested stakeholders in investment choices*	Organisations should not make decisions based solely on shareholder interests, but should also consider the interests and influences of all stakeholders involved in their business	Stakeholder Theory can provide a useful framework for understanding how green investment decisions meet stakeholder expectations. Since the PhD thesis relies on the main Ferry, Ro-Ro and Ro-Pax companies' sustainability reports as a source of information, it is firstly possible to identify the most relevant stakeholders for each investigated company (customers, suppliers, regulators, local communities, investors and environmental organisations): the analysis of sustainability reports based on Stakeholder Theory allows for an assessment of how Ferry, Ro-Ro and Ro-Pax companies recognise and respond to stakeholder interests regarding green investments (this approach can provide a clear and structured overview of the actions taken by companies and their response to relevant aspects for the stakeholders involved)

Source: Author's elaboration.

The conceptual framework proposed in this PhD thesis is tested by empirically investigating the profitability and feasibility of green investments pursued by European Ferry, Ro-Ro and Ro-Pax companies through a multiple case analysis carried out with data collection via IHS Maritime & Trade. For this purpose, two distinct samples of ships have been designed and populated as reported below and also an in-depth analysis of the green strategies performed by the most active European shipping companies operating in the focused target has been developed.

This first database, i.e., the "overall" or "extended" sample, is an ad hoc dataset on green investment options in the Ferry, Ro-Ro and Ro-Pax industry and has been developed grounding on IHS Maritime & Trade database. As a result, 1,680 Ro-Ro and Ro-Pax ships flying European flags have been identified as eligible by IHS Maritime & Trade.

Through the in deep analysis of ship units belonging to the "overall" sample using alternative and sustainable fuels as their main fuel, an additional dataset, i.e., "green" sample, is developed to identify and map the latest green technologies and investment options adopted by companies operating in the Ferry, Ro-Ro and Ro-Pax industry. The "green" sample is composed by 129 ships and is built by selecting from the database only ship units built from 2019 on, also including ships currently under construction that will be delivered until 2025, to map and deepen the latest green technologies available.

Furthermore, for each group owner part of the "green" sample, information is integrated about listed companies, public controls, golden share, etc, in order to better understand their managerial and governance behaviours. For this purpose, an analysis of the managerial and governance behaviours implemented by group owners is deepened and brief case histories about the main strategies adopted by them are proposed. In this way it has been possible to deepen the attitudes and strategies conducted by individual group owners, with specific focus in the top ten ranking of "top" group owners. To rank the top ten group owners in the "green" sample, two ranking lists have been drawn up: the first one based on the number of ships of the group owner (the first position is occupied by the group owner with the greatest number of ships in the "green" sample) while the second one is based on the GT size of the fleet (the first position is occupied by the group owner with the largest fleet size in terms of gross tonnage in the "green" sample). Then a single final ranking was drawn up weighing 50% both positions in the rankings for each group owners in the "green" sample.

In particular, IHS Maritime & Trade, now a part of S&P[40], holds the largest maritime ships database in the world, with detailed data on over 200,000 ships of 100 GT and above including ships on order and under construction, the current trading fleet, casualty, lost or broken up ships. Since 1764, IHS Maritime & Trade database has been the shipping industry benchmark. This DB is an easy-to-use service that provides a range of search functionalities, from simple searches to complex database queries. It allows the results to be shown in a platform which includes sort, group and features, with the option to export data, combining comprehensive data on ships, ship owners, shipbuilders, fixtures, casualties, port state control, ISM, real-time vessel movements and ports information into a single application.

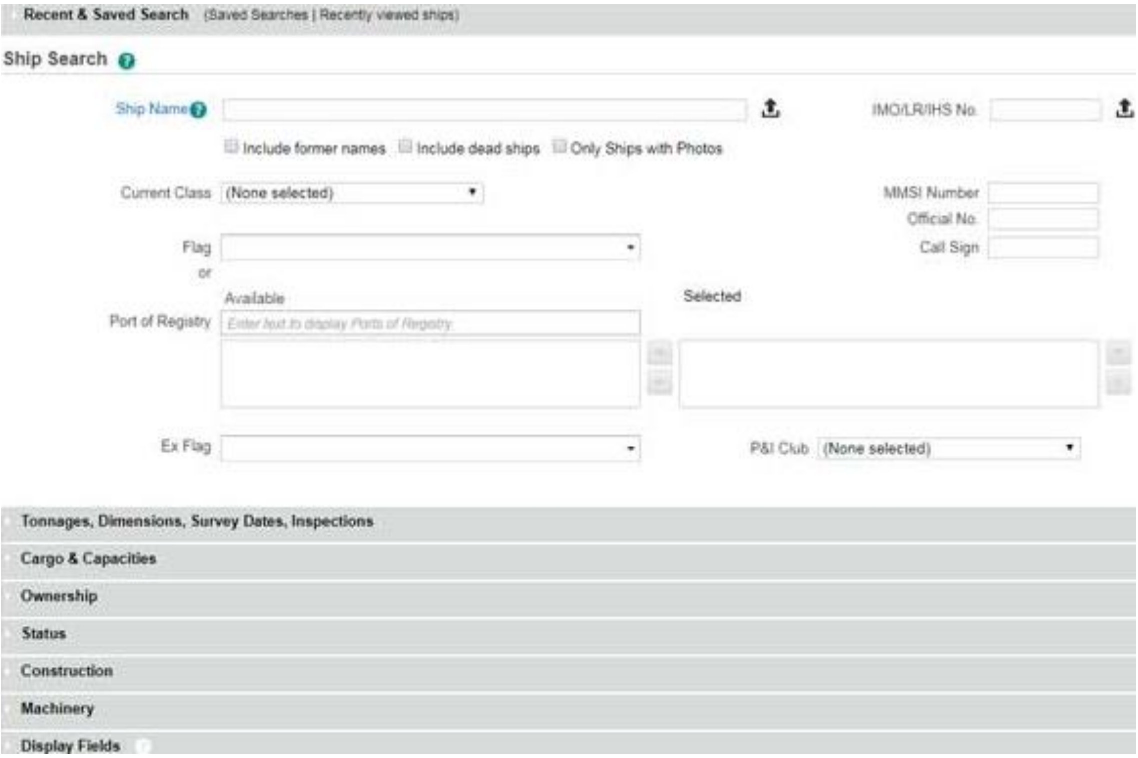
In this PhD thesis, the variables investigated within IHS Maritime & Trade are those regarding main and auxiliary engines, ballast tanks, fuel, hull materials and other technologies and equipment aimed at mitigating the pollution and reducing harmful emissions.

[40] S&P Global is an American publicly traded corporation headquartered in Manhattan, New York City with a primary areas of business in financial information and analytics.

IHS Maritime & Trade database enables data search by entering input in different dedicated sections, as shown in Figure 37 reporting the ship search screen. Such sections include:

- tonnages (DWT, GT, NRT, etc.), dimensions (in terms of length, breadth, depth and draught), survey dates and inspections (date, defects, etc.);
- capacity in term of cargo (TEU, number of Ro-Ro lanes, cars, etc.) and passengers;
- ownership, i.e., name of company, sale price and date, country of domicile, control and registration;
- status of the ship in term of ship in service, keel laid, on order, projected, under construction, etc.;
- construction, in which is collected data related to ship type group, hull type, ship type (tanker, bulk carrier, dry cargo/passenger, work vessel, offshore, etc.), date of built/ordered/keel laid/launched/delivered, shipbuilder, etc.;
- machinery in term of main and auxiliary engines specificities and generators.

Figure 37. Ship search screen from IHS Maritime & Trade.



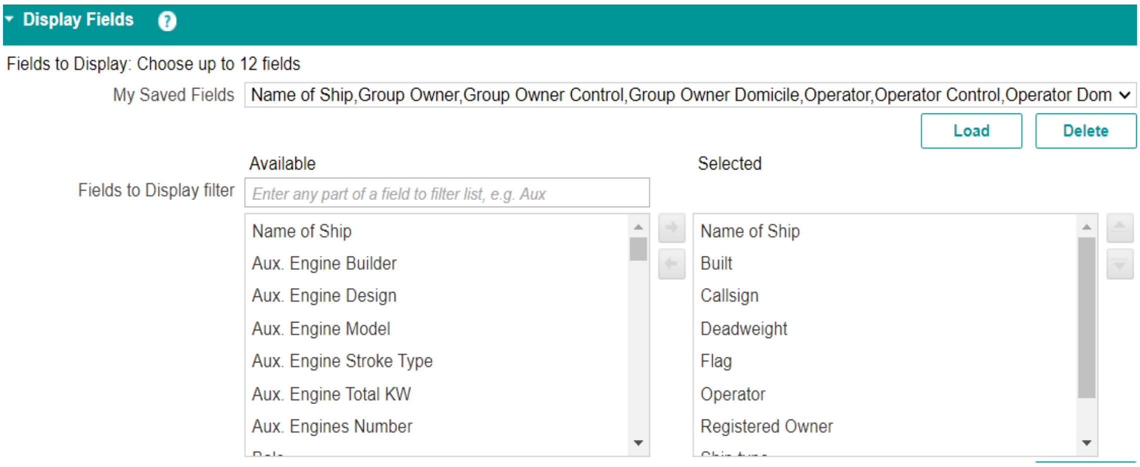
Source: Maritime.ihs.com

Once search input criteria have been entered, it is necessary to select the display options and fields to be returned and the number of results per page to be displayed. “Only” a maximum of 12 fields can be selected and displayed; so, to identify the variables of interest of this PhD thesis, several extractions were required, changing step by step each selection in the fields.

To implement the research conducted as part of this PhD thesis, several selected investigation criteria and information emerged as significative. For this reason, several extractions were needed before identifying all the selected investigation criteria and information. Selected investigation criteria and information are reported below:

- only European Countries have been selected with reference to the flag flown by the ships, in order to consider only companies operating at a European level;
- Ro-Ro cargo ship and Passenger/Ro-Ro cargo ship has been selected as ship type, in reason of the specific industry investigated in this PhD thesis;
- 55 “filed” (in the field interface) are selected to be displayed in the extraction (Figure 38), namely:
  - information related to the ship identification (IMO number, name of the ship, flag, ship type, status, year and year of built, shipbuilders, class) and related dimension (breath, draught, length, DWT, GT, number of decks);
  - information related to the owner, the operator and the management of each ship (group owner, group owner domicile, operator, operator domicile, ship manager and ship manager domicile);
  - ship capacity in term of number of cabins, crew, passengers, cars, RORO lanes (number and length);
  - specificities of the ship such as service speed, the presence of clean ballast and segregated ballast;
  - information related to the engine (main and auxiliary) such as engines number, engine type, engine model, engine stroke, total HP and KW main engine, aux engine number, aux engine stroke type, aux engine design, aux engine builder, aux engine total KW;
  - specificities of generator (generator number and generators KW);
  - type of fuel used and related tank capacity (propulsion type, fuel type 1 and fuel capacity 1, fuel type 2 and fuel capacity 2, fuel consumption main engine, fuel consumption total);
  - characteristic related to the hull (materials and type);
  - other information of the ship such as heating coils, manifold, propeller type.

Figure 38. Display fields screen from IHS Maritime & Trade.



Source: Maritime.ihs.com

6.2 Results from the analysis of the "overall" or "extended" sample (1,680 results)

Considering only 1,680 Ro-Ro and Ro-Pax ships flying European flags identified as eligible by IHS Maritime & Trade, a discussion of the main findings concerning the following issues will be presented:

- ship type, ship dimensions (DWT[41] and GT[42]) and ship capacity (passengers and linear metres), age of ship;
- ship status, to understand how many ships of the sample are in operation, under construction and laid up;
- the flag (nationality) of the ship,
- ship classification society in order to identify the class in which ships are registered;
- ship operators, group owner and ship manager;
- shipbuilder and building site;
- type of fuel used as main fuel by ships.

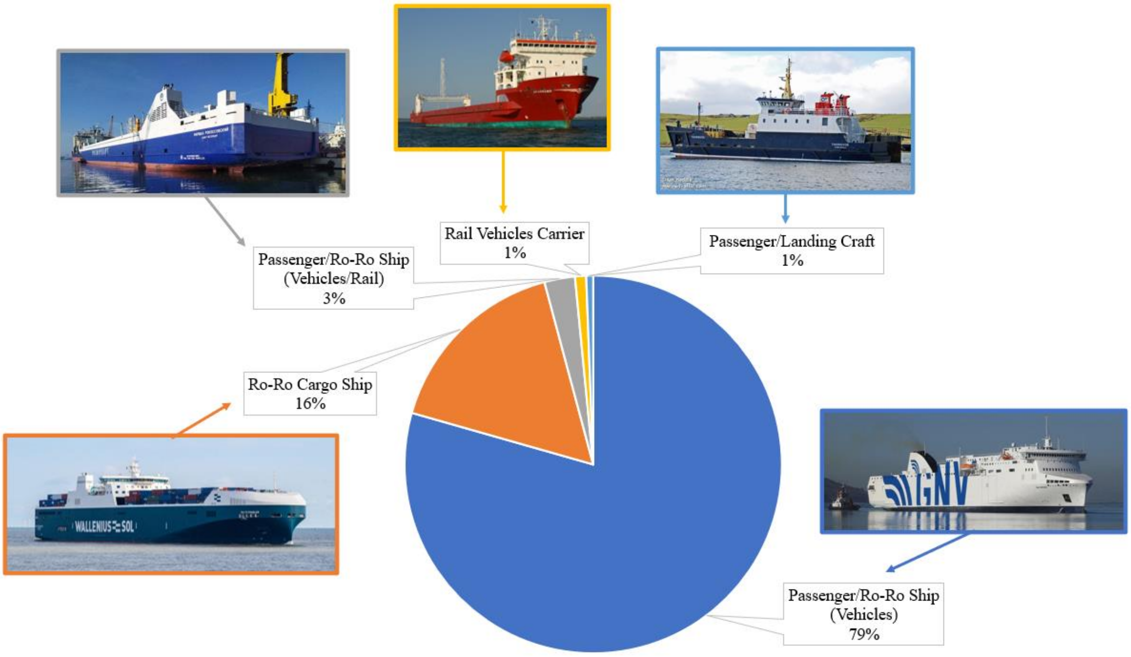
[41] Deadweight tonnage is a measurement of how much weight a ship can carry, including cargo, fuel, crew, passengers, food, water and not including the empty weight of the ship.
[42] Gross tonnage is a measure of a ship's overall internal volume (GT applies to the vessel, not to cargo) and is determined by dividing by 100 the contents, in cubic feet, of the vessel's enclosed spaces.

As already mentioned, the sample consists of 1,680 ships, for a total Gross Tonnes of 19 million GT and a passenger capacity of more than 830 thousand people (over 63,000 cabins) and freight transport amounted to about 1.4 million linear meters.

6.2.1 Ship type distribution in the sample

For the analysis of the ship types within the sample (1,680 Ferry, Ro-Ro and Ro-Pax ships), the selection of European flags related to Ro-Ro cargo ship and Passenger/Ro-Ro cargo ship (as ship type) on IHS Maritime & Trade has generated an extraction of 1,334 ship units falling within the Passenger/Ro-Ro Ship category (Vehicles), 276 Ro-Ro Cargo Ships, 44 Passenger/Ro-Ro Ships (Vehicles/Rail), 16 Rail Vehicles Carriers and 10 Passenger/Landing Crafts (Figure 39). The main ship category of the sample, i.e., the Passenger/Ro-Ro Ship (Vehicles) category, includes both Ro-Pax ferries, i.e., conventional ships with a relatively large passenger and cargo capacity, able to transport passengers with private cars and commercial vehicles with drivers, and Cruise ferries, that combines features of (Ro-Pax) ferries with those of cruise ships. Ro-Ro Cargo Ships are ferries designated to transport only trailers, semi-trailers, commercial vehicles, truck, etc., and their drivers. Passenger/Ro-Ro Ships (Vehicles/Rail) are ships which can carry vehicles and trains / railway vehicles: usually one level of the ship is fitted with railway tracks, and the vessel has a door at the front and/or rear to give access to the wharves. Passenger/Landing Craft ship type is the residual category of the sample, used for carrying cargo, but can also carry passengers.

Figure 39. Ship type distribution.

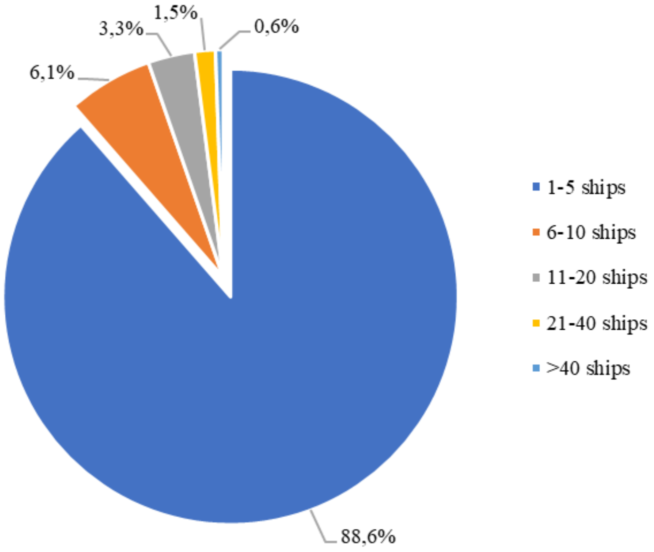


Source: Author's elaboration.

6.2.2 Analysis of fleet dimension in the sample

The sample was also examined considering the size of the operators in terms of the fleet of Ferries, Ro-Ro and Ro-Pax ships owned. For this reason, ships are grouped in different fleet dimension classes per each operator, namely between 1 and 5 ships; 6 and 10 ships; 11 and 20 ships; 21 and 40 ships and over 40 ships (Figure 40). Of the 543 operators included in the sample, 481 operators (89%) detain a small fleet (composed by 1-5 Ferries, Ro-Ro and Ro-Pax ships) of which 321 have only a single ship in their fleet, probably because of the diversification of the activities and operations of the operators. An example is represented by KTZ Express JSC, a multimodal company that provides a full range of transport and logistics services (transport by rail, sea, and road).

Figure 40. Distribution of operator's fleet dimension.

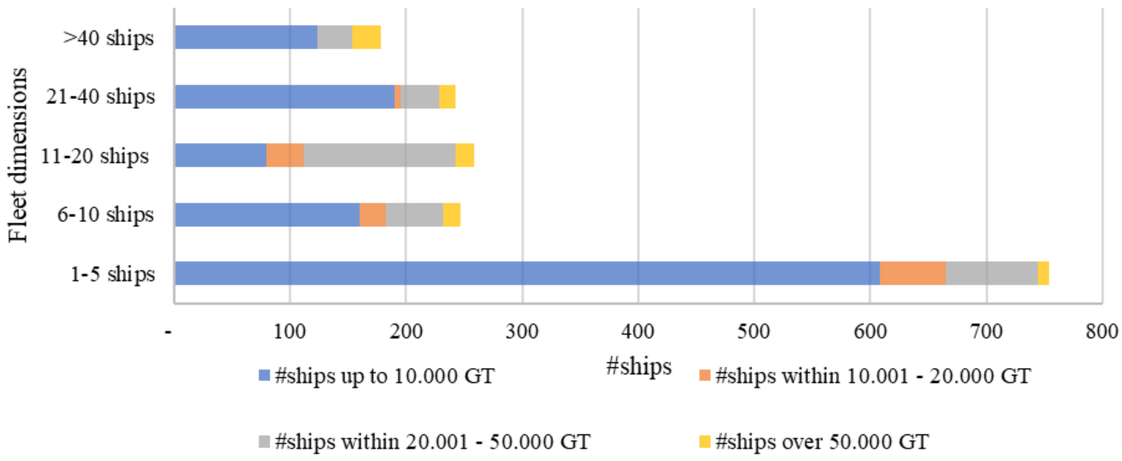


Source: Author's elaboration.

6.2.3 Analysis of ship dimension and ship capacity

To classify Ferry, Ro-Ro and Ro-Pax ships included in the sample in term of GT, 4 ship dimension classes have been defined, namely the categories "up to 10.000 GT", "10.001-20.000 GT", "20.001-50.000 GT" and "over 50.000 GT". The first class of GT, "up to 10.000 GT", represents 69% of the sample, so more than a half of the Ferry, Ro-Ro and Ro-Pax ships of the sample are smaller in terms of GT. This category accounts for 90% of Passenger/Ro-Ro Ships (Vehicles), and, despite the residual nature of the remaining component, it should be noted that the remaining part also includes 69% of Rail Vehicles Carriers and all Passenger/Landing Craft ships belonging to the entire sample. In the sample, ships with GT falling within the 20.001-50.000 GT class represent 19% of the sample and belong to the Passenger/Ro-Ro Ship (Vehicles) and Ro-Ro Cargo Ship categories. The ship dimension class of "10.001-20.000 GT" represent only 7% of the sample and includes, for more than 57%, the Passenger/Ro-Ro Ship (Vehicles/Rail) and Rail Vehicles Carrier categories. Finally, 54 Ro-Ro Cargo Ships and 26 Passenger/Ro-Ro Ships (Vehicles) belong to the dimension class "over 50.000 GT". Figure 41 shows the distribution of the fleet dimensions per each class / category of GT.

Figure 41. Distribution of the fleet dimensions per GT class.



Source: Author's elaboration.

The "passengers" and "RORO Lanes Length" drivers identify the transport capacity in terms of number of passengers and linear metres of the single ship units. The ship capacity in terms of transportable passengers is calculated for passenger/Ro-Ro ship (vehicles), passenger/Ro-Ro ships (vehicles/rail) and passenger/landing crafts, while the ship capacity in terms of linear meters is quantified for the ships that transport purely goods, trucks, semi-trailer trucks, trailers, that fall within the Ro-Ro cargo ship and rail vehicles carrier typologies.

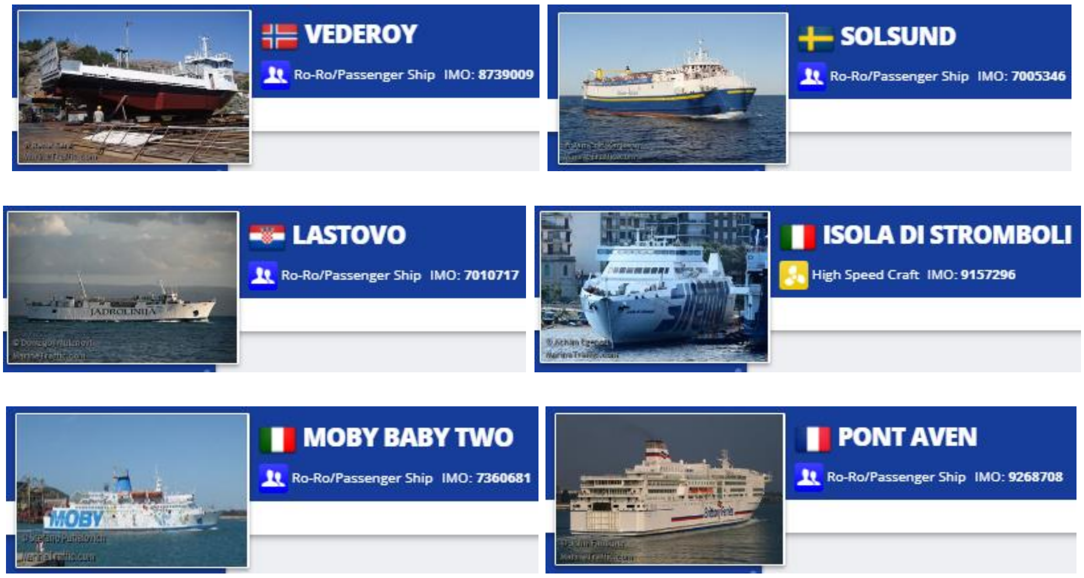
For purely passenger ships, it should be considered that IHS Maritime & Trade did not extract transport capacity in terms of passenger for 210 ships, reducing the sample to only 1,178 ships among passenger/Ro-Ro ships (vehicles), passenger/Ro-Ro ships (vehicles/rail) and passenger/landing craft ships. Within this analysis, classes of passenger transport capacity have been defined in order to classify different types of ships: in Table 13 the classes of transport capacity in term of passengers, the related number of ships and an example of ship per each category with related operational area is displayed, while in Figure 42 some illustrative images are reported.

Table 13. Class of passenger transport capacity in the sample.

Passenger transport capacity	#ships	Example of ship in the sample	Operating area
0-99 pax	95	MV Vederoy	Horten and Bastøy Island (Norway)
100-299 pax	273	MV Solsund	Kalmar and Färjestaden (Sweden)
300-499 pax	221	MV Lastovo	Gazenica and Lussinpiccolo Island (Croatia)
500-999 pax	288	MV Isola di Stromboli	Sicily and Aeolian Islands (Italy)
1,000-2,099 pax	245	MV Moby Baby Two	Elba Island and Tuscany (Italy)
>2,100 pax	56	MV Pont Aven	France and England (English Channel)
Total	**1.178**		

Source: Author's elaboration.

Figure 42. Examples of passenger ships in the sample.



Source: MarineTraffic.com

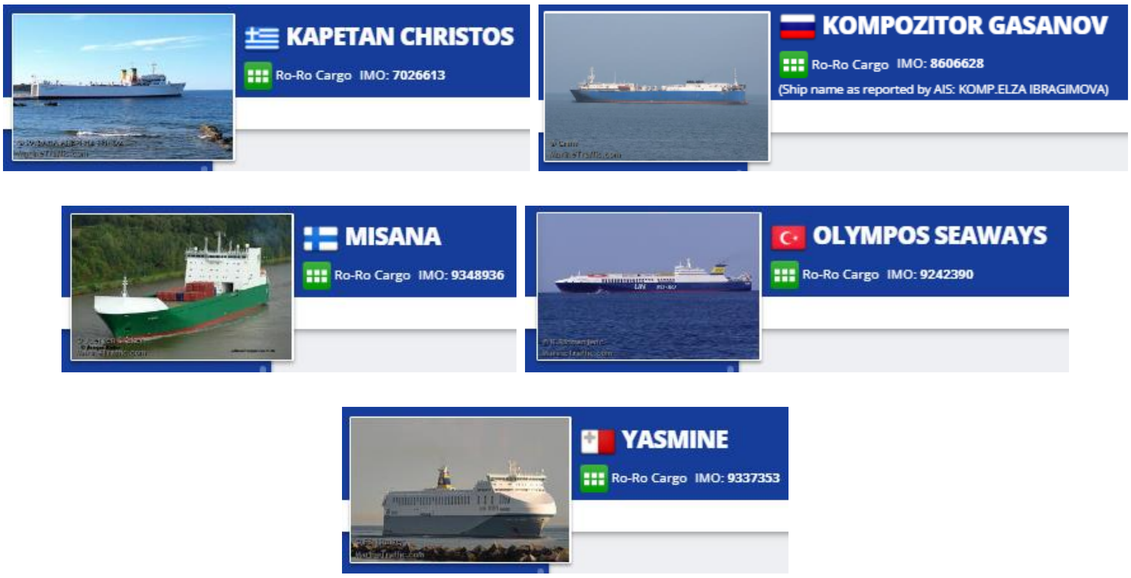
For purely cargo ships, it should be considered that IHS Maritime & Trade did not extract transport capacity in term of linear metres for only 24 ships, reducing the sample to 268 ships among Ro-Ro cargo ships and rail vehicles carriers. Within this analysis, classes of linear metres transport capacity have been defined in order to classify different ships types: in Table 14 the classes of transport capacity in terms of linear metres, the related number of ships and an example of ship per each category with related operational area are reported, while Figure 43 provides some illustrative images.

Table 14. Class of ML transport capacity in the sample.

Linear metres (LM) transport capacity	**#ships**	**Example of ship in the sample**	**Operating area**
0-699 LM	33	MV Kapetan Christos	Mikonos Island and Elefis (Greece)
700-1,199 LM	27	MV Kompozitor Elza Ibragimova	Novorossiysk and Kavkaz (Russian)
1,200-2,399 LM	58	MV Misana	Norway with Netherlands (North Sea)
2,400-3,599 LM	56	MV Olympos Seaways	Italy with Turkey (Adriatic Sea)
>3,600 LM	94	MV Yasmine	Belgium with United Kingdom
Total	**268**		

Source: Author's elaboration.

Figure 43. Examples of cargo ships in the sample.

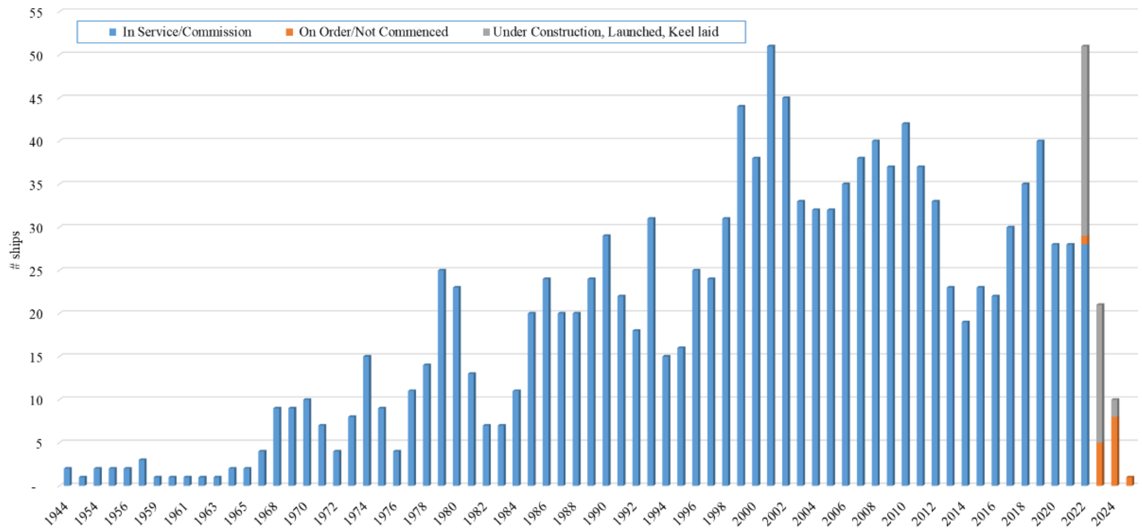


Source: MarineTraffic.com

6.2.4 Ship age distribution in the sample

Considering only "in service" and "in operation" ships, this PhD thesis analysed the current age of the sample ships from the date of built and the related distribution over the years. Also, the period from 2022 to 2025 was considered in this analysis, in order to show how many ships are currently under construction and on order/not commenced. Figure 44 shows that starting from 2022, 15 ships will enter in service until 2025. The remaining 45 ships currently under construction will come into operation by 2023-2024.

Figure 44. Year of built distribution in the sample.



Source: Author's elaboration.

Some examples of newbuilding that will enter into operation in 2024 are IMO 9969730, belonging to Balearia Eurolineas Maritimas; IMO 9946336, operating by Brittany Ferries BAI SA and owned by Stena AB; IMO 9977206 from Caronte & Tourist SpA and IMO 9935040 belonging to Grimaldi Group SpA. In

Table *15* some data concerning the above-mentioned new buildings is provided.

Table 15. Examples of newbuilding's in the sample.

IMO No.	Name of Ship	Ship Type	Flag	DWT	GT	Operator	Group Owner	Class	Passengers	RORO Lanes Length	Fuel Type 1
9977206	SEFINE 60	Passenger/Ro-Ro Ship (Vehicles)	Italy	11.742	8.778	Caronte & Tourist SpA	Caronte Shipping SpA	Registro Italiano Navale (RI)	1.500	n.a.	LNG
9969730	ARMON GIJON G026	Passenger/Ro-Ro Ship (Vehicles)	Cyprus	1.339	17.769	Balearia Eurolineas Maritimas	Balearia Eurolineas Maritimas	Bureau Veritas (BV)	1.200	1.125	LNG
9946336	CHINA MERCHANTS JL WEIHAI W0278	Passenger/Ro-Ro Ship (Vehicles)	Cyprus	5.495	30.000	Brittany Ferries BAI SA	Stena AB	Det Norske Veritas (NV)	1.400	2.517	LNG
9935040	HYUNDAI MIPO 8363	Ro-Ro Cargo Ship	Italy	45.700	85.000	Grimaldi Group SpA	Grimaldi Group SpA	Registro Italiano Navale (RI)	n.a.	4.700	Distillate Fuel

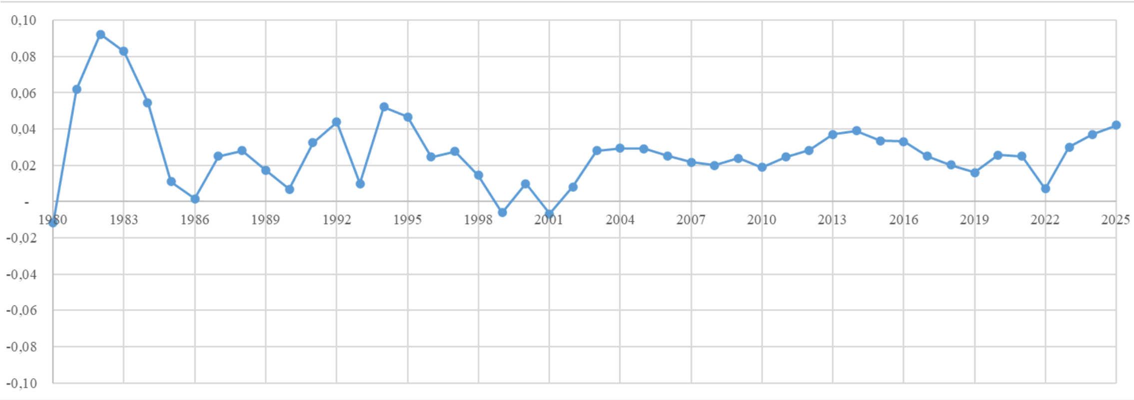
Source: Author's elaboration.

Focusing on the ship sample, to date ship units that have been "stopped" and that are "in causality or repairing" are between 30 and 60 years old. 88% of such units have small dimensions, up to 10,000 GT. Furthermore, the extraction on IHS Maritime & Trade has also identified all Ferry, Ro-Ro and Ro-Pax ships with European flag that are, to date, stopped/out of range, in laid up and to be broken up. To date, these no longer operational units have an average age of about 45 years.

The 209 ships that are no longer operational have given way to the new buildings, that are now partly operational and partly on order/not commenced or launched or under construction or with their keel laid. Indeed, considering the last 10 years, 281 ship units entered in service and most of them are Passenger/Ro-Ro Ship (Vehicles) with up to 10.000 GT. Furthermore, 55 ship units are now under construction and will be delivered over the next 3 years. In this context, it is therefore possible to say that during the last 10 years and in the next 3 years the Ferry, Ro-Ro and Ro-Pax fleet with European flag has undergone and will be subject to a significant renewal.

Figure 45 shows the trend of the rate of increase of the average age of the sample fleet per year, considering Ferry, Ro-Ro and Ro-Pax ships in operation and in service (until 2022) and, for next the 3 years, also those on order/not commenced, launched, under construction and with the keel laid. The trend shows that the growth rate of the average age of the fleet has almost stabilised only since the 2000s. Indeed, since 2003 the average ageing rate of the fleet has varied, year by year, between +2 and +4%, compared to the previous year. This trend is confirmed also considering ships will enter into operation on the market from 2023 to 2025.

Figure 45. Trend of the rate of increase of the average age of the fleet per year.



Source: Author's elaboration.

Considering the average age per type of ship, i.e., Passenger/Landing Craft, Passenger/Ro-Ro Ship (Vehicles), Rail Vehicles Carrier, Ro-Ro Cargo Ship, it can be said that Passenger/Landing Crafts are the oldest ship type of the sample (average age of 30 years), followed by Passenger/Ro-Ro Ship (Vehicles/Rail) and by Passenger/Ro-Ro Ship (Vehicles) with an average age of more than 24 and 22 years, respectively. The youngest ship type is represented by Ro-Ro Cargo Ship (average age of less than 16 years) followed by Rail Vehicles Carriers, with an average age of about 21 years.

6.2.5 Ship status analysis

The sample is analysed also focusing on the ship status of the 1,680 Ferry, Ro-Ro and Ro-Pax ships sample. To deepen the ship status of the sampled ships, for the oldest ones (built until the 2000s) a specific search for each ship has been conducted on Marine Traffic, i.e., the world's leading provider of ship tracking and maritime intelligence. In this way the exact status of the units has been found (

Table *16*): about 80% of the ships are "in Service/Commission" and operated in Europe and in the Mediterranean Sea; about 12% of them are "stopped/out of range" and/or "laid-up"; 5% are "stopped", "in casualty or repairing" and/or "to be broken up" status; 3% of the sample units have been launched, keel laid, under construction and/or on order/not commenced yet (

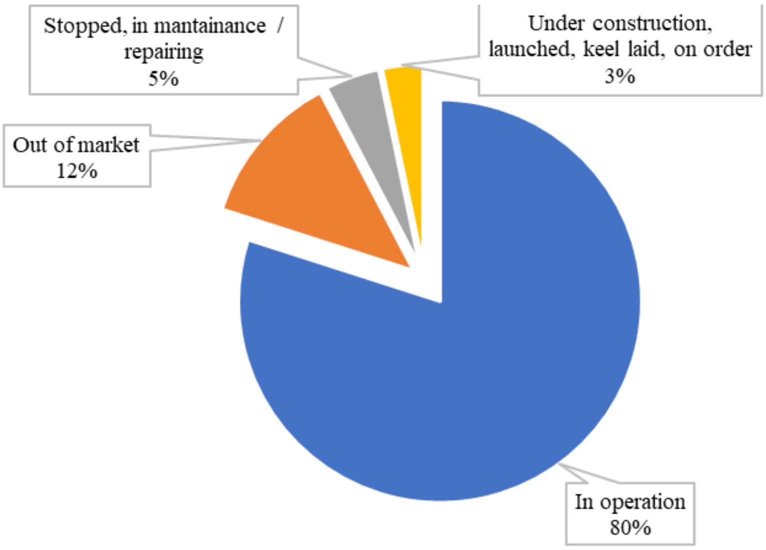
Figure *46*).

Table 16. Status of ship sample.

Ship status	**#ships**	**%**
In Service/Commission	1.343	68,49%
Stopped/out of range	195	9,94%
Stopped	66	3,37%
Launched	21	1,07%
Keel Laid	15	0,76%
On Order/Not Commenced	15	0,76%
Laid-Up	13	0,66%
In Casualty Or Repairing	7	0,36%
Under Construction	4	0,20%
To Be Broken Up	1	0,05%
Total	**1.961**	

Source: Author's elaboration.

Figure 46. Ship status distribution.



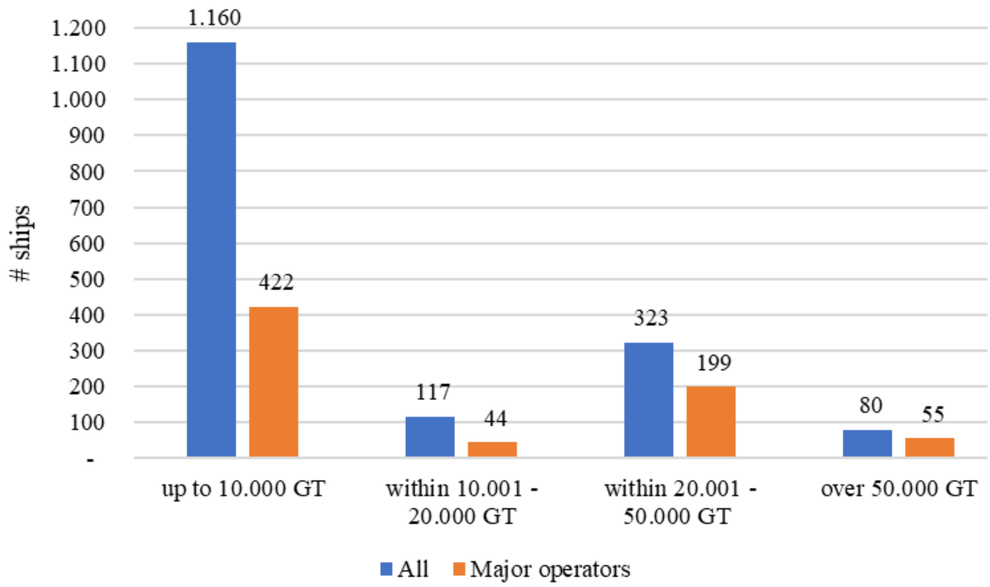
Source: Author's elaboration.

6.2.6 Analysis of Ferry, Ro-Ro and Ro-Pax operators, group owner and ship manager in the sample

Through this analysis, 33 operators were identified, representing the 6% of the sample operators, together operating 720 ships (43% of the sample). In this way, it was possible to classify the dimension in term of GT of Ferry, Ro-Ro and Ro-Pax ships belonging to the operators' fleet, by identifying the categories "up to 10.000 GT", "within 10.001 - 20.000 GT", "within 20.001 - 50.000 GT" and "over 50.000 GT" (

Figure 47).

Figure 47. GT class distribution.



Source: Author's elaboration.

In order to analyse the major European ferry operators, the four above mentioned ship dimension classes are taken into account. According to the analysis conducted on European ferry operators, 69% of them are of large dimensions since they operate a fleet composed by Ferry, Ro-Ro and Ro-Pax ships over 50.000 GT, and this means that bigger ships are operated mainly by operators that holds a large fleet (10-81 ships). Some examples are Grimaldi Group SpA, Grimaldi Euromed SpA, CLdN Ferries NV and Finnlines Plc. On the contrary, the Ferry, Ro-Ro and Ro-

Pax ships with dimensions up to 10.000 GT are operated mainly by smaller operators: so, the 89% of European operators in the sample holds only 1-5 ships (of which 81% with dimensions up to 10.000 GT). Also, major operators in the sample own ships with dimensions up to 10.000 GT: operators such as Fjord1 ASA, Torghatten Nord AS, Jadrolinija, Norled AS, Boreal Sjo AS, CalMac Ferries Ltd, Istanbul Deniz Otobusleri and Torghatten Midt AS operate 22 to 81 ships in their fleet and all up to 10.000 GT. In the sample, 62% of Ferry, Ro-Ro and Ro-Pax ships with dimensions ranging between 20.001 and 50.000 GT are held by major European operators. Shipping companies such as Grimaldi Group SpA, CLdN Ferries NV, Finnlines Plc, Grandi Navi Veloci SpA, operate 17-30 ships of 20.001-50.000 GT.

Considering the operators' domicile, Greece ranks first in the sample (accounting for 133 operators), followed by Norway (68 operators), Italy (40 operators) and Turkey (40 operators). Focusing only on major European ferry operators, this distribution is partially confirmed: 7 big operators are from Italy, 6 of them from Norway, 3 from Finland and 3 from Turkey. Table 17 shows the main European ferry operators of the sample, that are operators holding a fleet equal to or greater than 10 Ferry, Ro-Ro and Ro-Pax ships.

Table 17. Major European ferry operators in the sample.

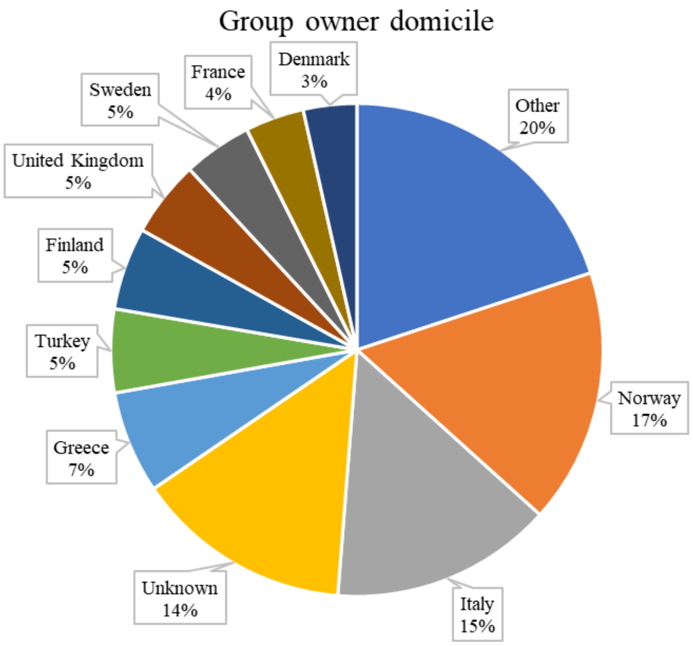
Operators	Operators domicile	#ships	#ships up to 10.000 GT	#ships within 10.001 - 20.000 GT	#ships within 20.001 - 50.000 GT	#ships over 50.000 GT
Fjord1 ASA	*Norway*	81	100%	0%	0%	0%
Grimaldi Group SpA	*Italy*	55	0%	0%	55%	45%
Torghatten Nord AS	*Norway*	42	100%	0%	0%	0%
Jadrolinija	*Croatia*	40	98%	3%	0%	0%
Norled AS	*Norway*	38	100%	0%	0%	0%
Boreal Sjo AS	*Norway*	33	100%	0%	0%	0%
CalMac Ferries Ltd	*United Kingdom*	33	100%	0%	0%	0%
CLdN Ferries NV	*Belgium*	26	0%	4%	65%	31%
Finnlines Plc	*Finland*	25	0%	12%	68%	20%
Istanbul Deniz Otobusleri	*Turkey*	25	100%	0%	0%	0%
Torghatten Midt AS	*Norway*	22	100%	0%	0%	0%
DFDS A/S	*Denmark*	18	0%	17%	83%	0%
DFDS Denizcilik ve Tasimacilik	*Turkey*	18	0%	6%	83%	11%
Grandi Navi Veloci SpA	*Italy*	18	0%	0%	100%	0%
Moby SpA	*Italy*	18	28%	17%	44%	11%
Balearia Eurolineas Maritimas	*Spain*	17	24%	35%	35%	6%
Suomen Lauttaliikenne Oy	*Finland*	17	100%	0%	0%	0%
Grimaldi Euromed SpA	*Italy*	16	0%	0%	44%	56%
Azerbaijan Caspian Shipping	*Azerbaijan*	15	53%	47%	0%	0%
Molslinjen AS	*Denmark*	14	71%	29%	0%	0%
Brittany Ferries BAI SA	*France*	13	0%	0%	100%	0%
Corsica Ferries France SA	*France*	13	8%	23%	69%	0%
Gestas Deniz Ulasim Turizm	*Turkey*	13	100%	0%	0%	0%
Stena Line Scandinavia AB	*Sweden*	13	8%	15%	62%	15%
Compagnia Italiana Di Navigaz	*Italy*	12	0%	8%	92%	0%
Transfennica	*Finland*	12	0%	8%	92%	0%
Caronte & Tourist Isole Minori	*Italy*	11	91%	9%	0%	0%
Caronte & Tourist SpA	*Italy*	11	91%	0%	9%	0%
Tallink Group Ltd	*Estonia*	11	0%	9%	82%	9%
Blue Star Ferries SA	*Greece*	10	0%	60%	40%	0%
Scotland Govt Shetland	*United Kingdom*	10	100%	0%	0%	0%
Service Transports de Mayotte	*Mayotte*	10	100%	0%	0%	0%
Tide AS	*Norway*	10	100%	0%	0%	0%

Source: Author's elaboration.

Considering group owners of ships sample, Fjord1 ASA (Norway), Grimaldi Group SpA (Italy) and Norled AS (Norway) represent the 3 major group owners of all sample, with a fleet of 81, 77 and 48 ships, respectively. The first 3 group owners of the sample are followed by Torghatten Nord AS (Norway, 42 ships), Jadrolinija (Croatia, 40 ships), Caledonian Maritime Assets Ltd (United Kingdom, 36 ships), Veolia Transport (France, 33 ships), Caronte Shipping SpA (Italy, 30 ships), Finnlines Plc (Finland, 25 ships), Tirrenia di Navigazione SpA (Italy, 25 ships), Istanbul Deniz Otobusleri (Turkey, 23 ships), Grandi Navi Veloci SpA (Italy, 21 ships) and Stena AB (Sweden, 20 ships).

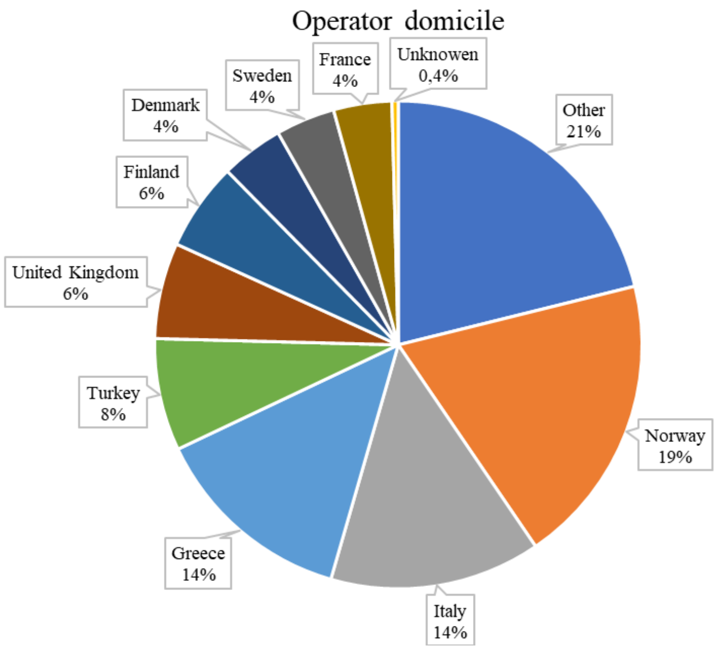
In this context, Figure 48 and Figure 49 show, respectively, the distribution of the domicile of group owners and operators included in the sample. The nation of domicile of operators and group owners of the sample partially matches, which means that frequently the group owner coincides with the operator. However, sometimes there are scenarios where this doesn't happen, meaning that the operator of the ship isn't also the group owner and this is the case of Brittany Ferries BAI SA, whose ships are partly owned by Brittany Ferries (France) while others are owned by Stena AB (Sweden), ICBC Financial Leasing Co Ltd (France) and Bank of Communications (China).

Figure 48. Distribution of group owners' domicile in the sample.



Source: Author's elaboration.

Figure 49. Distribution of operators' domicile in the sample.



Source: Author's elaboration.

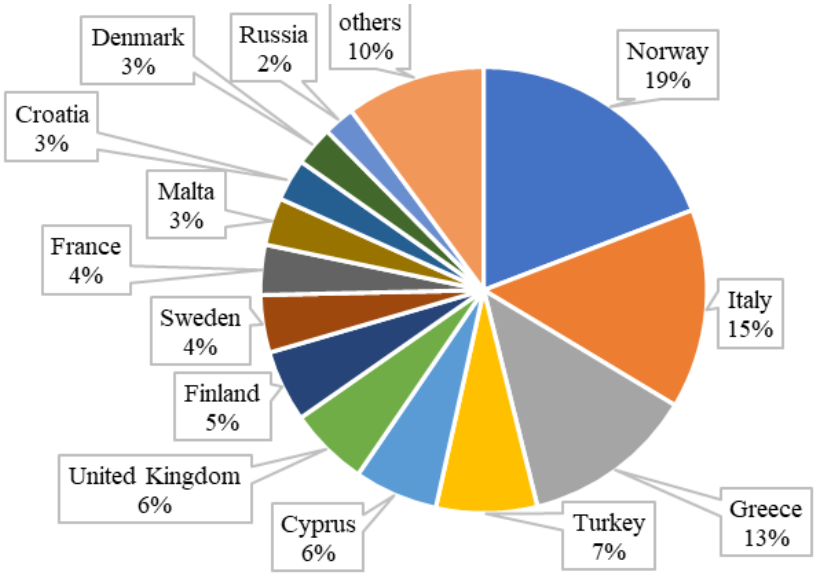
6.2.7 Maritime flag and ship classification society distribution

The Maritime Flag is a flag designated for use onboard ships because it represents the nationality of the ship, i.e., the ship is under the control of the registered country. Depending on the flag flown, the ship must comply with international and maritime law of the registered country in the open sea, thus solving a variety of ocean conflicts. For the sample analysis, only Ferry, Ro-Ro and Ro-Pax ships flying European flags have been selected. Within 1,680 ships sample, Norway, Italy, Greece, Turkey and Cyprus represent more than the majority of the flag countries of the sample (about 60%) while United Kingdom, Finland, Sweden, France, Malta, Croatia and Denmark together reach 28% of the entire sample (Figure 50 and Figure 51).

Figure 50. Geographical representation of the EU flag countries of the sample ships.

Source: Author's elaboration.

Figure 51. Distribution representation of the EU flag countries of the sample ships.

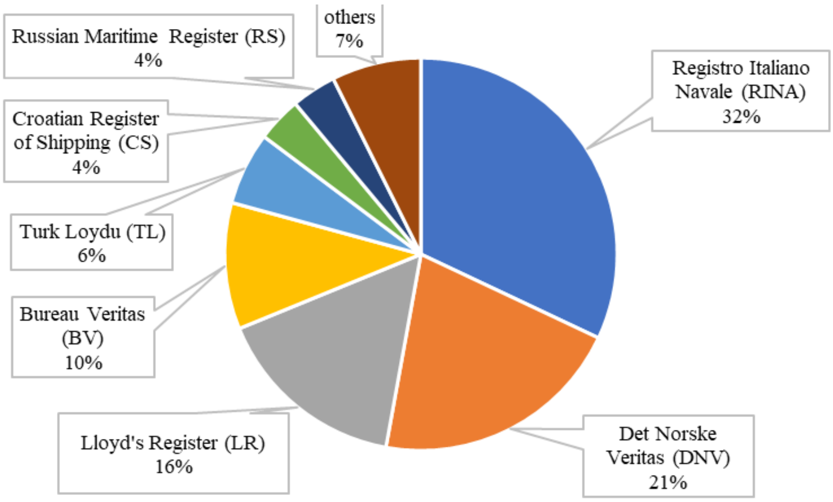


Source: Author's elaboration.

The analysis of the flag country of the ships sample shows that Italy has a central role at European level in the Ferry, Ro-Ro and Ro-Pax industry, representing alone about 15% of the sample, and this is confirmed with the analysis of the ship classification society of the ships sample (Figure 52). Ship classification societies or ship classification organizations are non-governmental organizations that establish and maintain technical standards for the construction and operation of ships. Classification societies certify that the construction of a vessel complies with standards and carry out regular surveys to ensure continuous compliance with the standards. Currently, more than 50 organizations operate in marine classification and eleven of them are members of the International Association of Classification Societies[43]. The classification registries take into account only launched, Keel laid and in service/operation ships (1,378 ships). Among them, for 22% of the ships, IHS Maritime & Trade has indicated the registry of classification as “unknown”. For this reason, the analysis has been conducted on the available classification registers extracted from the DB. Figure 52 shows the distribution of the classification registers within the sample: Registro Italiano Navale (RINA) plays a central role at European level in the Ferry, Ro-Ro and Ro-Pax industry, representing alone about 32% of the sample, following by Det Norske Veritas (DNV, 21%), Lloyd’s Register (LR, 16%) and Bureau Veritas (BV, 10%). RINA is a private, multinational company headquartered in Genoa, Italy and the ship classification has been at the core of its business: today RINA is one of the top-ranking marine classification societies in the world. Det Norske Veritas (formerly DNV-GL) is an international accredited registrar and classification society headquartered in Norway and is authorized by 130 maritime administrations to perform certification or verification on their behalf. Lloyd’s Register is a global professional services company specialised in engineering and technology for the maritime industry: it is the world’s first marine classification society, founded in 1760 to improve the safety of ships. Bureau Veritas is a French company specialized in testing, inspection and certification founded in 1828; it is one of the leading classification societies and a founding member of IACS.

Figure 52. Distribution of classification registers of the sample.

[43] IACS makes a unique contribution to maritime safety and regulation through technical support, compliance verification and research and development. Among members of IACS, American Bureau of Shipping, Bureau Veritas, Croatian Register of Shipping, DNV, Indian Register of Shipping, Lloyd’s Register, Korean Register, Nippon Kaiji Kyokai, Polish Register of Shipping, Registro Italiano Navale.



Source: Author's elaboration.

6.2.8 Shipbuilders distribution

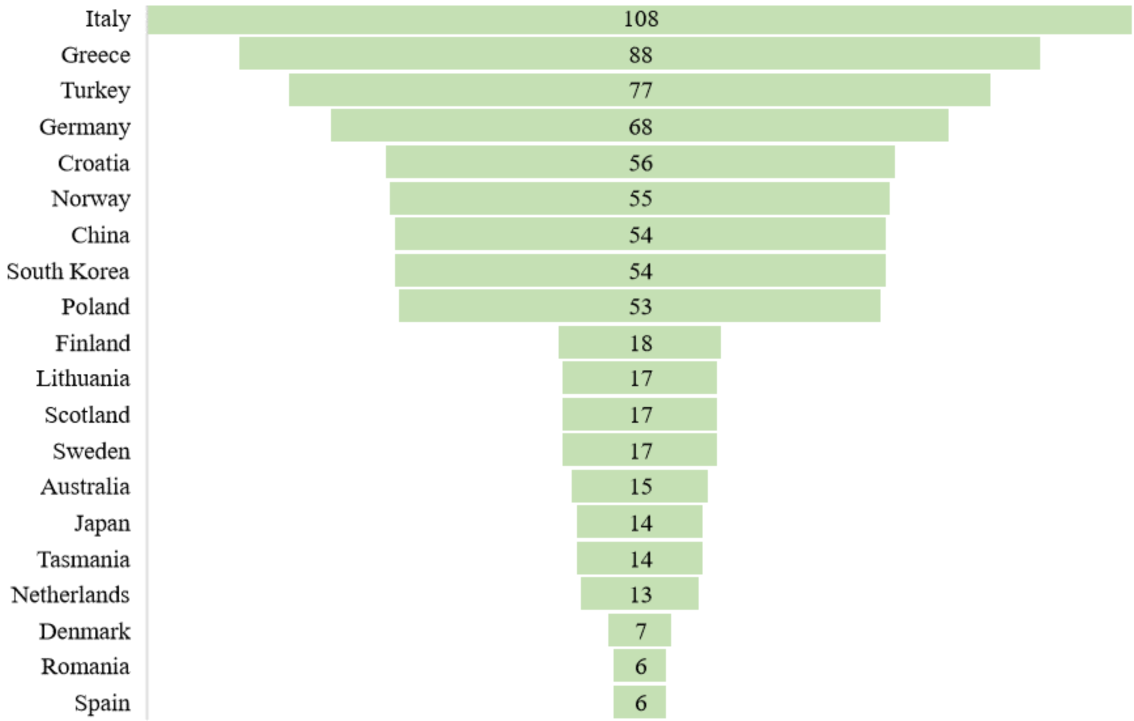
For the analysis of the construction of the ships of the sample, 544 shipyards worldwide have been identified. 76% of the shipyards built only 1 to 3 ships; consequently, they are considered as small shipyards, referring to the Ferry, Ro-Ro and Ro-Pax industry.

Shipyards that have constructed more than 5 ships belonging to the sample were identified as "major shipbuilders" of Ferry, Ro-Ro and Ro-Pax ships. Those shipbuilders represent 12% (65 different shipyards) of the shipbuilders in the sample, as they have built, altogether, 757 Ferry, Ro-Ro and Ro-Pax ships (representing the 45% of the ship sample). Of 65 major shipyards, Flensburger KG, in Germany, has built 39 ships of the sample, Hyundai Mipo Dockyard Co Ltd, in South Korea, has built 37 and Visentini Shipyard Srl, in Italy, 34 units. The Country of domicile of the major shipyard has been then identified, in order to characterize where the major shipyards in the world are located.

Among major shipyard in Ferry, Ro-Ro and Ro-Pax industry, those located in Italy represent alone 14% of all major shipyard in the sample, with shipyards as Visentini Cantiere Navale Srl (34 ships) and Visentini F&C (8 ships), Nuovi Cantieri Apuania SpA (21 ships), Fincantieri Stabia (16 ships), Palermo (15 ships) and Ancona (7 ships), Luigi Orlando (7 ships). In the ranking of the main shipyards in the Ferry, Ro-Ro and Ro-Pax industry, Greece and Turkey, place second and third, having built 88 ships in 8 shipyards and 77 ships in 7 shipyards, respectively (

Figure 53).

Figure 53. Geographical distribution of major shipbuilding in the sample.



Source: Author's elaboration.

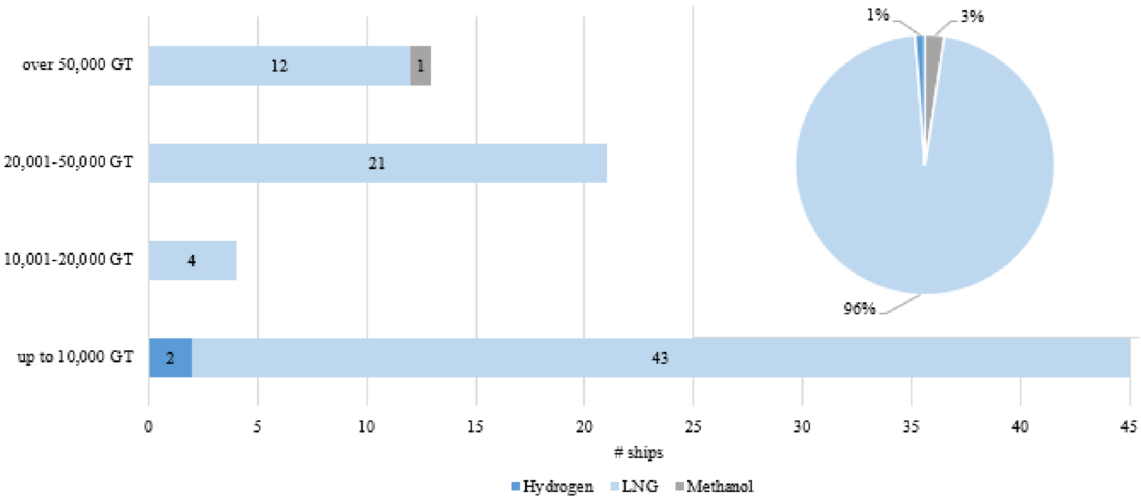
6.2.9 Fuel type

Due to the strategic issues covered in this PhD thesis, i.e., green strategies and green investment options in the Ferry, Ro-Ro and Ro-Pax industry, an in deep analysis on ship unites using alternative and sustainable fuels as first fuel type has been carried out. 63% of the ships in the sample use distillate fuel for their propulsion, i.e., fuel as marine gas oil (MGO) and marine diesel oil (MDO). These are the distillate fuels and used mostly in high and medium speed engines and gensets. Such fuels are characterized by a low viscosity and flash point and a lower energy content measured by volume (by weight they have a higher energy content) than more viscous fuels but are generally cleaner and produce fewer polluting emissions.

For 511 out of 1,680 Ferry, Ro-Ro and Ro-Pax vessels belonging to the sample, the type of fuel used could not be found, also because some ships were in stop, out of range, not in service or on order/under construction. Only 1% of the ship sample used residual fuel for the propulsion, such as hydrogen. According to the International Maritime Organization's (IMO) Third Greenhouse Gas Study, HFO is the most widely used type of fuel for ships, representing 86% of ship fuel used worldwide. HFO is cheaper than other fuels because it is the leftover or residual product from the oil refining process.

Only 5% of the sample ships use alternative fuels for propulsion. Specifically, 80 ship units in the sample use LNG, 2 ships use hydrogen and only one ship operates with methanol. It should be noted how 66% of the vessels in the sample using alternative fuel for the propulsion, are not yet operating and in service, but they are still under construction or on order/not yet commenced. Moreover, in terms of the size of ships using alternative fuels for propulsion, it must be noted that 54% of them are up to 10.000 GTs. This confirms that, in the Ferry, Ro-Ro and Ro-Pax industry, the main green and sustainable strategies are adopted especially by companies operating small ships.

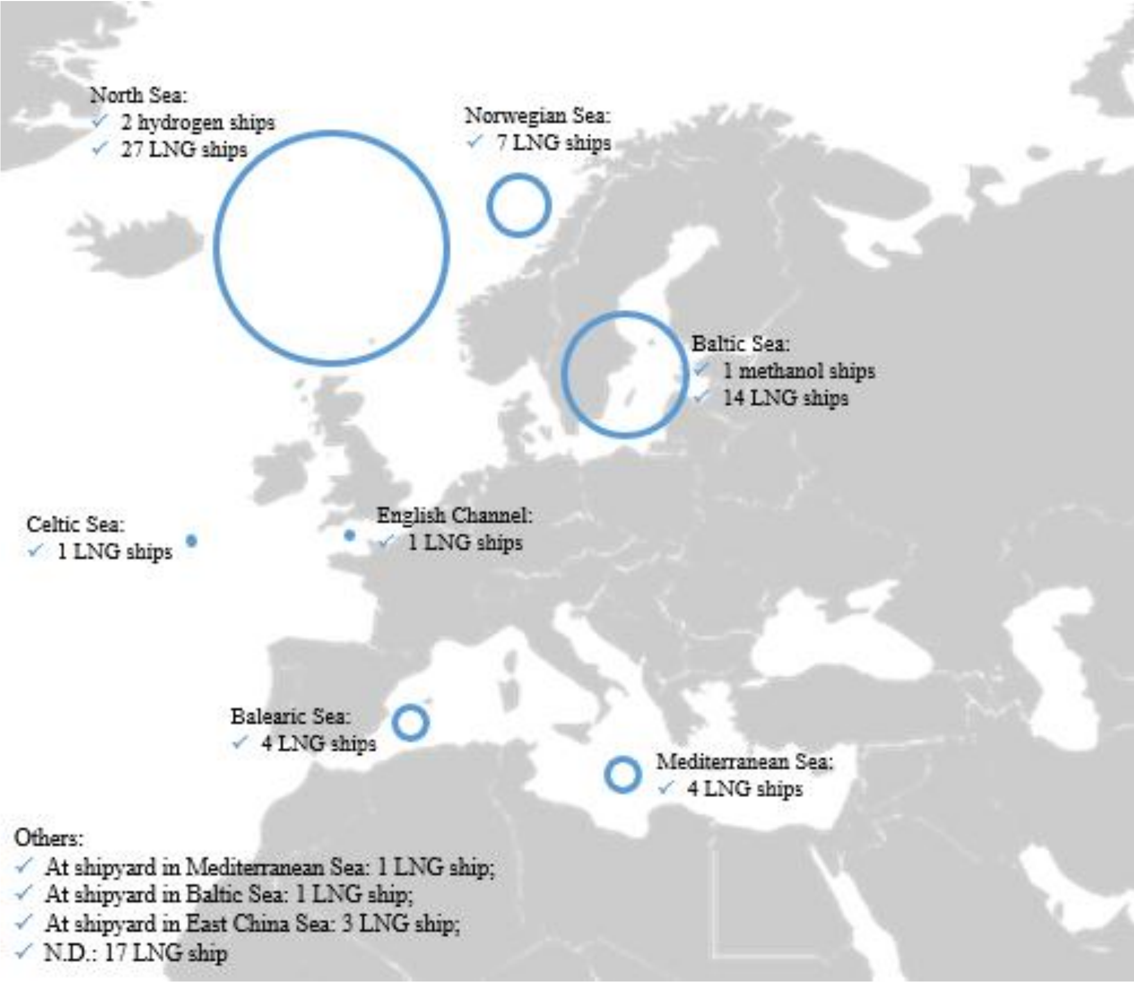
Figure 54. Distribution of ships using alternative fuel per class of GT.



Source: Author's elaboration.

To identify the location of ships using alternative fuel for the propulsion, ship-specific research has been conducted on Marine Traffic. For the ships in operation / in service, the research allowed to identify the specific location of the ship, through the analysis of the line operated, while for the ships under construction and on order, the shipyards where ship units are located were identified. Figure 55 shows the geographical distribution of Ferry, Ro-Ro and Ro-Pax ships using alternative fuels for propulsion: the dimension of the circle diameter represents the gradient of intensity relative to the percentage of ship units operating in the location.

Figure 55. Geographical distribution of ships using alternative fuel.



Source: Author's elaboration.

Furthermore, the companies operating in the Ferry, Ro-Ro and Ro-Pax industry are moving towards the construction of ships with alternative propulsion aiming at achieving more sustainable operations. However, due to the limited impact of the use of alternative fuels in the sector, it can be said that companies operating in the Ferry, Ro-Ro and Ro-Pax industry are also moving towards innovative technical solutions and cutting-edge technologies.

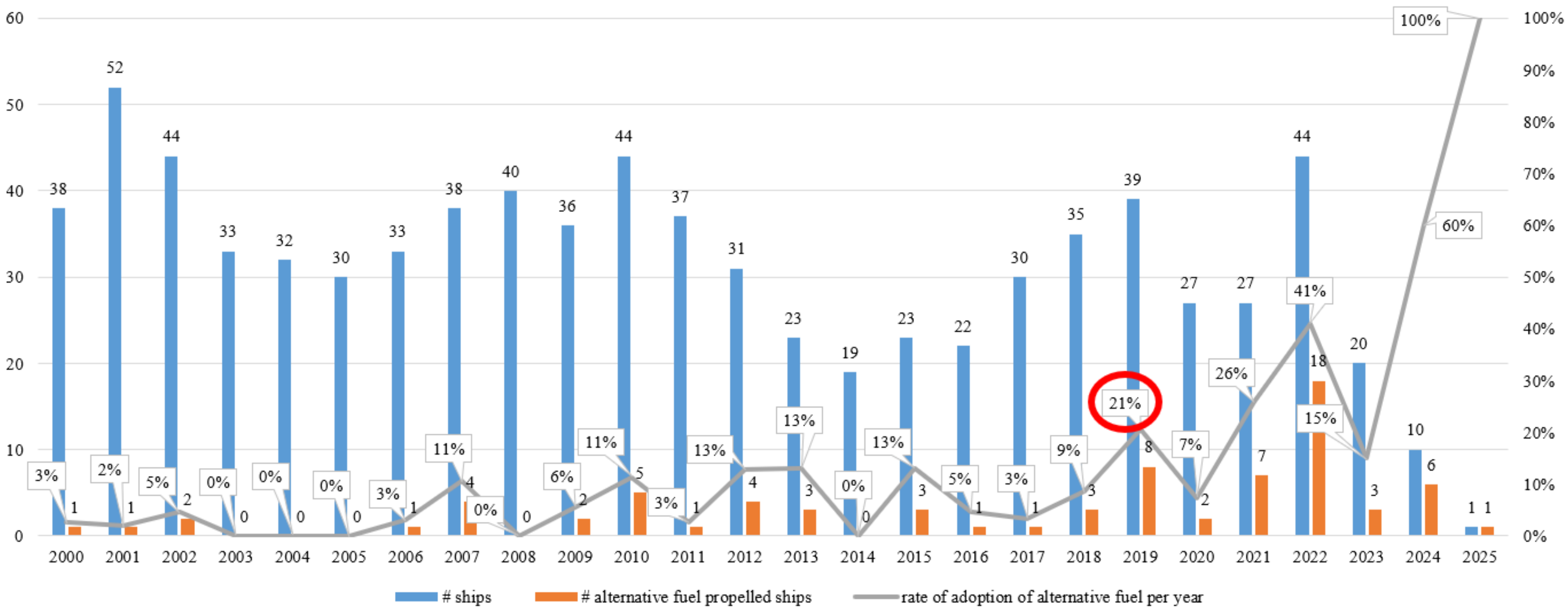
6.3 In deep analysis of the "overall" sample: a new "green" sample

For the aim of the thesis, the "overall" sample has been then scrutinized to focus on two ship types, namely Passenger/Ro-Ro Ship (Vehicles) (n. 1,334 ships) and Ro-Ro Cargo Ship (n. 276 ships), excluding Passenger/Landing Craft ships (n. 10 ships), Passenger/Ro-Ro Ships (Vehicles/Rail) (n. 44 ships) and Rail Vehicles Carriers (n. 16 ship). For this purpose, 70 ships were excluded from the sample, focusing only on 1,610 ships.

Through the in deep analysis of ship units using alternative and sustainable fuels as their main fuel in the Ferry, Ro-Ro and Ro-Pax industry, it has been revealed that only 81 ship units use, as first fuel type, LNG, Hydrogen and Methanol. To deal with this limited result, since it is not possible to develop an exhaustive analysis of green strategies grounding on the "overall" sample, it was decided to develop an additional "green" sample able to show the approaches, decisions and strategies adopted by each group owner and the related future trends on the adoption of green strategies in the sector.

Considering the 81 above-mentioned ships, the "green" sample has been built starting from the first year with a significant increase in growth rate of adoption of alternative propulsion fuels in the newbuilding. Consequently, the incidence of newbuilding using alternative fuels for the propulsion compared to overall newbuilding is calculated for each year. In this way, the year from which this incidence was most significant was identified. Starting from the 2000s until to the 2010s, the incidence of newbuilding's using alternative fuels for the propulsion among the newbuilding's for each year remained very low (average of 4%). Over the first 10 years of 2000s, 420 Ferry, Ro-Ro and Ro-Pax ships were built, of which only 16 using alternative fuels for the propulsion. Such rate has instead stabilized starting from 2010 until 2019, when the rate of adoption of alternative fuels for the propulsion increased from 9% (2018) to 21%. Consequently, starting from 2019, there was an intensive introduction of alternative fuels for the maritime propulsion in the Ferry, Ro-Ro and Ro-Pax industry, as shown in Figure 56. Subsequently, however, mainly because of the COVID-19 pandemic that affected the whole country and also the Ferry, Ro-Ro and Ro-Pax industry due to the travel restrictions, the rate of adoption of alternative fuels for the propulsion reversed its trend and declined sharply. After the COVID-19 pandemic, with a resumption of travels and an increasingly green oriented strategies adopted by shipping companies, such rate has resumed its increase, until reaching in 2022 values never seen in the last 13 years. For the years 2024 and 2025, the data are unrepresentative as they are only the orderbooks existing to 2022 for a few statistical units.

Figure 56. Distribution of ships using alternative propulsion fuels incidence year).



Source: Author's elaboration.

This is necessary to identify and map the latest green technologies and investment options adopted by companies in the Ferry, Ro-Ro and Ro-Pax industry. Of the 171 passenger/Ro-Ro ship (vehicles) and Ro-Ro cargo ships built starting from 2019, 129 ships with dimensions equal or over 2,000 GTs units have been selected. The “green” sample was built by selecting from the “overall” sample, only ship units built from 2019 on, also including ships currently under construction that will be delivered until 2025, to map and deepen the latest green technologies available. The “green” sample aims to understand the most recent approaches adopted by group owners operating in Ferry, Ro-Ro and Ro-Pax industry and the upcoming trends, considering the adoption of green strategies in the sector.

To identify the future area of operation the ships that are currently under construction, different sources such as press releases, institutional and academical website, trade magazines and communications on the corporate site of the group owners concerned were deepened. Only for 8 ship units of the “green” sample (6%) it was not possible to identify the area of operation, mainly since these ships are still in the first phase of construction (keel laid, launched, on order/not commenced, etc.), sometimes still without its name being assigned.

6.3.1 The implementation of the “green” sample

In order to implement the “green” sample, additional information about innovative technical solutions and cutting-edge technologies installed on board for mitigating the pollution and reducing harmful emissions was researched for each ship in the sample. In particular, the following information has been deepened in the “green” sample:

- the bulbous bow, that modifies the way the water flows around the hull, reducing drag and thus increasing speed, range, fuel efficiency and stability, through the consultation of IHS Maritime & Trade database in the specific section dedicated to construction details;
- the installation of exhaust gas cleaning and purification systems on board for the reduction and abatement of sulphur emissions. The aforementioned profiles were investigated by consulting press releases, institutional and academical websites, trade magazines and communications on the corporate websites of the group owners concerned;
- alternative fuel and propulsion system, i.e., the fuel type used by the ship (LNG, ammonia, hydrogen, methanol, distillate fuel, VLSFO, ULSFO, biofuels) if the

propulsion system is dual fuel and / or hybrid. Such information have been searched by deepening the "engine model" and the "fuel type 1" profiles (extracted from the IHS Maritime & Trade database) through press releases, institutional and academical website, trade magazines and communications on the corporate site of the group owners concerned;

- on board auxiliary system, such as solar/photovoltaic panels, wing sails to produce energy to be stored in batteries to produce energy for onboard services, analysed through the consultation of press releases, institutional and academical website, trade magazines and communications on the corporate site of the group owners concerned;
- batteries for an electric propulsion (cold ironing / cold ironing ready) to allow a "zero impact" operation: the information concerning such solution were extrapolated by deepening press releases, institutional and academical website, trade magazines and communications on the corporate site of the group owners concerned.

The "green" sample includes a column for innovative technical solutions and cutting-edge technologies installed on board for mitigating the pollution and reducing harmful emissions in order to add a binary variable for each ship/technology. Consequently, the value 1 means that such green strategy has been adopted on board ship, while the value 0 is assigned otherwise. In addition, three other columns have been inserted to indicate the source of the information, the link to the source and the comment extracted from the article, publication and/or news launched by the source. In this way it has been possible to provide an overall view of the various green equipment and components installed on board ships that are part of the "green" sample and the related source to allow an evaluation and examination from the point of view of the reliability and institutionalism of the source. Table 18 shows an extract of the "green" sample.

Table 18. Extract of the "green" sample.

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
1	9823467	*Pentland Ferries*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Local magazines
2	9969730	*Balearia Eurolineas Maritimas*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
3	9967196	*Balearia Eurolineas Maritimas*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
4	9878319	*Kvarken Link AB*	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
5	9884681	*Wallenius Lines AB*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
6	9875537	*Armas Naviera SA*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Institutional source
7	9878993	*T-Finans AS*	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	Energy magazines
8	9461207	*Bharati Shipyard Ltd*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
9	9855147	*Fjord1 ASA*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
10	9892896	*Bore Ltd*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
11	9892884	*Bore Ltd*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
12	9892901	*Bore Ltd*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
13	9884679	*Wallenius Lines AB*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
14	9924120	*Jifmar Offshore Services SAS*	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	other
15	9969766	*Torghatten Nord AS*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipbuilding corporate website
16	9946324	*Stena AB*	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	Energy magazines

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
17	9946336	*Stena AB*	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	Energy magazines
18	9946257	*Stena AB*	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	Energy magazines
19	9869722	*Grandi Navi Veloci SpA*	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Shipping companies corporate website
20	9824289	*Color Group AS*	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
21	9858321	*ICBC Financial Leasing Co Ltd*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Shipping companies corporate website
22	9596430	*Unknown*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	other
23	9871270	*Norled AS*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
24	9859600	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
25	9859545	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
26	9859571	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
27	9859612	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
28	9859557	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
29	9859583	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
30	9859595	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
31	9859569	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
32	9859533	*Grimaldi Group SpA*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
33	9863637	*Balearia Eurolineas Maritimas*	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
34	9945538	*Unknown*	0	1	0	1	0	0	0	1	0	1	0	0	0	1	0	Shipping magazines

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
35	9816830	*DFDS Denizcilik ve Tasimacilik*	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	Local magazines
36	9862009	*Fjord1 ASA*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	Shipbuilding corporate website
37	9824564	*Molslinjen AS*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Shipping magazines
38	9825829	*Torghatten Nord AS*	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	Institutional source
39	9889708	*CLdN*	1	0	0	1	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
40	9855135	*Fjord1 ASA*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
41	9794525	*Caledonian Maritime Assets Ltd*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Institutional source
42	9863132	*Norled AS*	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	Shipbuilding corporate website
43	9902421	*Finnlines Plc*	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping companies corporate website
44	9856830	*Finnlines Plc*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
45	9856842	*Finnlines Plc*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
46	9856854	*Finnlines Plc*	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	Shipping magazines
47	9902419	*Finnlines Plc*	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping companies corporate website
48	9822061	*Torghatten Nord AS*	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	Institutional source
49	9850721	*Fjord1 ASA*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
50	9865398	*Norled AS*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	Shipping magazines
51	9856189	*Bank of Communications*	1	0	0	0	0	0	0	0	1	1	0	0	1	1	0	Shipping magazines
52	9832303	*Fjord1 ASA*	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
53	9794513	*Caledonian Maritime Assets Ltd*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
54	9893369	*Grandi Navi Veloci SpA*	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Institutional source
55	9783071	*Gotland Rederi AB*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
56	9935014	*Grimaldi Group SpA*	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping magazines
57	9855408	*Fjord1 ASA*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipbuilding corporate website
58	9826108	*Polish Baltic Shipping Co*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Newspaper
59	9977658	*Unknown*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
60	9865221	*Torghatten Nord AS*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
61	9871268	*Norled AS*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
62	9825099	*Samskip hf*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Local magazines
63	9831177	*CLdN*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	other
64	9850719	*Fjord1 ASA*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
65	9832119	*Siem Shipping Inc*	1	0	0	1	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
66	9825805	*Torghatten Nord AS*	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	Institutional source
67	9887530	*Norled AS*	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	Shipping magazines
68	9498755	*Balearia Eurolineas Maritimas*	1	0	0	0	0	0	0	1	0	1	0	0	0	1	0	other
69	9935026	*Grimaldi Group SpA*	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping magazines

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
70	9935038	*Grimaldi Group SpA*	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping magazines
71	9935040	*Grimaldi Group SpA*	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping magazines
72	9935052	*Grimaldi Group SpA*	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping magazines
73	9935064	*Grimaldi Group SpA*	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	Shipping magazines
74	9963566	*CLdN*	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	Energy magazines
75	9963578	*CLdN*	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	Energy magazines
76	9823352	*CLdN*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
77	9869954	*Siem Shipping Inc*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Shipping magazines
78	9871282	*Norled AS*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	other
79	9822073	*Torghatten Nord AS*	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	Shipping magazines
80	9895472	*Veolia Transport*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
81	9865386	*Norled AS*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	Shipping magazines
82	9848479	*Tirrenia di Navigazione SpA*	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Shipping magazines
83	9498767	*Balearia Eurolineas Maritimas*	1	0	0	0	0	0	0	1	0	1	0	0	0	1	0	Shipping magazines
84	9866108	*Veolia Transport*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Energy magazines
85	9837509	*Moby SpA*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Newspaper
86	9837511	*Moby SpA*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Newspaper
87	9855159	*Fjord1 ASA*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
88	9892690	*Tallink Group Ltd*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
89	9887528	*Norled AS*	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0	Shipbuilding corporate website
90	9865685	*Aug Bolten Wm Miller's*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
91	9803663	*Balearia Eurolineas Maritimas*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Institutional source
92	9897614	*Norled AS*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	Shipbuilding corporate website
93	9895173	*Unknown*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Institutional source
94	9895161	*Unknown*	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Institutional source
95	9880946	*Aug Bolten Wm Miller's*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
96	9889382	*Fjord1 ASA*	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
97	9832315	*Fjord1 ASA*	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	Shipping magazines
98	9817274	*Virtu Ferries Ltd*	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	Local magazines
99	9867592	*ICBC Financial Leasing Co Ltd*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
100	9847009	*Fjord1 ASA*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
101	9825817	*Torghatten Nord AS*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	Shipping magazines
102	9886847	*ICBC Financial Leasing Co Ltd*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
103	9461219	*Seatrans AS*	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	Institutional source
104	9977206	*Caronte Shipping SpA*	0	1	0	1	0	0	0	1	0	1	0	0	0	1	0	Shipping magazines
105	9889710	*CLdN*	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	Energy magazines
106	9898400	*Rete Ferroviaria Italiana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Shipping magazines
107	9850733	*Fjord1 ASA*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Shipping magazines

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
108	9831165	*CLdN*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines
109	9832327	*Fjord1 ASA*	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	Shipping magazines
110	9855161	*Fjord1 ASA*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
111	9863144	*Norled AS*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	Shipping magazines
112	9855173	*Fjord1 ASA*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	Shipping magazines
113	9863003	*Financial Products Group Co*	1	1	0	0	1	0	0	0	0	1	0	0	1	1	0	Energy magazines
114	9807308	*Bank of Communications*	1	1	1	0	0	0	0	0	1	1	0	0	0	1	0	Shipping magazines
115	9807322	*Bank of Communications*	1	1	1	0	0	0	0	0	1	1	0	0	0	1	0	Shipping magazines
116	9807293	*Bank of Communications*	1	1	1	0	0	0	0	0	1	1	0	0	0	1	0	Shipping magazines
117	9895496	*Veolia Transport*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	Energy magazines
118	9832298	*Fjord1 ASA*	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
119	9925655	*Tennor Holding BV*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Shipping magazines
120	9883900	*Unknown*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Shipping magazines
121	9895484	*Veolia Transport*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipbuilding corporate website
122	9816842	*DFDS Denizcilik ve Tasimacilik*	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	Shipping companies corporate website
123	9855393	*Fjord1 ASA*	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
124	9901532	*Veolia Transport*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	Shipping magazines
125	9827877	*Viking Line Abp*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping companies corporate website
126	9891749	*Credit Agricole SA*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Local magazines
127	9807578	*Doeksen G*	0	1	1	0	0	0	0	1	0	0	0	0	0	1	0	Shipping magazines

#	IMO No.	Group Owner	Bulbous bow	Hybrid ship	Battery for onboard operations	Battery for propulsion	Electrification (also ready)	Eolic turbine	Wing sail	Solar Panel	Scrubber	Dual fuel	VLSFO / ULSFO	Hydrogen	Methanol	LNG	Biofuel	Source
128	9807580	*Doeksen G*	0	1	1	0	0	0	0	1	0	0	0	0	0	1	0	Shipping magazines
129	9823364	*CLdN*	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	Shipping magazines

Source: Author's elaboration.

6.3.2 The analysis of the "green" sample

In order to assess the reliability and institutional nature of the source of the information concerning the adoption of technical solutions and cutting-edge technologies installed on board for mitigating pollution and reducing harmful emissions, it is first necessary to identify the number of sources consulted for the creation of the "green" sample. In this analysis, 54 different sources have been examined, some from the journalistic contexts, others related to press releases and communications by the companies on their corporate website, some in academic and institutional contexts.

Ship-technology.com is one of a network of 30+ proprietary B2B websites, with a global audience of active decision makers, influencers, and opinion leaders across the world with a combined readership of 55 million industry professionals each year. As part of *GlobalData*[44], *Ship-technology.com* has access to over 1bn data points including companies, deals, projects, forecasts and trends to inform and support leading content in the shipping industry. With an expertise spanning more than 80 markets globally and driven by 800+ award-winning journalists, researchers, and analysts, *Ship-technology.com* allows to connect with the information that makes and breaks businesses every day. Ship-technology.com is the most analysed source of information in this PhD thesis for the drafting of the "green" sample, providing 15% of the contributions analysed in the sample. *Maritimt Magasin,* one of the leading magazines on everything maritime in Norway, has been examined in the 6% of cases. This because of the numerous ship units of the sample in service or that will operate in the North Sea or along the Norwegian coast. It deals with Ferry, Ro-Ro and Ro-Pax ships of property and operated from Fjord1 ASA, leading player in the Norwegian ferry market, and from Torghatten Nord AS, company making part of the Torghatten-group, working in the maritime transport in Norway.

The MediTelegraph is a shipping news website and maritime magazine dedicated to Logistics and Intermodal Transport in the Mediterranean through analysis, reports, events, video, interviews on the industry. Through its specific sections, *The MediTelegraph* publishes all the news from the shipping industry, with particular focus on the activities of Italian ports, cruises, shipyards, logistics, also providing insights into geopolitics, finance, law, both in Italian and in English. *The MediTelegraph* provides information on the entire field of shipping with a special focus on the Mediterranean, in fact it is consulted (5%) in this PhD thesis in order to select news and communications on ship units of Grimaldi Group SpA, a fully integrated multinational logistics group specialised in maritime transport of cars, rolling cargo, containers and passengers,

[44] *GlobalData* provides unique data, expert analysis & innovative solutions to companies in the world's largest industries.

and of Balearia Eurolineas Maritimas, providing ferry transportation services especially between Europe and Balearic Islands.

As part of the analysis, *Wikipedia* was also consulted, representing 5% of the examined sources for the drafting of the "green" sample. Wikipedia is a multilingual free online encyclopaedia, written and maintained by a community of volunteers through open collaboration and a wiki-based editing system. Wikipedia is considered as the largest and most-read reference work in history: it is consistently one of the 10 most popular websites ranked by Similarweb and formerly Alexa and, as of 2022, Wikipedia was ranked the 7th most popular site.

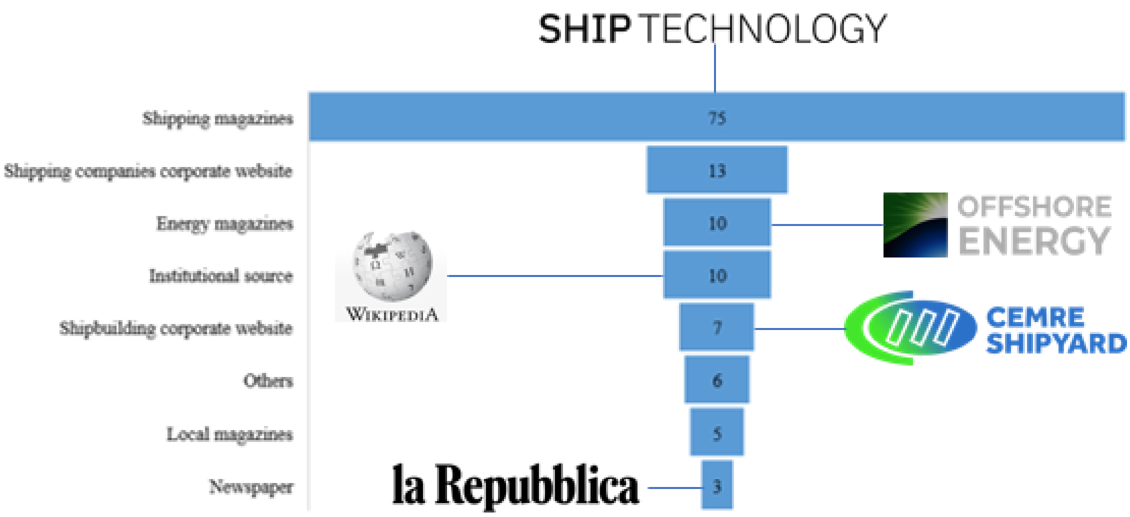
The consultation of *Ferry shipping news*, *Baird maritime*, *Offshore Energy* and *Shippax* represents, jointly, 15% of the examined sources for the drafting of the "green" sample. While *Ferry shipping news* and *Shippax* are sources of information specifically dedicated to the ferry sector, *Baird Maritime* is related to the maritime sector and *Offshore Energy* to the energy sector. *Ferry shipping news* is aimed at supporting the ferry industry with important news, digital access and free of charge and organizing the Ferry Shipping Summit, a conference of two days dedicated to the ferry industry whose participants are ferry operators, ferry ports and operators within the supply chain with top speakers and panellists of great interest for the industry. *Baird Maritime*, launched in 1978, is one of the world's premier maritime publishing houses. The company produces the leading maritime new portal *BairdMaritime.com*, home of the world-famous Work Boat World, Fishing Boat World, Ship World, Ausmarine, and Commercial Mariner sub-sites, and the industry-leading ship brokerage platforms WorkBoatWorld.com and ShipWorld.com. The *Offshore Energy* platform connects communities to share information regarding energy transition and sustainable solutions in the maritime and offshore world. *Offshore Energy* is consulted in the drafting of the data due to its focus on different markets that are not only fossil energy, offshore wind, dredging and subsea but also clean fuel, green marine and marine energy that are issues of primary relevance in this PhD thesis. For over 50 years, the business idea of *Shippax* has been to provide information about the ferry, cruise, ro-ro and hi-speed market in the most accurate and thorough way, reporting, commenting, and gathering statistics and information that are then published in *Shippax* annual publications, monthly magazine and website. *Shippax* online database is the most comprehensive passenger shipping database available on the market. *Shippax* also organizes the annual Shippax Ferry Conference, which participants are the main players in the Ferry industry.

Additional journals and industry information sources have been examined for "green" sample drafting, such as *LNG Prime* (2%), *Poland Sea* (2%), *Riviera Maritime Media* (2%), *Ship friends* (2%), *Shipping Italy* (2%), etc., academic sources from research centres were also investigated. For example, the analysis of the main outcomes of the project *TDI RETE GNL* (Tecnologie e Dimensionamento di Impianti per la RETE di distribuzione primaria di GNL nei porti dell'area transfrontaliera) from the University of Genoa, allowed to collect information about LNG-propelled ships in operation and new buildings that will come into service in the coming years.

Moreover, in addition to the impartial and neutral information from magazines, journalistic, academic and/or institutional sources, this study has also examined the corporate websites of shipping companies and group owners of "green" sample ships. Some examples are the corporate websites of Bore (2%), Finnlines (2%), Wallenius Lines (2%), Viking Line (1%), Gotland (1%), Stena Line (1%), DFDS (1%), Caledonian Maritime (1%).

With the aim of summarising the different types of sources examined in the "green" sample, Figure 57 shows the macro-categories of sources consulted: local magazines, newspaper, energy magazines, shipping magazines, shipbuilding corporate website, shipping companies' corporate website, institutional sources and others.

Figure 57. Distribution of different type of source in the "green" sample, and examples of them.

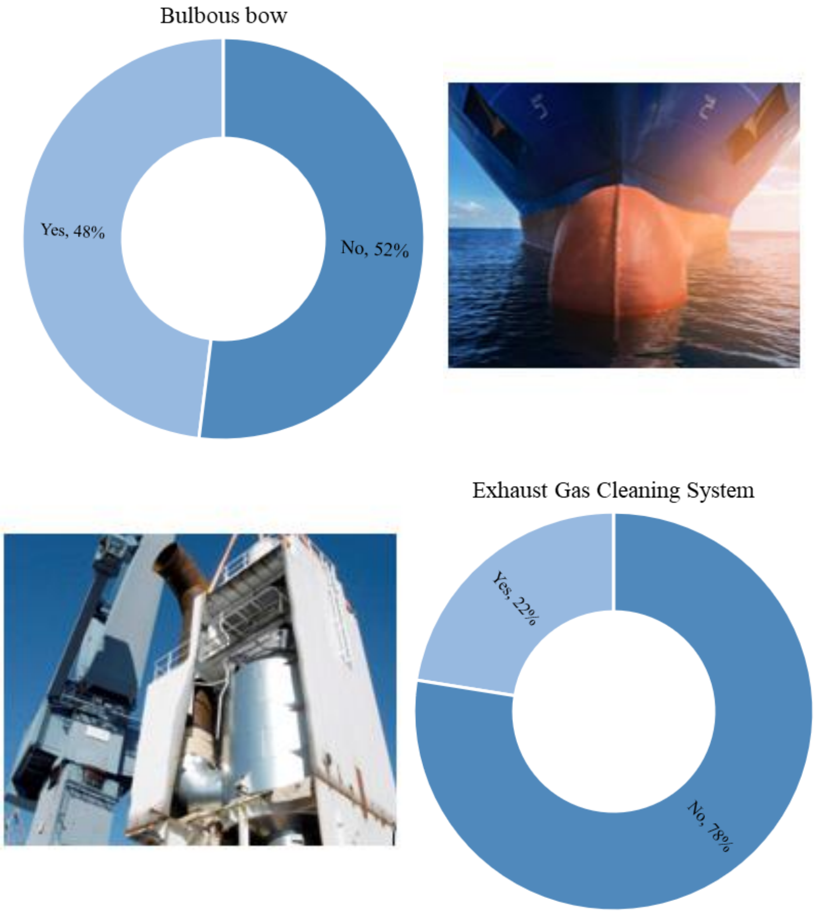


Source: Author's elaboration.

Through the implementation of the "green" sample, it has been possible to provide an overview of the various innovative technical solutions and cutting-edge technologies installed on board of ships for mitigating pollution and reducing harmful emissions installed on board vessels that are part of the "green" sample.

Among the “green” sample, only the 48% of ships are equipped with bulbous bow even if it can help to reduce a ship’s resistance and thus to save the fuel consumption up to 15% (Liu et al., 2015). Among the 62 ships in the “green” sample with bulbous bow, most of them are built after 2021. Considering the exhaust gas cleaning systems, the “green” sample reveals that most of ships in the “green” sample (78%) are not equipped of scrubber. This is because the 29 ships equipped with scrubbers use distillate fuel for propulsion, while most of the sample includes hybrid ship, ships equipped with dual fuel engines or with engines using alternative fuels for the propulsion.

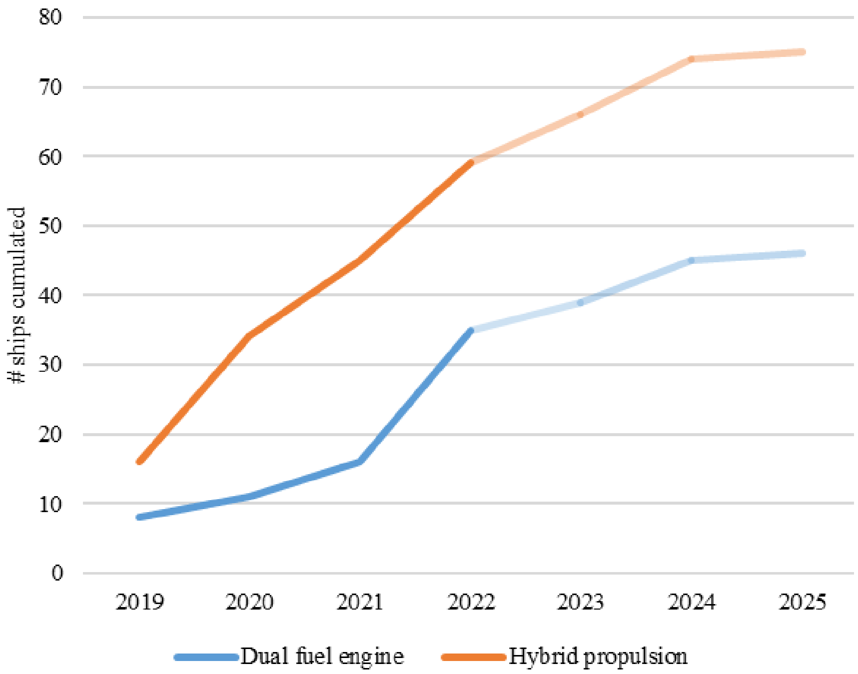
Figure 58. Adoption of bulbous bow and scrubber in the “green” sample.



Source: Author’s elaboration.

In the “green” sample the 36% of the ships are equipped with dual fuel engines allowing them to be operated on either LNG or conventional liquid marine fuels, including LFO, HFO. Most of these ships are built in 2022, doubling the rate of growth of newbuilding, and are operating and will operate in the Baltic Sea (22%), Mediterranean Sea (20%) and North Sea (15%). In the "green" sample the 58% of ships are hybrid ships, i.e., ship designed and constructed to use a combination of alternative means of propulsion mainly from a conventional gas or fuel-powered engine and also, from electrical sources derived from rechargeable devices such as batteries. Most of hybrid ship are operating and will operate in North Sea (52%), Mediterranean Sea (20%) and Norwegian Sea (11%). Figure 59 shows the trend of the new constructions of hybrid ship and ships with dual fuel propulsion.

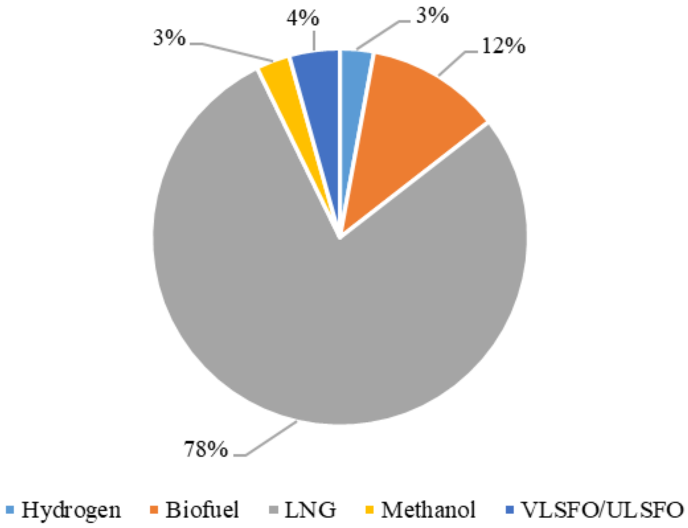
Figure 59. Trend of the new constructions of hybrid ship and ships with dual fuel propulsion.



Source: Author's elaboration.

Among the "green" sample, only 70 ships are equipped with engines using alternative fuels for the propulsion (Figure 60). 78% of them uses LNG for the propulsion and 85% of them uses it in dual fuel engines, especially with diesel but also with methanol (MV Galicia, MV Stena Ebba). In the "green" sample there are only 2 ships, MV Hydra and Nesvik, using hydrogen as fuel for the propulsion and both are owned by Norled, one of Norway's largest ferry and speedboat operators. 15% of the 70 ships that are equipped with engines using alternative fuels for the propulsion uses biofuel while the 4% uses VLSFO/ULSFO.

Figure 60. Distribution of alternative fuel propulsion in the "green" sample.



Source: Author's elaboration.

Considering the use of renewable sources for the production of energy, only 19 ships of the "green" sample are equipped on board of solar panels and wing sails to recharge the on-board batteries. Among the 18 ships in the "green" sample equipped with solar panels, most of them are built after 2021 and half of them are owned by Grimaldi Group (Grimaldi Euromed SpA and Finnlines).

Among the "green" sample, 78 ships are equipped with batteries to store energy to be used partly for onboard services and operations (23%) and partly for propulsion (77%). Batteries can be recharged during navigation, through shaft generators using peak shaving system and solar panels.

Almost 30% of the "green" sample ships are provided also with electric engines to avoid emissions in port. These are hybrid and full electric Ferry, Ro-Ro and Ro-Pax ships. 29% of them are full electric and almost all of them have small dimensions, with less than 3,000 GT: e.g., MV Malmefjord, MV Tomrefjord and MV Vestrefjord operating in Norwegian fjords and owned by Veolia Transport. The only exception in term of ship dimensions is represented by MV Basto Electric, of over 7.900 GTs, that is the greatest electric ferry to the world. It is owned by T-Finans AS and operates in the North Sea.

6.3.3 *The analysis of the managerial and governance behaviours of best group owners*

Following the examination of the green strategies and solutions available to operators in the sector, carried out in the fifth Chapter of this PhD thesis, it is necessary to analyse the managerial and governance behaviours implemented by group owners included of the "green" sample and then deepen, through brief case histories, the main strategies adopted by them. In this way it has been possible to deepen the attitudes and strategies conducted by individual group owners, with specific focus in the top ten.

For each group owner part of the "green" sample, information is integrated about listed companies, public controls, golden share, etc, in order to better understand their managerial and governance behaviours. For this purpose, an analysis on Aida database is conducted for Italian companies of the "green" sample. Aida is the database that collects complete information about companies in Italy, with a history of up to ten years, allowing research, consultation, analysis and processing of economic and financial information, biographical / personal and commercial data of all limited companies operating in Italy. Similarly, for European companies, Amadeus database was also used within this research: Amadeus is the database of comparable financial information for over 21,000,000 public and private companies across Europe.

Aida and Amadeus represent a tool that allows to identify the company information of Italian and European companies and companies. The first section of the tool shows data and information related to contact details, legal, account, size and group information and industry classification. There is also a second area with information concerning key financial data and employees, balance sheet of the last ten years, where available, with the calculation of global ratio as profitability report, operational ratio, structure ratio, per employee ratio. Aida and Amadeus can also show data and contact of current directors and managers and staff of companies. For the aim of this PhD thesis, the section related to controlling shareholders and current subsidiaries has been the most analysed in the DB, in order to identify any public and government participation in the Ferry, Ro-Ro and Ro-Pax companies of the "green" sample. Moreover, for each group owner, corporate website was consulted, in order to identify more information about the history of group owners.

For example, referring to Norwegian companies operating in Ferry, Ro-Ro and Ro-Pax industry, until the late 1990s, most of them were publicly owned and not profit-oriented, merely representing a tool by means of which the local authorities provided a transport service. There was no competition between the companies during this period, but then, in the late 1990s, the Norwegian parliament (under the guide of Storting) decided to privatize the entire ferry industry.

Companies therefore went from being 100% publicly owned to being commercial enterprises and this required wide-ranging internal restructuring processes which, combined with unfavourable contractual terms, made it hard for them to make profit during this period. Subsequently, “second generation contracts” offered better terms, and the entire industry has seen its framework conditions improve since the 2000s, and today, ferry companies enjoy foreseeable contractual terms and regulations, with a companies' competition on price and environment in the new contracts.

The situation of Moby SpA is different because in the course of 2012, through the Compagnia Italiana di Navigazione S.p.A. (of which Onorato Partecipazioni s.r.l. was shareholder of majority), the company Tirrenia was acquired. As a result, from July 2015 the new company passed under the control of the Onorato family while to the Italian State only the relative bad company remained (with about 800 million euros of debts). In September 2019, it was declared that Moby SpA has not yet paid the Italian State 180 million for the purchase of the activities of Tirrenia. In October 2021, in order to cope with the debts accumulated by the company, Onorato reached an agreement with the creditors who asked for the transfer of the company to people outside the family: Vincenzo Onorato announces the withdrawal from the presidency, being replaced by Professor Gualtiero Brugger. In November 2021, to postpone the meeting of creditors, a plan was announced that provided for the payment in four years of 80% of the debt to the main creditors (including Tirrenia in Extraordinary Administration) and the transfer of all the ships to a vehicle society of new constitution, ShipCo, managed from a saving society, from which the operating society OpCo (i.e., Moby SpA) will rent the ferries with the possibility to repurchase them in 2025. With the acquisition of 22% of Moby SpA by the company MSC in March 2022 (whose shareholdings increased in August 2022 to 49% of the capital), Moby SpA saw its capital increase, to save itself from bankruptcy. At the same time, restructuring plans are also filed that provide for the payment of credit to Tirrenia in A.S. by Moby and ShipCo. Following the agreements will proceed with the merger of Moby and Tirrenia CIN, previously opposed in 2018.

To analyse the managerial and governance behaviours of group owners, only the top ten group owners in the “green” sample are selected. Group owners which hold the largest number of ships and the bigger dimensions of fleet in term of gross tonnage has been selected. To rank the top ten group owners in the “green” sample, two ranking lists have been drawn up: the first one based on the number of ships of the group owner (the first position is occupied by the group owner with the greatest number of ships in the “green” sample) while the second one is based on the GT size of the fleet (the first position is occupied by the group owner with the largest fleet size in terms of gross tonnage in the “green” sample). Then a single final ranking was drawn up weighing 50% both positions in the rankings for each group owners in the "green" sample (Table 19).

Table 19. Ranking of the best group owners in the "green" sample.

Ranking by # of ships			Ranking by GT of fleet			Final ranking			
Group owners	**#ships**	**score**	**Group owners**	**GT**	**score**	**Group owners**	**score #ships**	**score GT fleet**	**final score (50% #ships and 50% GT fleet)**
Fjord1 ASA	17	1	*Grimaldi Group SpA*	1.113.063	1	***Grimaldi Group SpA***	**2**	**1**	**1,5**
Grimaldi Group SpA	15	2	*CLdN*	403.562	2	***CLdN***	**4**	**2**	**3**
Norled AS	10	3	*Finnlines Plc*	310.751	3	***Finnlines Plc***	**8**	**3**	**5,5**
CLdN	8	4	*Bank of Communications*	166.684	4	***Balearia Eurolineas Maritimas***	**6**	**5**	**5,5**
Unknown	6	5	*Balearia Eurolineas Maritimas*	144.892	5	***Bank of Communications***	**10**	**4**	**7**
Balearia Eurolineas Maritimas	6	6	*Moby SpA*	139.000	6	***Unknown***	**5**	**10**	**7,5**
Torghatten Nord AS	6	7	*ICBC Financial Leasing Co Ltd*	122.547	7	***ICBC Financial Leasing Co Ltd***	**12**	**7**	**9,5**
Finnlines Plc	5	8	*DFDS Denizcilik ve Tasimacilik*	120.930	8	***Fjord1 ASA***	**1**	**19**	**10**
Veolia Transport	5	9	*Wallenius Lines AB*	119.642	9	***DFDS Denizcilik ve Tasimacilik***	**16**	**8**	**12**
Bank of Communications	4	10	*Unknown*	118.614	10	***Moby SpA***	**19**	**6**	**12,5**
Bore Ltd	3	11	*Aug Bolten Wm Miller's*	101.138	11	***Aug Bolten Wm Miller's***	**14**	**11**	**12,5**
ICBC Financial Leasing Co Ltd	3	12	*Stena AB*	98.000	12	***Stena AB***	**13**	**12**	**12,5**
Stena AB	3	13	*Siem Shipping Inc*	76.017	13	***Torghatten Nord AS***	**7**	**20**	**13,5**
Aug Bolten Wm Miller's	2	14	*Viking Line Abp*	65.211	14	***Wallenius Lines AB***	**21**	**9**	**15**
Caledonian Maritime Assets Ltd	2	15	*Grandi Navi Veloci SpA*	65.162	15	***Norled AS***	**3**	**28**	**15,5**
DFDS Denizcilik ve Tasimacilik	2	16	*Polish Baltic Shipping Co*	55.000	16	***Siem Shipping Inc***	**20**	**13**	**16,5**
Doeksen G	2	17	*Tallink Group Ltd*	50.629	17	***Grandi Navi Veloci SpA***	**18**	**15**	**16,5**
Grandi Navi Veloci SpA	2	18	*Financial Products Group Co*	45.000	18	***Bore Ltd***	**11**	**26**	**18,5**
Moby SpA	2	19	*Fjord1 ASA*	44.976	19	***Veolia Transport***	**9**	**31**	**20**
Siem Shipping Inc	2	20	*Torghatten Nord AS*	43.570	20	***Armas Naviera SA***	**22**	**21**	**21,5**

Ranking by # of ships			Ranking by GT of fleet			Final ranking			
Wallenius Lines AB	2	21	*Armas Naviera SA*	39.761	21	***Financial Products Group Co***	**27**	**18**	**22,5**
Armas Naviera SA	1	22	*Credit Agricole SA*	37.599	22	***Caledonian Maritime Assets Ltd***	**15**	**30**	**22,5**
Bharati Shipyard Ltd	1	23	*Tirrenia di Navigazione SpA*	32.936	23	***Credit Agricole SA***	**26**	**22**	**24**
Caronte Shipping SpA	1	24	*Tennor Holding BV*	32.770	24	***Polish Baltic Shipping Co***	**33**	**16**	**24,5**
Color Group AS	1	25	*Gotland Rederi AB*	32.447	25	***Color Group AS***	**25**	**27**	**26**
Credit Agricole SA	1	26	*Bore Ltd*	27.653	26	***Gotland Rederi AB***	**28**	**25**	**26,5**
Financial Products Group Co	1	27	*Color Group AS*	27.164	27	***Tallink Group Ltd***	**37**	**17**	**27**
Gotland Rederi AB	1	28	*Norled AS*	26.106	28	***Viking Line Abp***	**42**	**14**	**28**
Jifmar Offshore Services SAS	1	29	*Kvarken Link AB*	24.036	29	***Doeksen G***	**17**	**39**	**28**
Kvarken Link AB	1	30	*Caledonian Maritime Assets Ltd*	14.080	30	***Kvarken Link AB***	**30**	**29**	**29,5**
Molslinjen AS	1	31	*Veolia Transport*	13.907	31	***Caronte Shipping SpA***	**24**	**35**	**29,5**
Pentland Ferries	1	32	*Molslinjen AS*	11.345	32	***Bharati Shipyard Ltd***	**23**	**37**	**30**
Polish Baltic Shipping Co	1	33	*Jifmar Offshore Services SAS*	10.640	33	***Tennor Holding BV***	**38**	**24**	**31**
Rete Ferroviaria Italiana	1	34	*Virtu Ferries Ltd*	9.044	34	***Jifmar Offshore Services SAS***	**29**	**33**	**31**
Samskip hf	1	35	*Caronte Shipping SpA*	8.778	35	***Tirrenia di Navigazione SpA***	**40**	**23**	**31,5**
Seatrans AS	1	36	*T-Finans AS*	7.911	36	***Molslinjen AS***	**31**	**32**	**31,5**
Tallink Group Ltd	1	37	*Bharati Shipyard Ltd*	7.695	37	***Seatrans AS***	**36**	**38**	**37**
Tennor Holding BV	1	38	*Seatrans AS*	7.695	38	***Pentland Ferries***	**32**	**42**	**37**
T-Finans AS	1	39	*Doeksen G*	7.488	39	***T-Finans AS***	**39**	**36**	**37,5**
Tirrenia di Navigazione SpA	1	40	*Torghatten ASA*	3.480	40	***Samskip hf***	**35**	**41**	**38**
Torghatten ASA	1	41	*Samskip hf*	3.270	41	***Virtu Ferries Ltd***	**43**	**34**	**38,5**
Viking Line Abp	1	42	*Pentland Ferries*	2.991	42	***Rete Ferroviaria Italiana***	**34**	**43**	**38,5**
Virtu Ferries Ltd	1	43	*Rete Ferroviaria Italiana*	2.530	43	***Torghatten ASA***	**41**	**40**	**40,5**

Source: Author's elaboration.

In the “green” sample, there are different trends to invest in green technologies, solutions, and equipment. Indeed, the “green” sample consists not only of group owners whose trend is to adopt the same technology on board ships of their fleet, without diversifying investments, with an intensive scaling approach aimed at achieving economies of purpose and cost reduction; both of those who, instead, adopt different strategies investing in several and different green technologies and equipment, through a green approach of energy mix and functional technologies, adapting to the evolution.

The trend of top performer group owners to invest in onboard technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions can be found by comparing their own fleet (in terms of GT) adopting green technologies, solutions, and equipment, with their overall fleet. This analysis is performed with a data gathering through IHS Maritime & Trade to examinate, for each group owners in the top ten ranking of the “green” sample, the total amount of their fleet and the related GT. With the extraction of data from IHS Maritime & Trade, for each group owner only Ferry, Ro-Ro and Ro-Pax ships with GT equal or over 2,000 GT are selected, in compliance with ships selection criteria adopted in the “green” sample. Among the top ten group owners in the “green” sample, the group owner “Unknown”, holding 6 ships (118,614 GT), is excluded because unable to trace the identity of that group owner.

The different trends of each group owner to invest in green technologies and equipment is shown by the comparison of the total GT with the related “green” GT and the total number of ships belonging to the total fleet with the number of “green” ships, for each group owner in the top ten ranking. Such analysis and comparison are shown in Table 20.

Table 20. Top ten group owners and relative "green" fleet.

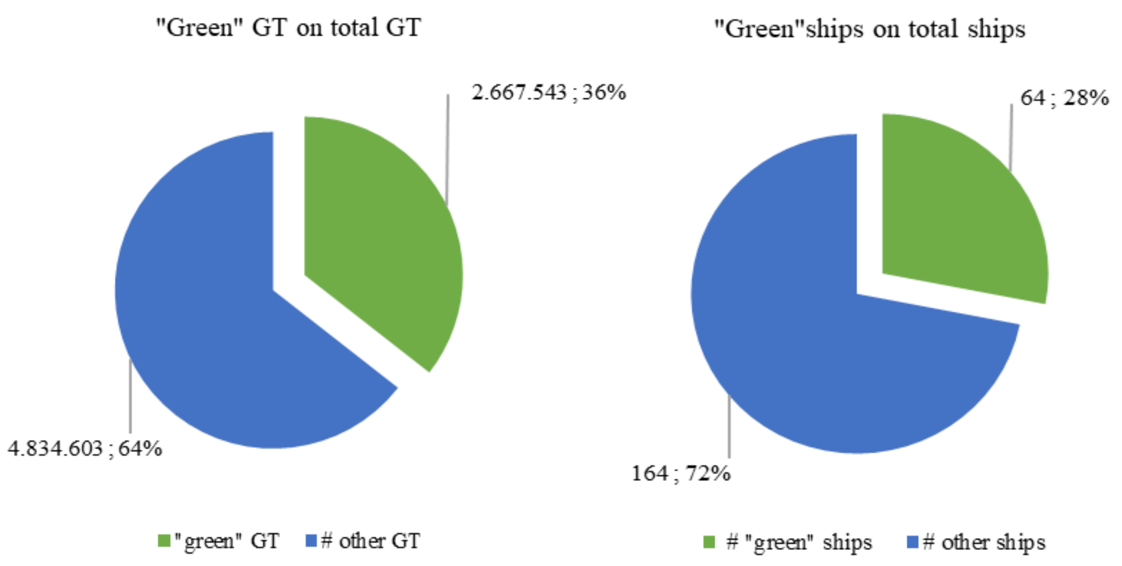
#	Top ten group owner	Group owner domicile	# "green" ships	"green" GT	# total ships	total GT	% "green" ships	% "green" GT
1	Grimaldi Group SpA	Italy	15	1.113.063	78	3.883.523	19%	29%
2	CLdN	Belgium	8	403.562	17	719.332	47%	56%
3	Finnlines Plc	Finland	5	310.751	24	941.854	21%	33%
4	Balearia Eurolineas Maritimas	Spain	6	144.892	13	246.289	46%	59%
5	Bank of Communications	China	4	166.684	7	216.507	57%	77%
6	ICBC Financial Leasing Co Ltd	China	3	122.547	3	122.547	100%	100%
7	Fjord1 ASA	Norway	17	44.976	45	149.262	38%	30%
8	DFDS Denizcilik ve Tasimacilik	Turkey	2	120.930	14	485.263	14%	25%
9	Moby SpA	Italy	2	139.000	18	432.131	11%	32%
10	Aug Bolten Wm Miller's	Germany	2	101.138	9	305.438	22%	33%
	Total		**64**	**2.667.543**	**228**	**7.502.146**	**28%**	**36%**

Source: Author's elaboration.

Considering the total amount of the fleet belonging to the top ten group owner in the "green" sample, i.e., 228 ships for a total of more than 7,500,000 GT, the number of ships with green technologies, solutions and equipment amounts to 64 (28% of the total number of ships) for a gross tonnage almost equal to 2,670,000 GT (36% of the total GT) (

Figure *61*).

Figure 61. "Green" GT and ships in the "green" sample.



Source: Author's elaboration.

With the percentage of "green" GT on the total GT fleet and of number of "green" ships on the total fleet belonging to each group owner, the dimension of GT "green" fleet of them is represented by the dimension of the bubbles (per each group owner) in Figure 62.

The first group owner in in the ranking is Grimaldi Group with 15 "green" ships for a total gross tonnage more than 1.110.000 GT. With a total fleet of 78 ships, corresponding to around 3.880.000 GT, 19% of them in term of number of ships and the 29% of them in term of GT are equipped with technical solutions and cutting-edge technologies for mitigating pollution and reducing harmful emissions.

Although the fleet of Balearia Eurolineas Maritimas is notably smaller than Grimaldi Group's fleet (13 Ferry, Ro-Ro and Ro-Pax ships, for a total of 246,289 GTs), the incidence of the "green" fleet of Balearia Eurolineas Maritimas is equal to 46% in terms of number of ships and 59% in terms of GT, of the total fleet. Consequently, the relative "bubble" in Figure 62 has a lower diameter than that one of Grimaldi Group, due the "green" GT of the fleet (in absolute terms), even if it is placed higher in Figure 62 the because of the incidence of its "green" ships on the total fleet.

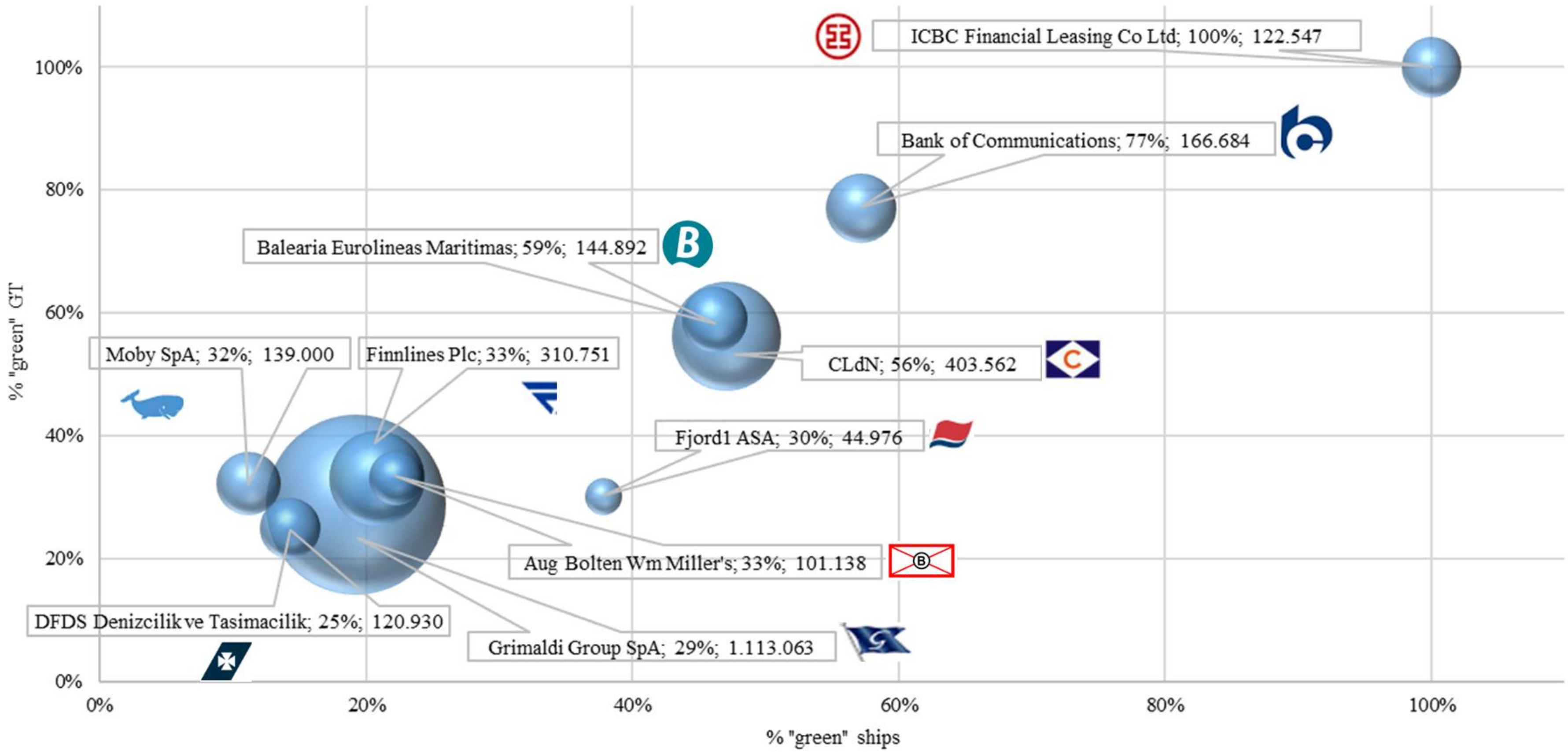
The second and the third position in the ranking are occupied by CLdN and Finnlines Plc, with a fleet respectively corresponding to 17 and 24 Ferry, Ro-Ro and Ro-Pax ships (with GT equal or over 2,000 GT), for a total gross tonnage exceeding 710,000 GT and 940,000 GT. Considering CLdN, 47% of ships fleet and 56% of GT fleet is attributable to "green" ship. Referring to Finnlines Plc, the incidence of the green fleet turns out to be below the average of the "green" sample: 21% of number of "green" ships and 33% of "green" GT on the total fleet belonging to Finnlines Plc.

Moby SpA and DFDS Denizcilik ve Tasimacilik, the former with domicile in Italy and the latter in Turkey, have a similar fleet size: 18 ships of Moby SpA, for a total gross tonnage of about 430.000 GT and 14 ships of DFDS Denizcilik ve Tasimacilik, for a total gross tonnage of about 480.000 GT. Both group owners own only 2 ships (one each) adopting green technologies, solutions and equipment, represents, respectively, 139.000 GT for Moby SpA and more than 120.000 GT for DFDS Denizcilik ve Tasimacilik.

Although the total fleet of Fjord1 ASA corresponds to a half of that of Grimaldi Group SpA, in term of number of ships, and to 4%, in term of gross tonnage, 38% Fjord1 ASA fleet is composed of ships with onboard technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions, compared to 19% of Grimaldi Group SpA. At the bottom of the ranking, the Aug Bolten Wm Miller's, i.e.., a group owner from Germany, presents the same proportions of Finnlines Plc in terms of incidence of "green ships" (22%) and "green GT" (33%) on the total fleet, despite the fleet of Aug Bolten Wm Miller's, represents only 32% in terms of GT of the fleet of Finnlines Plc.

In the ranking, the fifth and sixth places are occupied not by shipping and transport companies but by banks established in China, i.e., Bank of Communications and ICBC Financial Leasing Co Ltd, solely financed by Industrial and Commercial Bank of China. Bank of Communications and ICBC Financial Leasing Co Ltd holds Ferry, Ro-Ro and Ro-Pax ships that are operating and will operate by DFDS Seaways SAS, Brittany Ferries BAI SA, StraitNZ Bluebridge Ltd, Hurtigruten Coastal AS and Stena Line Irish Sea Ferries. While Bank of Communications holds 7 ships for a total gross tonnage over 210,000 GT, ICBC Financial Leasing Co Ltd detains 3 ships, with a GT equal to 122,547. The incidence of "green" gross tonnage on the Bank of Communications fleet is 77%, although 57% of its fleet ships is considered "green", especially because of the big dimensions of ships (average of more than 30,000 GT per ship and 4 ships over 40,000 GT). However, all ships in ICBC Financial Leasing Co Ltd fleet are equipped with technical solutions for reducing harmful emissions and pollutions, so 100% of ships and of GT is considered as "green". Consequently, the ICBC Financial Leasing Co Ltd bubble in Figure 62 is located in the highest and rightmost location of the figure, due to the highest incidence of "green" ships in the fleet.

Figure 62. "Green" fleet per each group owner (dimensions in term of "green" GT).



Source: Author's elaboration.

One of the technologies and systems aimed at mitigating the environmental impact of the sector most widely adopted in the “green” sample is the bulbous bow which, according to the main extant literature, reduces fuel consumption up to 15% (Liu et al., 2015). The bulbous bow is installed on almost the 50% of Ferry, Ro-Ro and Ro-Pax ships of the “green” sample, such as on all ships of CLdN and Bank of Communications and of all ships of Grimaldi Group SpA and Finnlines Plc just entered in service and in operation.

Furthermore, all Grimaldi Group and Stena AB Ferry, Ro-Ro and Ro-Pax ships in the “green” sample are hybrid ships. Some of the ships held by Grimaldi Group are also arranged for the supply of electricity from the ground during mooring and the port stop, while Stena AB Ferry, Ro-Ro and Ro-Pax ships will feature dual-fuel engines and a hybrid battery solution.

Among the most widely used alternative fuels for propulsion (biofuel, LNG, methanol, hydrogen, VLSFO/ULSFO), LNG is the most widely used by group owners in the “green” sample. Specifically, the 43% of the Ferry, Ro-Ro and Ro-Pax ships in the “green” sample is LNG-propelled. Among them, almost all units are dual fuel, while only 18% of them are hybrid ships with LNG propulsion and onboard battery for storing energy to be used for the propulsion: this is the case of the Ferry, Ro-Ro and Ro-Pax ships owned by Torghatten Nord AS, Doeksen G and Seatrans AS.

Through the “green” sample collecting the most adopted green technologies and solutions, it is possible to analyse the corporate strategies and the green oriented approach of the top ten group owners of the “green” sample, in order to deepen, through brief case histories, the main strategies adopted by them. In this vein, Table 21 shows the most adopted technologies and systems aimed at mitigating the environmental impact of the Ferry, Ro-Ro and Ro-Pax industry.

Table 21. Technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions adopted by group owners.

Group Owners	#ships	Dual fuel	Electrification (ready)	Biofuel	LNG	Methanol	Hydrogen	VLSFO / ULSFO	Scrubber	Solar Panel	Wing sail	Eolic turbine	Battery for propulsion	Battery for onboard operations	Hybrid ship	Bulbous bow
Fjord1 ASA	17	0	12	2	0	0	0	0	0	0	0	0	17	0	7	5
Grimaldi Group SpA	15	0	6	0	0	0	0	0	15	9	0	0	6	9	15	9
Norled AS	10	0	4	6	0	0	2	0	0	0	0	0	9	0	9	1
CLdN	8	8	0	0	8	0	0	0	0	0	0	0	2	0	3	8
Torghatten Nord AS	7	0	2	0	5	0	0	0	0	0	0	0	6	0	4	0
Unknown	6	1	2	0	1	0	0	0	0	1	0	0	3	0	1	2
Balearia Eurolineas Maritimas	6	5	1	0	5	0	0	0	0	2	0	0	1	0	1	3
Finnlines Plc	5	0	2	0	0	0	0	0	5	3	0	0	2	3	4	3
Veolia Transport	5	0	4	0	0	0	0	0	0	0	0	0	5	0	2	0
Bank of Communications	4	4	0	0	4	1	0	0	4	0	0	0	0	3	3	4
Bore Ltd	3	3	0	0	3	0	0	0	0	0	0	0	0	0	0	2
ICBC Financial Leasing Co Ltd	3	2	0	0	2	0	0	0	0	0	0	0	0	0	0	3
Stena AB	3	3	0	0	3	0	0	0	0	0	0	0	3	0	3	3
Aug Bolten Wm Miller's	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	2
Caledonian Maritime Assets Ltd	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0
DFDS Denizcilik ve Tasimacilik	2	0	0	0	0	0	0	2	2	0	0	0	0	0	0	2
Doeksen G	2	0	0	0	2	0	0	0	0	2	0	0	0	2	2	0
Grandi Navi Veloci SpA	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
Moby SpA	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Siem Shipping Inc	2	1	0	0	1	0	0	0	0	0	0	0	1	0	0	2
Wallenius Lines AB	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	1
Armas Naviera SA	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Bharati Shipyard Ltd	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Caronte Shipping SpA	1	1	0	0	1	0	0	0	0	1	0	0	1	0	1	0

Group Owners	**#ships**	**Dual fuel**	**Electrification (ready)**	**Biofuel**	**LNG**	**Methanol**	**Hydrogen**	**VLSFO / ULSFO**	**Scrubber**	**Solar Panel**	**Wing sail**	**Eolic turbine**	**Battery for propulsion**	**Battery for onboard operations**	**Hybrid ship**	**Bulbous bow**
Color Group AS	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1
Credit Agricole SA	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Financial Products Group Co	1	1	1	0	1	1	0	0	0	0	0	0	0	0	1	1
Gotland Rederi AB	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Jifmar Offshore Services SAS	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0
Kvarken Link AB	1	1	0	0	1	0	0	0	0	0	0	0	1	0	1	1
Molslinjen AS	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentland Ferries	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Polish Baltic Shipping Co	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Rete Ferroviaria Italiana	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Samskip hf	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0
Seatrans AS	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Tallink Group Ltd	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Tennor Holding BV	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
T-Finans AS	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0
Tirrenia di Navigazione SpA	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Viking Line Abp	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Virtu Ferries Ltd	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0

Source: Author's elaboration.

6.3.3.1 Grimaldi Group SpA

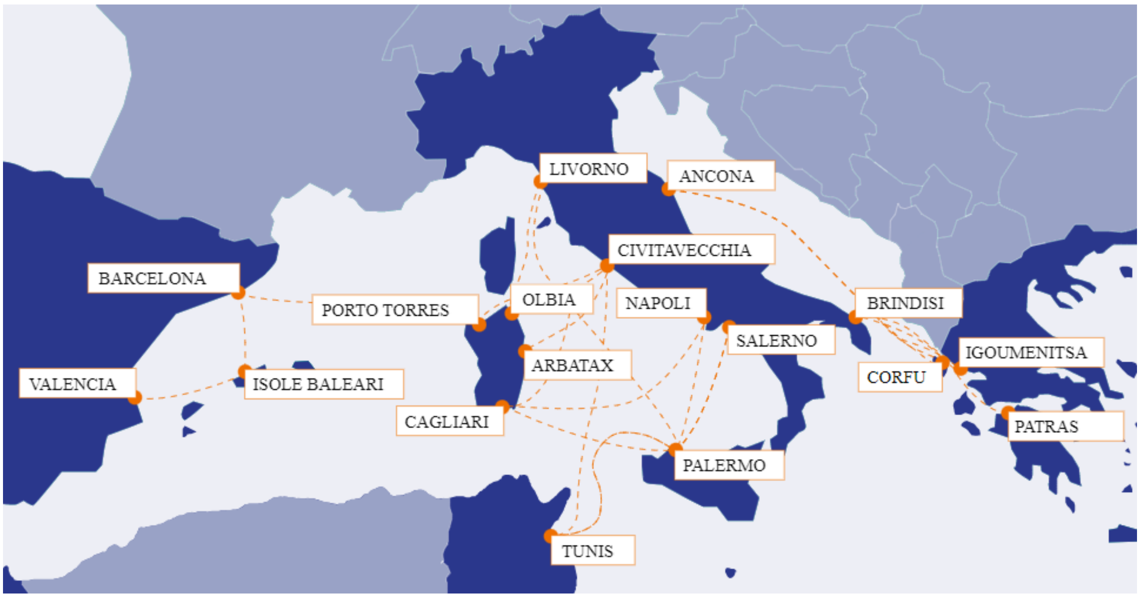
Grimaldi Group is the holding company of the Group that includes seven main shipping companies:

- Grimaldi Euromed, that is specialized in passenger transportation in Mediterranean Sea, in transportation of rolling stock between Northern Europe and the Mediterranean (Euromed), on the Motorways of the Sea in the Mediterranean and freight transport between the Mediterranean and North America (especially car carriers);
- Grimaldi Deep Sea, transporting rolling stock and containers between ports of North Europe, the Mediterranean, West Africa and South America;
- Atlantic Container Line (ACL), that manages maritime lines mainly dedicated to container traffic that connect North America, Northern Europe and West Africa;
- Malta Motorways of the Sea (MMOS), with four ships used mainly for links between Malta, Sicily and Greece;
- Minoan Lines, that provides short-sea shipping of goods and passengers in Greece;
- Finnlines, transporting goods and passengers between countries on the Baltic and North Sea coasts, as well as Spain and Great Britain;
- Trasmed GLE, the Spanish company specialising in the transport of passengers and goods between the Iberian Peninsula and the Balearic Islands.

The Chairman is Gianluca Grimaldi and the Managing Directors are Emanuele Grimaldi and Diego Pacella. The company has played an important role in the Group's history, being at the forefront of all corporate development actions in shipping, ports and logistics. Grimaldi Group SpA owns stakes in the Group's shipping companies as well as in the main port terminals: Antwerp Euroterminal (AET), the Group's Northern European hub; Unikai terminal of Hamburg; Wallhamn Holding, the company that owns the Swedish port of Wallhamn; Port & Terminal Multiservices Limited (PTML), the company which operates the West African Ro/Ro terminal in Lagos.

With a fleet of over 100 vessels, the Group provides maritime transport services for rolling cargo and containers between North Europe, the Mediterranean, the Baltic Sea, West Africa, North and South America and passenger services within the Mediterranean and Baltic Sea (Figure 63).

Figure 63. Grimaldi Lines ferry destinations.



Source: Grimaldi Lines corporate website, 2022.

The implementation and certification of the environmental management system (ISO14001), achieved by the shipping companies of the Group, has been a decisive strategic choice to reflect the high sensitivity to pollution issues in the company procedures. Also considering the strict regulations imposed by the EU and the MARPOL Convention on the emission of sulphates, the Group has completed in 2021 the installation of exhaust gas cleaning systems onboard of their own ships, for an investment of over 300 million euros. In 2021 the Group kept on maintaining the continuous fleet renewal policy, by replacing the old ships with new units equipped with the most modern technologies, aimed at reducing consumptions and emissions. This has led to a reduction in the average age of the Group's fleet which, now, is about 14 years old and it is set to decrease further with the delivery of newbuildings. In accordance with recent IMO ballast water management regulations, aimed at containing and reducing the invasion of pathogenic marine organisms from other geographical areas, in 2021, the Group installed on board ships treatment plants and systems.

Furthermore, with the aim of highlighting the company's vision based on prospects to sustainably create shared value, Grimaldi Group periodically published the Sustainability Report. The Report was prepared to provide a tool to learn more about the Grimaldi Group business model, not only in the merely economic sense, but with a wider view that also encompasses tangible and intangible effects.

Decarbonisation and energy efficiency are at the core of the Grimaldi Group's agenda when it comes to reducing its environmental footprint (Grimaldi Group Sustainability Report, 2021). In 2021, the Group programmed its investments in order to reduce its environmental impact, not only in terms of direct emissions produced by its own ships, which at the end of 2021 amounted to 127 units, but also in terms of reducing indirect emissions produced by the logistics operations required in ports and terminals. As emerged from the "green" sample, Grimaldi Group projects concern interventions to improve vessel performance and innovative technologies for newbuilding, as well as projects related to the electrification and decarbonisation of ports and terminals owned by the Group. Specifically, Grimaldi Group has invested and is investing in hybrid ships and in the electrification equipping Ferry, Ro-Ro and Ro-Pax with batteries for the propulsion, without too much diversification in its investment strategy. During 2021, the electricity drawn from the batteries during port stays amounted to 3,710 MWh: the use of batteries during port stays contribute to reduce emissions, as shown in Table 22.

Table 22. Emission reduction in port by ships.

Ship	Reducing emissions in port			
	CO_2 [kg]	CO [kg]	HC [kg]	NOX [kg]
Cruise Roma	601,123	277	300	10,751
Cruise Barcelona	568,456	262	284	10,167
ECO Valencia	487,522	211	302	6,503
ECO Livorno	293,374	127	182	3,913
ECO Savona	382,709	166	237	5,105
Total	2,333,184	1,043	1,305	36,439

Source: Grimaldi Group Sustainability Report, 2021.

Manifold investments are made by Grimaldi Group for the control of the emissions, for example the equipment of ships with solar panels, bulbous bows, batteries for onboard operations. Moreover, all ships are equipped with scrubbers, since ships do not use alternative fuels like VLSFO/ULSFO, hydrogen, methanol or LNG, but distillate fuel, with a higher sulphur content, comparing with innovative fuels. So, in the Grimaldi Group Sustainability Report (2021) fuels as methanol, biofuel and LNG are not mentioned as fuels used for the propulsion of ships in operation and those under construction.

Among ships of the "green" sample, the MV Eco Valencia (2020) received the *Shippax Ro-Ro technology and environmental award*, further demonstrating the innovativeness and efficiency of the entire GG5G class of ships. A further four GG5G-class of ships was delivered to Grimaldi Euromed in 2021: MV Eco Barcelona, MV Eco Livorno, MV Eco Savona and MV Eco Catania. MV Eco Adriatica, MV Eco Italia, MV Eco Malta, MV Eco Mediterranea are delivered in 2022 and will be operated in Mediterranean Sea. The Grimaldi Group has also commissioned the building of six new ships to the Korean Hyundai Mipo Dockyard Co. Ltd shipyards. The G5 Hyundai Class ships will feature the adoption of several innovative technological solutions aimed at energy efficiency and reduced environmental impact:

- ships will be ready for shore-side power supply;
- the electricity consumption of on-board machinery (pumps, fans, etc.) will be reduced by installing converters and optimising the ventilation system through air quality monitoring;
- the hydrodynamic efficiency of the hull with reduced hull friction will be the result of the application of latest-generation antifouling paints with low roughness and self-cleaning characteristics and the Air Lubrication System;
- exhaust gas cleaning systems to reduce sulphur and particulate emissions will also be installed on board the ships.

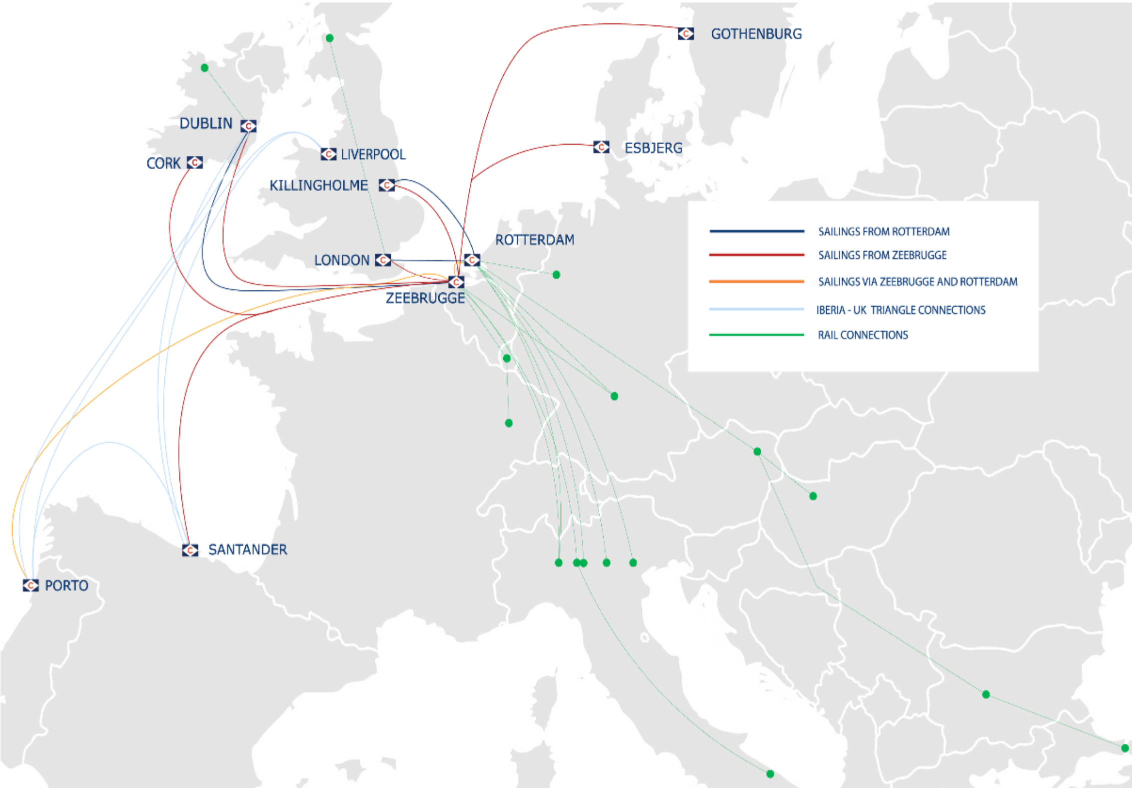
Such units will allow a reduction of the emissions of CO_2 for transported ton up to 43% compared to the other ships of the fleet. The delivery of the six ships commissioned will allow the replacement of the oldest ships of the Group in order to further elevate the quality of the maritime transport services offered by the Group.

6.3.3.2 CLdN

CLdN SA (Compagnie Luxembourg de Navigation) is a logistics company based in Luxembourg. Through CLdN Ro Ro SA and CLdN Cobelfret SA, CLdN operates regular Ro-Ro ferries and bulk carriers, respectively, between European ports and also owns and manages European ports. In 2017 CLdN linked, with its Ro-Ro ships, different European ports in Belgium, Netherlands, UK, Ireland, Sweden, Denmark and Portugal. Through its subsidiary, C.RO ports, it operates Ro-Ro ports in Belgium (Zeebrügge), Netherlands (Rotterdam and Vlissingen) and in United Kingdom (London, Killingholme and Sutton Bridge): for examples, the Gothenburg port, i.e., Gothenburg Ro-Ro Terminal AB, is owned by DFDS (65%) and C.RO ports (35%).

In 2017 and 2018, CLdN took up the world’s largest short-sea Ro-Ro ships, i.e., the sister ships MV Celine and MV Delphine, combining the capacity and technology of deep-sea with the agility and adjustability of shortsea ferries. With over 140 sailings per week, guaranteeing clients a reliable and steady cargo flow, the North Sea coast is the heart of CLdN business. In Zeebrugge and Rotterdam, the company has shipping services from four different European regions coming together, giving their customers access to through shipment opportunities by Ro-Ro ships or transhipment via road, rail or river (Figure 64).

Figure 64. CLdN sailing schedules.



Source: CLdN corporate website, 2022.

As announced on 20th September 2022, CLdN has completed the agreement to acquire all shares in Seatruck Ferries Holding Ltd from Clipper Group of Denmark. Through Seatruck's long term presence in the ports of Heysham and Warrenpoint (as shown in Figure 65) as well as in CLdN's key hubs of Dublin and Liverpool, a special growth of the group's network has started, requiring more investments and capacity to shipping lanes. Seatruck's activities offers and will offer customers seamless transhipment opportunities from the start of 2023, allowing direct access to the group's Iberian, Irish, UK and continental European markets.

Figure 65. CLdN adds new schedules with the acquisition of Seatruck Ferries.

Source: CLdN corporate website, 2022.

Luxembourg-based shipping company CLdN decided upon a fleet renewal strategy in 2015 and had the largest relative fleet increase (22% CAGR or five vessels) over the period 2018-20. Consequently, CLdN operates the youngest fleet with an average vessel age of 12.7 years compared to peer group average of 17.2 years. A further CLdN mission is to go so far as to prepare for future legislation. For this reason, CLdN latest ships are LNG ready (MV Hermine, MV Laureline, MV Sixtine, MV Ysaline, MV Faustine, MV Seraphine) and two more (MV Hyundai Mipo 8382 and MV Hyundai Mipo 8383) are ordered, complete with a 320 cubic meter capacity C-type LNG fuel storage tank located on the main deck. CLdN is also currently setting up an LNG supply chain in Rotterdam and Zeebrugge.

According to its missions, CLdN have developed, jointly with the technology group Wärtsilä, an innovative hybrid design for two new Ro-Ro ship, i.e., MV Hyundai Mipo 8382 and MV Hyundai Mipo 8383, entering in service in Q4 2024 and in Q1 2025, respectively. The propulsion arrangement is such that the ships can operate both as gas/diesel-mechanical vessel both as gas/diesel-electric vessel. The Wärtsilä hybrid system includes Energy Storage Systems, two large PTO/PTI generators and electric motors, multidrive converters, and the Wärtsilä Energy Management System that controls and optimises the hybrid operations. This innovative solution will minimize the ships' CO_2 emissions, supporting the shipping sector's decarbonisation ambitions.

As confirmed in CLdN corporate website, the shipping company invested and will invest in LNG as a fuel for its Ro-Ro ships, in addition to the use of the best available techniques able to minimize daily emissions in all of their business activities. As from the "green" sample, CLdN's investment strategy in innovative technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions seems not highly diversified but focused almost purely on LNG and dual fuel engine for their Ro-Ro ships, batteries for the propulsion and Bulbous bow.

6.3.3.3. Finnlines Plc

As a member of the Grimaldi Group, Finnlines offers liner services throughout the Grimaldi network, providing goods and passenger transport services in Baltic Sea, the North Sea, and the Bay of Biscay, the geographic area with the highest economic growth in Europe (Figure 66). With more than 170 weekly freight and 80 passenger departures, Finnlines' extensive line network provides Finnish imports and exports with a reliable connection to the European markets, ensuring efficient shipping services and availability of emergency supplies, such as medicines, machinery, components, and other commodities.

Figure 66. Finnlines's operating area.

Source: Finnlines' Annual Report, 2021.

Finnlines has been dealing with passenger and freight transport for around seventy years and its fleet of ships and ferries is modern and up to date as Finnlines are always investing in new technology. Indeed, over the coming years they are going to introduce three brand new “green” ships with low environmental impact.

Among the sustainability measures implemented by the company is the “Green Newbuilding programme”, aimed at reducing friction and aerodynamic drag on ships by installing energy-efficient engines and an air lubrication system. With its investment in innovative system and cutting-edge technologies, Finnlines reduced its CO_2 emissions by more than 30% compared to 2008. Over the last decade, Finnlines has dedicated around € 1 billion in investments to improve its levels of environmental sustainability, by renewing its fleet with larger ships, installing emission reduction systems on 21 ships, optimizing its ships and routes, monitoring fuel consumption, applying silicone coatings to reduce the wear and tear of ships, and upgrading and lengthening of ships.

As emerged from the “green” sample, according to Grimaldi Group strategic management, Finnlines invested and is investing in hybrid ships and in the electrification, equipping Ferry, Ro-Ro and Ro-Pax with batteries for the propulsion, without diversifying its own investment strategy. Finnlines newbuilding’s are under construction and belonged to Grimaldi Green 5th Generation-class (GG5G-class) ships and to Superstar class. The former are hybrid ships with latest-generation engines, controlled electronically and powered by fossil fuels. Specifically, these ships (MV Finneco I, MV Finneco II and MV Finneco III) do not use alternative fuels like VLSFO/ULSFO, hydrogen, methanol, or LNG, but distillate fuel, with treatment of the exhaust gases at sea (SOx and PM emissions appropriately treated and reduced with post-combustion systems) and electricity during stays in port. During stays at berth, these hybrid ships can meet the energy demands of onboard activities with just electricity stored in lithium batteries that are recharged during navigation by shaft generators and solar panels. Superstar class ships are currently under construction and their design is the result of a careful analysis aimed at guaranteeing the highest energy efficiency. MV Finncanopus and MV Finnsirius will be equipped with the latest-generation scrubbers, the Air Lubrication System, which creates a layer of micro-air bubbles below the hull and to guarantee zero emissions in port, and battery packs (approximately 5.0 MWh).

The progressive sustainability-oriented strategy of Finnelines company has carried to remarkable results not only in terms of Gross Tonnage dimensions and maintained service speed related to the last generation new ships, but also in terms of reduction of the emissions of CO_2 (Figure 67). In thirty years, Finnlinnes has managed to increase the service speed of its ships by about 20% and reduce by almost 60% the CO_2 emissions generated per nm x GT, also almost tripling the size of its ships (from about 21,000 GT to over 60,000 GT).

Figure 67. Evolution of Finnlines' Ro-Ro Vessels.

	Baltica In Finnlines traffic 1995–2011, both owned and chartered	**Finnmill** In Finnlines traffic since 2002, both owned and chartered	**Finnbreeze** In Finnlines traffic since 2011, owned	**Finnbreeze** (lenghtened) Lengthened in 2018	**Finneco** Will be delivered in 2022
Year of Built	1990	2002	2011	2018	2022
Service Speed [kn]	17.3	19.8	20.0	19.6	20.7
Gross Tonnage	21,224	25,731	28,002	33,816	60,370
g CO_2/(nm x GT)	18.5	17.5	15.5	13.7	7.9

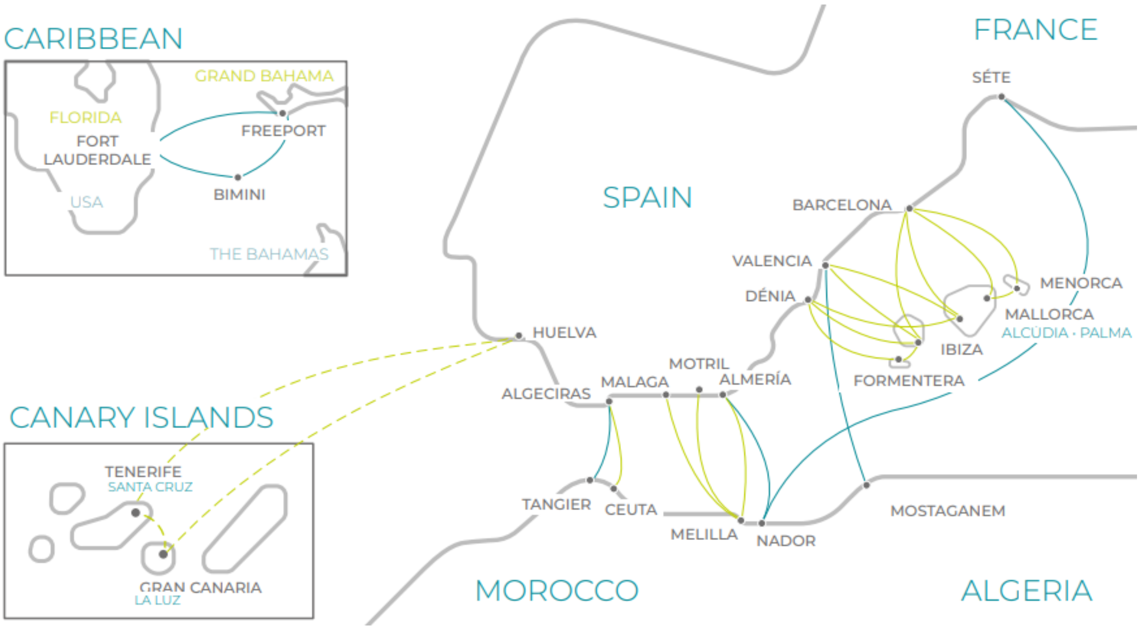
Source: Finnlines' Annual Report, 2021.

6.3.3.4. Balearia Eurolineas Maritimas

Balearia is a leading shipping company for the transport of passengers and goods on the connections between the Iberian Peninsula and the Balearic Islands, the cities of Ceuta and Melilla and the Canary Islands. Balearia also offers international services in Morocco, Algeria and the Caribbean (between the United States and the Bahamas) (

Figure 68).

Figure 68. Balearia's routes.



Source: Balearias' Sustainability Report, 2021.

With a fleet of 32 ships, in 2019 Balearia has transported more than 4,480,000 passengers and 6,111,000 linear meters of goods. The mission of the group is to respond to the needs of maritime transport of the company by offering its customers a quality service that respects the environment, to its shareholders a suitable profitability and to its employees the possibility of growth in professional and personal. Indeed, the vision of the Balearia is to be a leading navigation group and constantly growing with global presence, being characterised by the provision of excellent quality services through continuous improvement and excellence in sustainable environmental management, which means strengthening and creating links between the companies united by their maritime lines, contributing to its own development and progress.

In order to achieve the objectives of the 2030 Agenda of the United Nations, Balearia is increasingly focusing on economic, social and environmental sustainability. Specifically, considering the innovative technical solutions and cutting-edge technologies installed on board for mitigating the pollution and reducing harmful emissions discussed in this PhD thesis, for Balearia LNG is certainly the most relevant solution. For this reason, Balearia can be considered a worldwide pioneer in the use of natural gas (Balearia Sustainability report, 2021): the fleet of Balearia counted, in 2021, 9 LNG-propelled ships, between new constructions and retrofitting, for a total investment of 380 million euros. With the incorporation of the fast ferry MV Eleanor Roosevelt, the reengining of the MV Martín i Soler and the start of the retrofit of the MV Hedy Lamarr, in 2021, Balearia entered the final phase of converting its fleet to sail on natural gas.

As from the “green” sample, the Balearia’s investment strategy in innovative technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions seems not too diversified but focused almost purely on LNG. The only exception in the “green” sample is the MV Armon Vigo V138, currently under construction and scheduled for delivery in 2023. Such unit will have a double ended diesel-electric engine for the pursue of a “zero emissions in port” strategy. In this perspective, Balearia wants to base its strategy on eco-efficiency, digitalization and smart ships, working on projects linked to future energy sources with the final goal of zero emissions by 2050. So, as from Balearia Sustainability report (2021), the company has also started building the first 100% electric passenger and cargo ferry in the Mediterranean, which produces zero emissions during port stays and approaches by using green hydrogen as a test bed for this energy source.

Balearia manifold investments are focused on the control of emissions, for example the equipment of the ships with bulbous bow and solar panel. All ships in “green” sample are not equipped of scrubber, because ships are LNG-propelled with an emission reduction potential of about 30% of CO_2, 85% of NOx and 100% of SOx and particulate matter. So, in the Grimaldi Group Sustainability Report (2021) fuels as methanol, biofuel and LNG are not mentioned as fuels used for the propulsion of ships in operation and those under construction.

As confirmed also by Balearias’ Sustainability Report (2021), the company invests mainly on LNG propulsion, transitioning towards full decarbonisation, and on smart technologies, offering a fuller and more personalised experience, exploiting the capabilities of big data to become a data-driven company (Figure 69).

Figure 69. Balearias' fleet.

FERRIES						
Abel Matutes	23 kn	190 m	900	625	●	●
Bahama Mama	23 kn	154 m	1,000	350	●	●
Dènia Ciutat Creativa	19 kn	150 m	399	430		
Hedy Lamarr	24 kn	186 m	600	646	●	●
Hypatia de Alejandría	24 kn	186 m	880	608	●	●
Marie Curie	24 kn	186 m	880	608	●	●
Martín i Soler	23 kn	165 m	1,200	567	●	●
Nápoles	23 kn	186 m	1,600	339	●	●
Passió per Formentera	22 kn	100 m	800	105		
Poeta López Anglada	18 kn	133 m	1,257	243		
Posidonia	17 kn	69 m	550	90		
Regina Baltica	19 kn	145 m	1,600	350		
Rosalind Franklin**	22 kn	188 m	860	624	●	
Sicilia	23 kn	186 m	1,000	481	●	●
Wasa Express**		140 m	1,500			

(**) The Rosalind Franklin completed its charter in November, and the Wasa Express was incorporated that same month.

● To natural gas ● To natural gas (projected)
● Smart ship ● Smart ship (projected)
● Scrubbers

FAST FERRIES						
Avemar Dos	34 kn	82 m	855	174		
Bimini Blue Marlin	30 kn	39 m	356	-		
Cecilia Payne	38 kn	86 m	800	200		
Formentera Direct	30 kn	50 m	309	36		
Eco Aqua	28 kn	28 m	355	-		
Eco Aire	28 kn	28 m	355	-		
Eco Terra	28 kn	28 m	355	-		
Eco Lux	28 kn	28 m	355	-		
Eleanor Roosevelt	35 kn	123 m	1,200	450	●	●
Jaume I	32 kn	78 m	623	130		
Jaume II	32 kn	81 m	624	140		
Jaume III	32 kn	81 m	655	140		●
Nixe	32 kn	63 m	546	122		
Ramon Llull	32 kn	83 m	476	120		●

ONLY CARGO				
Virot	12 kn	64 m	41	117

(*) Aguila Pescadora, Corb Marí and Rolón Plata Dos.

Source: Balearias' Sustainability Report, 2021.

6.3.3.5. Bank of Communications

Bank of Communications Limited isn't a shipping company but is the fifth-largest bank in mainland China. Listed on the Stock Exchange of Hong Kong in June 2005 and on the Shanghai Stock Exchange in May 2007, the Bank of Communication was ranked n. 151 among Fortune Global 500 in terms of operating income by the Fortune and n. 11 among the global top 1,000 banks in terms of Tier 1 Capital rated by the London-based magazine "The Banker".

Today, the Bank of Communications is amongst the top 5 leading commercial banks in China and has an extensive network of over 2,800 in over 80 major cities. Apart from Hong Kong, the Bank has also established overseas branches in New York, Tokyo, Singapore and representative offices in London and Frankfurt. As of end 2002, the Bank had over 88,000 employees and a total asset reaching RMB 5.15 trillion. Bank of Communications is one of the major financial service suppliers in China with its business scope covering commercial banking, securities, trust, financial leasing, fund management, insurance, offshore financial services, and shipping, too.

Bank of Communications holds Ferry, Ro-Ro and Ro-Pax ships that are operating and will operate by StraitNZ Bluebridge Ltd, Brittany Ferries BAI SA, Hurtigruten Coastal AS, Stena Line Irish Sea Ferries. Bank of Communications holds 7 ships for a total gross tonnage of over 210,000 GT. As anticipated, the incidence of "green" gross tonnage on the Bank of Communications fleet is 77%, although 57% of its fleet ships is considered "green", especially because of the big dimensions of ships (average of more than 30,000 GT per ship and 4 ships over 40,000 GT).

As confirmed by the "green" sample, last ship owned by Bank of Communication are MV Stena Estrid, entered in service in 2019, MV Stena Edda, MV Stena Embla and MV Galicia, in operation from 2020. Among the Stena's E-Flexer ferries, which are for Stena Line and on long-term charter for other ferry operators, the MV Stena Estrid is the first in Stena Line's new line of E-Flexers and has been hailed as the "most efficient ship in Stena's history". Built by China Merchants Jinling Shipyard, with the help of Deltamarin as designer and as a provider of comprehensive project management services to support the shipyard in the vessels' construction, the E-Flexer ferries are equipped with energy efficiency innovations and cutting-edge technologies. With a freight capacity of 3,100 linear metres, these ferries are built paying special attention to the vessels' fuel efficiency as well as maximising the cargo space, in order to combine maximum cargo intake, quick turnarounds and high passenger comfort with low fuel consumption. Considering the benefits of the propulsion system, conventional ferries usually have four main engines for redundancy and to optimise the speed ranges with 85% MCR and shaft generator at constant speed, while the MV Stena Estrid is designed with two diesel-powered main engines, variable frequency shaft generators and with ability to feather the propeller blades on either side giving the vessel's machinery a wider range to optimise the cost and fuel consumption. The MV Stena Estrid is scrubber and gas-ready to meet any future route-specific requirements. Singling out other environmentally friendly and energy efficient features, the MV Stena Estrid's hull has an excellent hydrodynamic performance. The MV Stena Estrid's Energy Efficiency Design Index (EEDI) is significantly better than similar older tonnage and regardless of which fuel will be consumed onboard, it will be much less than conventional tonnage. Furthermore, the ship highlights other energy efficient and innovative solutions used:

- antifouling – Selektope (bio-repellent, organic, non-metal compound),
- high lift streamlined flap rudders of twisted leading-edge (type with rudder bulbs),
- trimmed thruster grids optimised for the design draft bulb wake (improving the hull performance),
- duck tail interceptor (reducing the stern wake and optimising the hull performance),
- propellers with feathering mode (optimising the speed ranges),
- fuel management system,
- stern tubes with anti-leaking system,
- LED lightning for low energy consumption,
- variable frequency shaft generators,
- frequency-controlled pumps and fans.

In this way, it is possible to confirm that the innovative technologies on the latest versions of the E-Flexer series make energy efficiency gains, contributing to a 25% reduction in CO_2 emissions compared to current generation Ro-Ro vessels. Among the others, also the MV Stena Edda and the MV Stena Embla are E-Flexer ferries, having the same technical characteristics and innovative solutions and cutting-edge technologies on bord as the MV Stena Estrid. There are only some technical differences and adjustments between Stena Estrid and the other ferries in the E-Flexer series. For example, MV Stena Edda and MV Stena Embla are powered by an LNG dual-fuel system, while the MV Galicia is a day ferry with a specialised port interface for the quick turnaround in the English Channel.

The MV Galicia, owned by Bank of Communication and operated by Brittany Ferries in the Biscay Bay along the Portsmouth – Santander route and in the English Channel along the Portsmouth – Cherbourg route, is built to a modified version of Stena's E-Flexer platform as used on MV Stena Estrid, MV Stena Edda and MV Stena Embla. In common with other vessels in the E-Flexer class, GALICIA is designed to be efficient and more environmentally friendly than existing vessels. MV Galicia and her part-sisters are designed to be smoother, quieter, and have less vibration than existing ships as well as less emissions. MV Galicia is equipped with an exhaust gas scrubber system, which removes the most harmful particulates from her exhaust, and with a long and slender hull to make for excellent seakeeping in all weathers.

As verified also by the “green” sample, both MV Stena Estrid, MV Stena Edda and MV Stena Embla are equipped with dual fuel propulsion allowing to use both distillate fuel and LNG, a scrubber, to reduce sulphur emissions, a bulbous bow to improve the operating efficiency. Furthermore, to build on well-established energy saving principles, a novel application of permanent magnet technology is used: this is a good concept for a hybrid propulsion train that could easily be extended with the addition of energy storage. The MV Galicia hasn’t batteries on board but, unlike MV Stena Estrid, MV Stena Edda and MV Stena Embla, has a main-propulsion package that can used both methanol both LNG, in addition to distillate fuel.

As demonstrated by the “green” sample, it is possible to confirm, through a green approach of energetic mix and technologies, a remarkable diversification of the investments in innovative solutions and green technologies for the ships owned by Bank of Communication.

6.3.3.6. ICBC Financial Leasing Co Ltd

ICBC Financial Leasing Co., Ltd. (ICBCFL) is one of the largest financial leasing companies in China and is a wholly owned subsidiary of Industrial and Commercial Bank of China Limited (ICBC). ICBCFL has developed strong technical expertise across different business lines: it has a specialized subsidiary for aviation, a dedicated business unit for shipping, and three geographically divided business units for domestic leasing business covering transportation, energy, large equipment and other leasing business.

ICBC Financial Leasing Co Ltd holds Ferry, Ro-Ro and Ro-Pax ships that are operating and will operate by DFDS Seaways SAS and Brittany Ferries BAI SA: three of them are MV Salamanca, MV Santona and MV Côte d’Opale, with a gross tonnage between 20.001 and 50.000 GT. As anticipated, all ships in ICBC Financial Leasing Co Ltd fleet are equipped with technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions, so 100% of ships and of GT is considered as “green”.

The MV Salamanca is a new E-Flexer-class vessel that is operated by the French shipping company Brittany Ferries. It was constructed by Chinese shipyard CMI Jinling (Weihai). The MV Salamanca was delivered to Brittany Ferries in November 2021 and is operating in Celtic Sea.

With a length of 214.5m, draught of 6.4m and breadth of 27.8m, the MV Salamanca offers 2,723 lane metres of space for freight and can accommodate 1,100 persons, including passengers and crew. Powered by LNG dual-fuel engines, the MV Salamanca is the first vessel in the series to feature gas engines. Like the other E-Flexer ferries, the MV Salamanca is equipped with bulbous bow for greater hydrodynamics.

The MV Santona, operated by Brittany Ferries, was floated out at China Merchants Jinling Shipyard (Weihai) on 20 April 2022. It is the second of four new LNG-fuelled ferries operating by Brittany Ferries. With a capacity for 1,015 passengers and up to 2,705 linear metres, the MV Santona is a virtual copy of the MV Salamanca, and, as her sister, the MV Santona is equipped with bulbous bow, to improve the operating efficiency and reduce the emission, and is powered by two Wärtsilä dual-fuel engines.

The MV Côte d'Opale is the fifth in the E-Flexer Ro-Pax class. The group owner has signed a long-term charter agreement with DFDS, which has been highly involved in the ship's unique design. With its 214 meters, the MV Côte d'Opale has become the longest ferry operating in the English Channel along the Dover-Calais route. The MV Côte d'Opale differs from other E-Flexer vessels in the smaller number of cabins. As other E-Flexer ferries, also the MV Côte d'Opale is at the forefront in terms of sustainability, even if it is not equipped with LNG engines. The stern of the MV Côte d'Opale is especially designed to fit the quayside facilities in ports and in addition, it is equipped with a third bow thruster to facilitate the many daily manoeuvres in port.

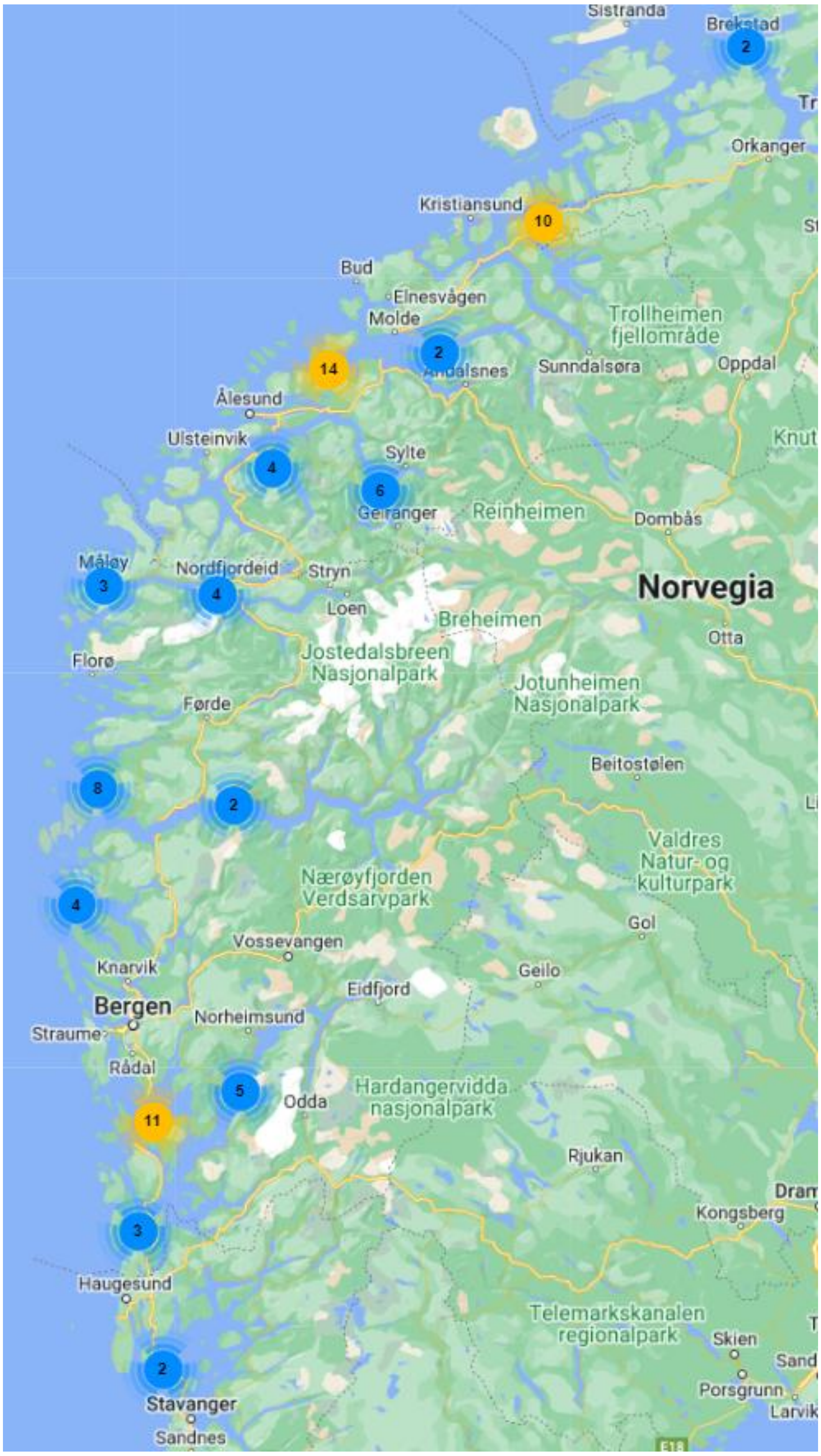
Also because of the reduced number of ships in examination owned by ICBC Financial Leasing Co Ltd, it is possible to affirm in this PhD thesis that the investments in green technologies and innovative solutions by the group owner are little diversified but exclusively concentrated on the LNG and the hydrodynamics of the units.

6.3.3.7. Fjord1 ASA

The Norwegian ferry and passenger boat market has undergone extensive consolidation in recent years. Earlier, there were several players in this market, but increasing competition and challenges proved to be extremely demanding for companies: today, there are only four players in the Norwegian ferry and passenger boat market, i.e., Fjord1, Torghatten, Norled and Boreal Transport. Fjord1 ASA is a Norwegian transport conglomerate, formed in 2001 by the merger of Møre og Romsdal Fylkesbåtar and Fylkesbaatane i Sogn og Fjordane. With headquarters in Florø and a market share of 50%, the company has 75 ships, 394 buses and 147 trucks and transported

24 million passengers in 2005. Its main assets are the two ferry companies which serve the fjords of Møre og Romsdal, Rogaland, Trøndelag and Vestland countries (Figure 70).

Figure 70. Fjord1 ASA map routes.

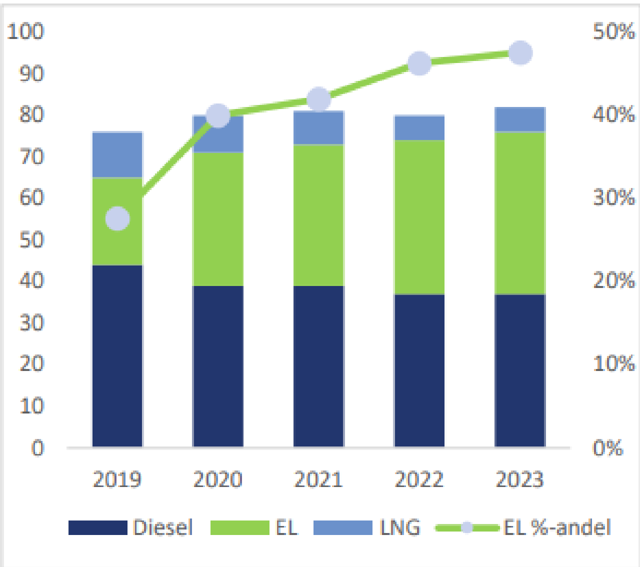


Source: Fjord1 ASA corporate website, 2022.

As confirmed by Fjord1 on its corporate website, the company is converting to green technologies and innovative solutions, which require massive investments. Today, the Norwegian ferry industry leads the world in terms of technology, vessels, the environment and safety and Fjord1 is one of thos who will make a significant contribution to maintaining this position in the future. Since 1858, Fjord1 has changed up to date: technology has evolved, moving on from steamships via gas ferries to today's electric ferries. Fjord1 has also integrated the United Nations Sustainable Development Goals (SDGs) into its overarching strategy.

In 2020, the company completed a newbuild programme comprising 25 new vessels delivered over four years: this programme focuses on the electrification of ships, converting them from LNG to hybrid-electric propulsion. At the end of 2021, the company counted 34 hybrid-electric vessels, of which 28 are operated electrically. The company has commissioned two new vessels for delivery in 2023 and signed contracts for two rebuilds at Westcon in Florø and one rebuilding at Havyard in Leirvik, Sogn (Figure 71).

Figure 71. Fjord1's ferries and fuel mix.



Source: Fjord1's Annual Report, 2022.

In order to reduce the level of greenhouse gas emissions caused by its activity, Fjord1 has been using 100% renewable biofuel as an energy source or natural gas propulsion. In the latest years, Fjord1 launched the world's first fully electric ferry connection, preparing the company for the building of eight new zero-emissions vessels in 2019. With new environmental contracts and electrification of its fleet, Fjord1 maintains its position as the leading company within the Green Shift, achieving a substantial reduction in CO_2 emissions. Consequently, it is possible to say that parts of the company's CSR focus on environmental responsibility and environmentally friendly technology. This is confirmed by Fjord1 corporate website, which communicates that the company has established guidelines for SEEMP on all vessels, with the goal of improving on-board energy efficiency and is seeking certification according to ISO 50001 (Energy management). The Fjord1 emission reduction strategy focuses on phasing out older vessels and replacing them with new, environmentally friendly vessels, as well as converting existing ones. The company's fleet renewal programme entails a gradual transition to a fleet and operations with zero- and low-emissions technology based on electric propulsion.

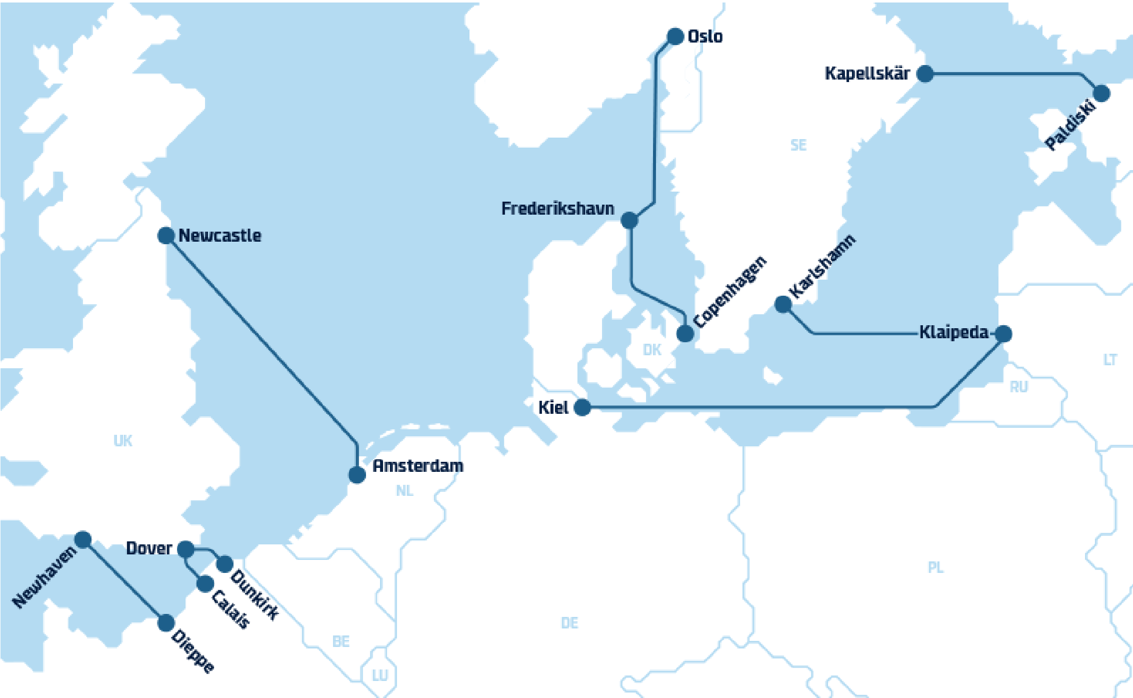
As confirmed also by the "green" sample, Fjord1's main green investment options focus on the electrification, demonstrating the willingness of the company to invest on the same technology massively on board of almost all of the fleet and also an intensive scaling approach aimed at achieving economies of purpose and cost reduction. Already in 2018, Fjord1 signed a contract with Havyard Group to design seven battery-powered ferries that met low energy consumption in adverse weather conditions. Also in the latest years, this trend is confirmed; for examples one of the latest ships entered into service, i.e., MV Rødvenfjord, is designed with a diesel-electric backup system in accordance with the changing environmental requirements of the last century. In this way, the ferry will be able to operate in all-electric mode, hybrid mode and diesel-electric mode, charging batteries from the shore.

6.3.3.8. DFDS Denizcilik ve Tasimacilik

DFDS is a Danish international shipping and logistics company, and it is the busiest shipping company of its kind in Northern Europe and one of the busiest in Europe. DFDS' activities are structured in two commercial divisions, i.e., ferry division, moving freight and passengers on ferry routes in Europe and logistics division, providing transport and logistics solutions for a wide range of businesses. The company's name is an abbreviation of Det Forenede Dampskibs-Selskab (literally "The United Steamship Company"). Since the 1980s, DFDS focused on shipping industry on northern Europe and today operates a network of 25 routes with 50 freight and passenger ships in the North Sea, Baltic Sea, and the English Channel under the name DFDS Seaways, while the rail and land-based haulage and container activities are operated by DFDS Logistics.

While freight services generate 83% of DFDS' total revenue, passenger services generate the 16%: freight is carried on all routes in DFDS network (60% of the routes carry only freight); transport and logistics solutions are mainly full and part loads as well as contract logistics; passenger services are provided on 9 routes, that are graphically shown in Figure 72.

Figure 72. DFDS European ferry routes.



Source: DFDS corporate website, 2022.

DFDS' strategy sets the direction for the growth of the company and, at the same time, for the reduction of their impact on the environment. Their people and customer-driven focus, working to improve solutions across business areas ensuring DFDS stays competitive, enables DFDS to move for all to grow towards a greener and more digitised operation. In order to take responsibility for reducing the impact on the climate, DFDS' plan is based on the nature of its operations, where vessels are the main source of emissions. In this vein, in the short term, DFDS is improving the existing fleet, making it pollute less and be more efficient, while, in the long term, the company is developing new technologies, partnerships and business models. DFDS Climate Plan consists of two overall tracks covering the tonnage adaption in short term and long term, as well as a third track with the name of "getting the house in order" that covers all other things like facilities and terminal equipment.

The short-term tonnage adaption plan consists of initiatives to be implemented throughout the next 10 years, resulting in close to 45% reduction from 2008 to 2030: it consists of minor technical upgrades, including solutions such as the use of the correct coatings on vessel hulls and decision support systems. Furthermore, DFDS' fleet will also undergo major upgrades, like modifications of bulbs and propellers, the improve of hulls and coating. DFDS corporate website explains that the company will reduce emissions by 45 % from 2008 to 2030 through upgrades to existing vessels with new hull coating on four of its new vessels that is expected to reduce our annual CO_2 emissions by 10,000 tons. The new paint will reduce water resistance and enable a reduction in fuel consumption., giving the vessels a smooth surface below the waterline. Among the DFDS Climate Action Plan for the short-term Plan sections, DFDS plans to introduce small amounts of methanol in the existing propulsion machinery on many of vessels, in the four-stroke engines that make up the most part of DFDS fleet. Together with onsite-produced hydrogen, the company will inject the methanol into combustion chambers, replacing up to 10-15% of the heavy fuel oil needed to fuel the same voyage (this technology is still under development, but the initial testing and the results look promising). DFDS wants to be able to push the market demand for sustainable fuels like green methanol, to have a positive ripple effect on the development of green fuel production nationally and internally.

Considering the DFDS long term plan, the company wants to be climate neutral by 2050. This will happen through not only energy savings and incremental improvements alone, but also with the adaptation and the replacement the fleet. At the moment, the company is studying new kinds of fuels and technologies for its fleet. For example, for this purpose, a partnership aims to develop hydrogen ferry for Oslo-Copenhagen has been established. DFDS and its partners (ABB, Ballard Power Systems Europe, Hexagon Purus, Lloyd's Register, KNUD E. HANSEN, Ørsted and Danish Ship Finance) have applied for EU support for development of a ferry powered by electricity from a hydrogen fuel cell (100% hydrogen powered ferry) which only emits water. The partnership has applied for support from the EU Innovation Fund because there are no ferries of this kind in the world today. The development of the ferry "Europa Seaways" will also require public involvement and could be in full operation as early as 2027. Among this partnership, hydrogen will be produced locally in Greater Copenhagen based on offshore wind, and the project will investigate how to optimally integrate with the local energy system.

DFDS manifold investments are focused on the equipment of the ships with bulbous bow and scrubber. As confirmed also by "green" sample, DFDS latest mega freight ferries operating in Aegean Sea and in Turkey, i.e., the sister MV Troy Seaways and MV Ephesus Seaways, are over 60.000 GT and entered in operation in 2019. Both ships are equipped with bulbous bows, have the same energy-efficient capabilities and can use VLSFO / ULSFO in addition to the distillate fuel (with onboard gas insulation system), in order to reduce sulphur oxide emissions in accordance with the sulphur limitation regulation.

6.3.3.9. Moby SpA

Founded by the Onorato family in Naples in 1959, Moby S.p.A. is an Italian shipping company with registered office in Milan and administrative headquarters in Portoferraio. Moby S.p.A. is one of the Italian shipping companies that offers transport of people and freight to the Mediterranean Sea, to Sardinia, Corsica and Elba Island (Figure 73).

Figure 73. Moby destination.

Source: Moby corporate website, 2022.

On 2 January 2012, Moby acquired Toremar, Compagnia Regionale Toscana and in July 2015, 100% of Tirrenia. At the end of March 2021, to meet the debts accumulated by the company, Onorato announced that he had drawn up a plan to restore part of them through the sale of seven ships, the tug division and two properties in Olbia and Milan. On October 11, 2021, Vincenzo Onorato announced his retirement from the presidency, in order to reach an agreement with the creditors asking for the passage of the company to people outside the family, being replaced by Professor Gualtiero Brugger. In November 2021, to postpone the meeting of creditors, a plan is announced that provides for the payment in four years of 80% of the debt to the main creditors (including Tirrenia in Extraordinary Administration) and the transfer of all the ships to a vehicle society of new constitution, the ShipCo, managed from a saving society, from which the operating society OpCo (that is Moby S.p.A.) will rent the ferries with the possibility to repurchase them in 2025. In March 2022, MSC purchased 25% of Moby to increase its capital, saving it from bankruptcy. In the same month they are also deposited of the restructuring plans that preview the payment of the credit to Tirrenia in A.S. from Moby and ShipCo. In August 2022, MSC increased its shareholdings in Moby to 49% of the capital.

The fleet of Moby S.p.A. consists of 18 units to which will be added the MV Moby Fantasy and MV Moby Legacy in 2023. Moby S.p.A. seeks to consolidate its position as an established leader in the field of maritime transport to and from the islands of the Upper Tyrrhenian Sea, as well as introducing its brand-name on new routes and into new markets. Investments in new ships and new routes, innovative services and distribution as well as pricing strategies, strict, quality-oriented hiring policy and uncompromising attention to safety and the environment are the success key factors per Moby S.p.A. The corporate website of Moby Lines contains little information about business strategies and managerial attitudes of the company from the point of view of Corporate Social Responsibility.

The Moby S.p.A. fleet of consists of 18 ship units. The two ships currently under construction will enter in operation on the Olbia-Livorno; this will produce a domino effect, for which the ships used in the “strategic” routes will shift towards the smaller ones, and the older ones will be removed from the service. Considered as “largest and greenest in the world”, MV Moby Fantasy and MV Moby Legacy are two twin sisters ships with 237 meters of length, 32 of width and a tonnage of 69500 tons that can transport until 2500 passengers in 550 cabins and until 1300 cars or 300 trucks in the garages. The engines, which can also be powered at LNG, have a power of 10.8 megawatts, for a cruising speed of 23.5 knots, with peaks of 25 knots. The ships are equipped with innovative technologies that will allow to reduce the emissions, orienting the company more and more to the energetic and ecological transition and a greater protection of the atmosphere.

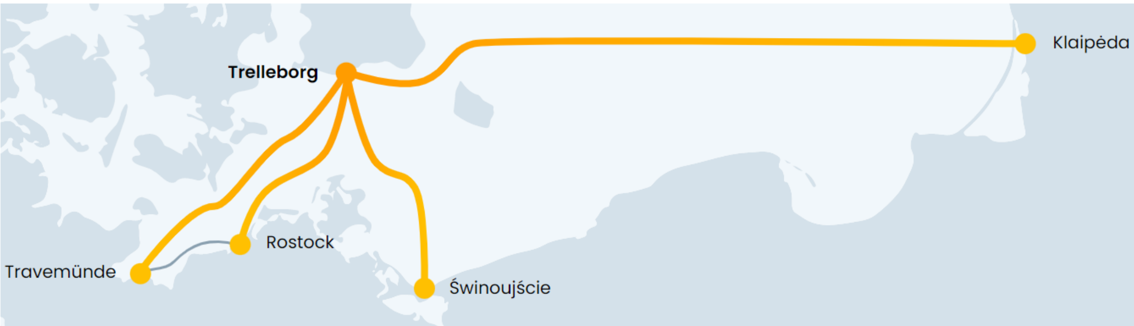
As confirmed by the “green” sample, manifold investments are focused on LNG, in fact the new buildings will have a propulsion working both with traditional fuel both with liquified natural gas, without too much diversification in the company’s investment strategy.

6.3.3.10. Aug Bolten Wm Miller’s

Aug Bolten Wm Miller’s is Germany’s second-eldest shipping company. Born as customs clearance and sales company on behalf of the Scottish fishing industry, the company really began to expand with the advent of steam-powered vessels. With the foundation of the Hamburg-America (1847) and Hamburg-Süd (1871) shipping lines, the company gained expertise in operation and chartering of ships and managed to build up its own fleet. In World War II the fleet has been completely lost, and the company was forced to start new activities and only in 1951 the company took delivery of its first newbuilding MV August Bolten which entered into the North Sea and Baltic Sea trade, and which was followed by other newbuilding’s. To add to its tramp shipping activities, the TT-Line was founded in 1962 and operates in privately-owned Ro-Ro/passenger ferry service sector between Germany and Sweden.

Over the decades, the dry-cargo fleet has been renewed and increased and the commercial range of Aug. Bolten’s activities has expanded continuously. Nowadays, the Bolten group operates a modern fleet of bulk carriers of approx. 24,000-39,000 TDW, i.e., handy-size bulkers. As confirmed by the “green” sample both the newbuilding’s commissioned by the group owner Aug Bolten Wm Miller’s will be operated by the operator TT-Line within its lines between Sweden, Germany and Lithuania, with calls in ports of Trelleborg, Travemünde, Rostock, Świnoujście and Klaipėda, respectively (Figure 74).

Figure 74. TT-Line destination.



Source: TT-Line corporate website, 2022.

Aug Bolten Wm Miller's ordered the first vessel in a new series of two Ro-Pax ferries that are LNG- powered and will be operated by the German operator TT-Line, a German shipping company operating between the German ports of Rostock and Travemünde and the Swedish port of Trelleborg. Built by CMI Jinling Shipyard in China, the MV Nils Holgersson is the seventh in the TT-Line fleet and has a length of 230 metres, a beam of 31 metres, a draught of 6.7 metres, and capacity for 800 passengers housed in 239 cabins and 4,000 lane metres or the equivalent volume of 200 trailers with lorries. The passengers are housed in 239 cabins for a total of 644 berths. The ferry, that will operate in the southern Baltic Sea, is powered by two dual-fuel engines that are also capable of operating on LNG and that allow a maximum speed of 22 knots. Compared to the propulsion systems of conventionally powered ferries, MV Nils Holgersson's LNG propulsion ensures reductions of particulate matter, sulphur dioxide, and NOx emissions of 93%, 98%, and 82%, respectively. The ship is also equipped with a waste heat recovery system, an optimized hull form with a bulbous bow, a special underwater hydrodynamic coating, and the use of LED lighting throughout the ship, with the aim of reducing emissions and improving operating efficiency. Another unit was ordered by shipowner Aug Bolten Wm Miller's at the Chinese shipyards of Jiangsu Jinling: it is the Ro-Pax ships MV Peter Pan, with similar size and capacity compared to Nils Holgersson. The ship will be powered by two main dual fuel engines that can use both distillate fuel and LNG and will be also equipped with an optimized hull form with a bulbous bow to improve the operating efficiency and reduce the emission of PM, SOx and NOx.

As verified by the "green" sample, both newbuilding's MV Nils Holgersson and MV Peter Pan will be equipped with dual fuel engines that are also capable of operating on LNG, in order to reduce the emission of PM, SOx and NOx, and of an optimized hull form with a bulbous bow, to improve the operating efficiency and reduce the emission during the navigation. As from the "green" sample, Aug Bolten Wm Miller's investment strategy in innovative technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions seems not diversified but focused almost purely on the LNG and bulbous bow.

CHAPTER 7

CONCLUSIONS OF THE PHD THESIS

7. Conclusions

This PhD thesis provides an overview of the investments in different “green” solutions and technologies implemented by companies operating in the Ferry, Ro-Ro and Ro-Pax sector. In the sixth Chapter “Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the play”, an analysis of the of the managerial and governance behaviours of the best group owners of the “green” sample is also conducted.

After the analysis of the corporate strategies and the green oriented approaches pursued by the top ten group owners of the “green” sample, it is necessary to place the bases to the main insights on the managerial and governance behaviours and attitudes implemented by shipping companies in the Ferry, Ro-Ro and Ro-Pax industry. The “top ten group owners” of the “green” sample are such group owners who are placed at the top of a ranking that is drown up weighing 50% both positions in the other two rankings: the first one based on the number of ships of the group owner (the first position is occupied by the group owner with the greatest number of ships in the “green” sample) while the second one is based on the GT size of the fleet (the first position is occupied by the group owner with the largest fleet size in terms of gross tonnage in the “green” sample). Among others group owners in the “green” sample (Table 23), it is possible to say that companies such as Grimaldi Group SpA, Fjord1 ASA, Norled AS and CLdN are the ones that, at European level, have invested the most in innovative technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions.

Table 23. ''Green'' sample extraction on green investment and solutions for each group owner.

Group owners	**"Green" investments and solutions**
Grimaldi Group SpA	69
Fjord1 ASA	43
Norled AS	31
CLdN	29
Bank of Communications	23
Finnlines Plc	22
Balearia Eurolineas Maritimas	18
Torghatten Nord AS	17
Stena AB	15
Veolia Transport	11
Unknown	11
Doeksen G	8
Bore Ltd	8
ICBC Financial Leasing Co Ltd	7
Aug Bolten Wm Miller's	6
DFDS Denizcilik ve Tasimacilik	6
Financial Products Group Co	6
Siem Shipping Inc	5
Wallenius Lines AB	5
Caronte Shipping SpA	5
Kvarken Link AB	5
Color Group AS	4
Caledonian Maritime Assets Ltd	4
Grandi Navi Veloci SpA	4
Moby SpA	4
T-Finans AS	3
Bharati Shipyard Ltd	3
Jifmar Offshore Services SAS	3
Gotland Rederi AB	3
Armas Naviera SA	3
Viking Line Abp	3
Samskip hf	3
Seatrans AS	2
Tirrenia di Navigazione SpA	2
Virtu Ferries Ltd	2
Credit Agricole SA	2
Tallink Group Ltd	2
Polish Baltic Shipping Co	2
Pentland Ferries	1
Tennor Holding BV	1
Molslinjen AS	0
Rete Ferroviaria Italiana	0

Source: Author's elaboration.

As confirmed by the empirical investigations conducted during the PhD period, the shipping company Grimaldi Group SpA has invested mainly in hybrid ships. All the ships of Grimaldi Group SpA that have entered in service from 2020 and that will become operating within 2024 are hybrid ships and will be employed mainly along the routes of the Mediterranean Sea, specifically in the West Mediterranean Sea, in the Adriatic Sea and Tyrrenian Sea. Such geographical allocation of the ships derives from the need to answer more efficiently to the issues related to transport quality services on the deep-sea routes, reconciling the needs of international goods traffic and environmental protection. In addition to the peculiarity of being hybrid and designed to be fed with electricity from berth during the stop in port and mooring operations, ships of future or current construction also have a design that is the result of a careful study of the internal configuration to make it more innovative and fully customized. In addition, the main engine and the diesel auxiliary generators allow to meet the NOx levels imposed by the Tier III regulation and the integrated propulsion system between rudder and propeller allows to minimize the vortex losses and, consequently, optimize the propulsive efficiency and reduce fuel consumption. The Ferry, Ro-Ro and Ro-Pax ships are equipped and will be equipped also with hybrid exhaust gas cleaning systems to reduce SOx and PM emissions. Also, with the variable frequency drive devices and the application of innovative paints, Grimaldi Group SpA estimates a greater efficiency of ships and a reduction of CO_2 emissions per transported ton until 43%, regarding the other Ferry, Ro-Ro and Ro-Pax ships of the Grimaldi fleet. Consequently, it is possible to affirm that the Grimaldi Group SpA continues to invest in the strengthening and modernization of its fleet.

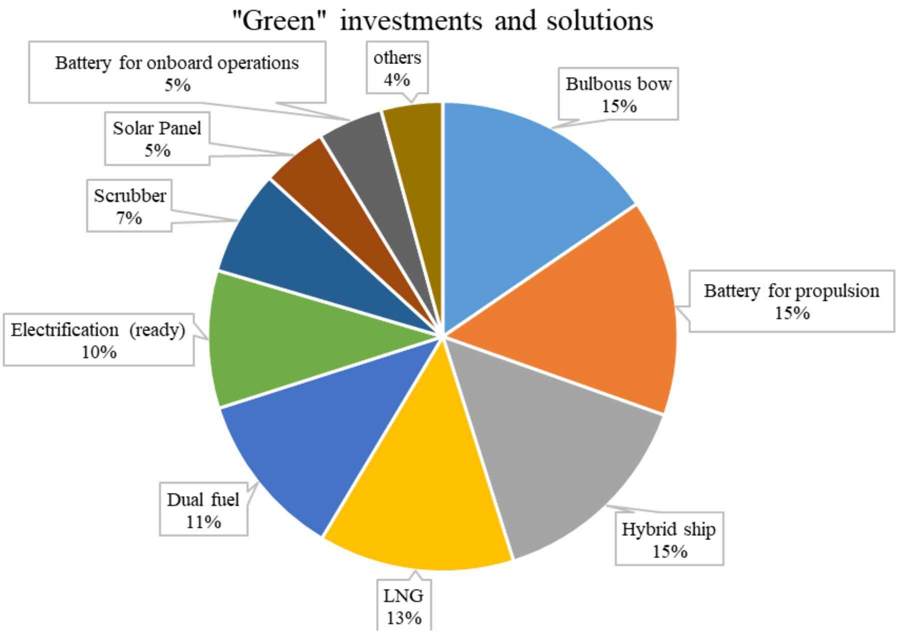
The leading player in the Norwegian ferry market, i.e., Fjord1 ASA is at the forefront when considering the development of environment-friendly tourism and ferry operations in Norway. As confirmed by the “green” sample, the electrification of Fjord1 ASA’s ferry operations is well underway. Despite the stringent requirements in terms of the rapid development of zero-emission technology and the implementation of electrically powered vessels in the ferry sector, fixed by the Norwegian Authorities in several tender competitions, Fjord1 ASA has won nine long-term tender competitions. Indeed, Fjord1 ASA has been assessed in accordance with strict environmental requirements relating to energy consumption, CO_2, and NOx emissions, as well as, in accordance with the high consume of energy derived from electrical power. This has resulted in the largest renewal of the fleet in the company’s history. All Ferry, Ro-Ro and Ro-Pax ships that entered in service in the last four years, are equipped with batteries for the propulsion; most of them are fully electric vessels and some of them operates both in all-electric mode, hybrid mode and diesel-electric mode. In 2020, Fjord1 ASA’s CO_2 emissions were reduced by 7% compared to 2019 (Fjord1 ASA’s Annual Report, 2020) despite an increase of distance sailed, within the routes and ports covered by the transport activities of the company, by approximately 10%. With the delivery of 7 ferries, having electricity as the primary energy source, it is possible to state that since 2020 the 40% of the fleet of Fjord1 ASA is composed by electric ferries. Consequently, the overall emission reduction is the result of an increased electrification and energy efficiency.

The largest company within express ferry and boat operators, i.e., Norled AS, is owned by the Canadian company CBRE Caledon Capital Management and operates 80 ferry and express boat services from the Oslofjord to Troms County, in Norway. As confirmed by the "green" sample, Norled AS has invested significantly in new types of vessels and eco-friendly technology and has developed solutions used solely by the company. In just a few years and in partnership with some of the best technology communities in the world, Norled AS has developed completely new technologies capable of radically reducing emissions in our industry. Indeed, Norled AS' ambition is the gradual reduction of emissions from the Norwegian ferry fleet as new types of vessels are phased in. The main objective is the replacement of diesel vessels with gas vessels on longer journeys, while, on shorter journeys, the use of battery-powered ferries, which reduce local emissions by 100%. As confirmed by the "green" sample, the ten ships that have been built over the last 3 years are hybrid ships equipped with batteries for the propulsion. Indeed, such ferries can operate also with alternative fuels: the 60% of ferries in the "green" sample uses biofuel for propulsion and only two ships (MV Hydra and MV Nesvik) are hydrogen-propelled. Norled AS has also built some of the largest express boats in the world in carbon, which is lighter than aluminium and therefore uses less fuel. Furthermore, since it is not possible to replace all ferries simultaneously, Norled AS is also testing solutions that can reduce emissions from the old diesel-powered ferries, with limited investments.

Headquartered in Luxembourg, the CLdN Ro-Ro network covers shortsea connections between the European continent, the United Kingdom, Ireland, Iberia and Scandinavia. With their Ro-Ro ships, CLdN provides transport services with sustainable, reliable, and cost-effective transport solutions. The "green" sample identifies eight ships owned by CLdN, of which six were taken into operation in the last four years, while two that are under construction and will enter in service in 2024 and 2025. All ships of the "green" sample are equipped with bulbous bow for greater hydrodynamics and are in service and will operate mainly in the North Sea but also in the English Channel and Biscay Bay. In addition, all Ro-Ro ships of the "green" sample are equipped with dual fuel engine that allow to operate also with LNG. With the Ro-Ro ships entered into service in 2021 and 2022, i.e., the MV Faustine and the MV Seraphine, respectively, CLdN has realized the largest investment in their history. Specifically, it is the result of two years of intense engineering and development together with Hyundai Mipo Dockyard. With two LNG dual-fuel main engines and two electric propulsion motors, these ships can achieve a cruising speed of 16 – 17 kn in full-electric mode. Both ships represent the first step to the future-proofed to allow expansion or integration of technological advancements. Reducing its carbon footprint in 2021, CLdN claimed to be the top performer amongst its RoRo shipping peers in Northwest Europe for CO_2 emissions per tonne of freight carried. Compared with CLdN's largest Ro-Ro ships currently in operation, the new ships that will enter in service in 2024 and in 2025, will further reduce GHG emissions by 40% and will be NOx TIER III compliant.

With the aim of collecting relevant data to draw the conclusions of this PhD thesis, Figure 75 shows the distribution of innovative technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions in which the shipping companies belonging to the "green" sample have invested.

Figure 75. Green investment and solutions distribution in the "green" sample.



Source: Author's elaboration.

One of the most achieved investments in green technologies is the bulbous bow, due to the ever-increasing need for reduction in carbon emission and fuel consumption during navigation and also of the contained times necessary for the removal of the old bulbous (1 month) and the installation of the bulbous bow (3 months), compared to other more time demanding installations and interventions that force the ship unit greater time in the shipyards in dry dock. As anticipated in the previous chapters (cf. the fourth Chapters “Green strategies: literature review” and 5 “Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the art”) of this PhD thesis, scholars and academics analyse geometry modelling, shape transformation, optimisation, and performance evaluation, in order to find new techniques in hull form design (Ang et al., 2015). This trend is confirmed also by the “green” sample, since 48% of Ferry, Ro-Ro and Ro-Pax ships belonging to the “green” sample are equipped and will be equipped with bulbous bow, allowing the ship to change the characteristics of strength and power output. Grimaldi Group SpA, CLdN and Fjord1 ASA are group owners that have invested more than others in the extension of the hull just below the load waterline.

Secondly, the installation of on-board batteries for propulsion, represents a “green” solution widely implemented by shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry. Through the use of batteries, high quantities of energy can be stored to guarantee adequate efficiency at the system (Ruggiero, 2021). As confirmed by previous chapters (cf. fourth Chapters “Green strategies: literature review” and the fifth Chapter “Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the art”) of this PhD thesis, several studies and research considered that the batteries with the greatest potential for application in the Ferry, Ro-Ro and Ro-Pax industry are lithium-ion batteries. For an even lower impact on the environment, the use of batteries as a source of energy, especially with additional technologies such as Fuel cell, photovoltaic (PV), Cold Ironing (Buitelaar, 2014; Rafiei et al., 2021, Wu et al., 2021), is already a solution implemented by the shipping companies operating in the Ferry, Ro-Ro and Ro-Pax industry.

As confirmed by the “green” sample, batteries have been installed, especially, onboard ships owned by Norwegian, Swedish, Finnish and Icelandic Ferry, Ro-Ro and Ro-Pax companies, to reduce emissions: these are Fjord1 ASA, Norled AS, Torghatten Nord AS, T-Finans AS and Color Group AS domiciled in Norway; Stena AB and Kvarken Link AB in Sweden; Finnlines Plc and Samskip hf with domicile in Finland and Iceland, respectively. Moreover, according to the available data (also referring to the units still under construction), the ships equipped with batteries belonging to the “green” sample operate and will enter in service mainly along routes within the Baltic Sea, the English Channel, Iceland, the North Sea and the Norwegian Sea and, therefore, along routes located in Northern Europe. This result is no surprise as Northern European states are globally recognized as extremely at the forefront of sustainability, also drawing the route for the full introduction of electric ships in the market. Such assumption is confirmed also by the number of hybrid Ferry, Ro-Ro and Ro-Pax ships that are currently in service and will enter in operation in the next few years along routes of the Northern Europe: such ships are 59 among the 129 ships of the “green” sample and they are, for example but not limited to MV Rodvenfjord, owned by Fjord1 ASA; MV Hydra, belonging to Norled AS; MV Heilhorn, hold by Torghatten Nord AS; n. 3 newbuilding ordered by Stena AB; MV Aurora Botnia, owned by Kvarken Link AB; MV Finncanopus belonging to Finnlines Plc; MV Herjolfur holds by Samskip hf; etc.

This trend is also confirmed by the number of electric ferries and the electric-ready ships in the "green" sample: about 30% of Ferry, Ro-Ro and Ro-Pax ships in the "green" sample are designed to be powered with electricity from the berth while the ship is in port. Norway has always been at the forefront of environmental evolution and, as confirmed by the "green" sample, the main group owners that have invested in the ships' electrification are Norwegian. For example, as from the "green" sample, Color Group AS holds the world's largest plug-in hybrid ferry, i.e., MV Color Hybrid, with a length of 160m and a capacity for 2,000 passengers and up to 500 cars. The 65-tonne battery pack can power the vessel for almost one hour at a speed of less than 12 knots and this is enough to leave the berth (in Sandefjord), and head for the open seas. On the other hand, the battery power is also being used to help absorb peak loads, which results in a lower fuel consumption. In this way, the consumption of (fossil) fuel has been lowered by 20%. The construction project of the MV Color Hybrid has seen the involvement of the Export Credit Agency (ECA) for the financing loans with guarantees from GIEK (Norwegian Export Credit Guarantee Agency – Garantiinstituttet for eksportkreditt) and from a Norwegian commercial bank (DnB Bank Norway): together they funded 80% of the project for a value of approximatively NOK 1 billion, over a 12-year period.

Furthermore, almost 36% of the Ferry, Ro-Ro and Ro-Pax ships of the "overall" sample are equipped with a dual fuel engine. About 60% of such ships operates in the North European seas, especially in the Baltic and North Sea. These Ferry, Ro-Ro and Ro-Pax ships are mainly owned by Aug Bolten Wm Miller's and Wallenius Lines AB (and operated in the Baltic Sea by Green ropax GmbH & Co KG, TT-Line GmbH & Co KG and Swedish Orient Line AB companies) and Bore Ltd and CLdN (and operated in the North Sea by UPM-Kymmene and CLdN Ferries NV companies). All ships powered by dual-fuel engines are also capable of operating on LNG, ensuring reductions of sulphur dioxide, particulate matter, and NOx emissions of 98%, 93%, and 82%, respectively. Some of them are fitted with a propulsion system that can operate on LNG and biogas (LBG) or methanol.

Moving on to other "green" technologies, more than 70% of the ships equipped with scrubbers are currently in service or will enter in operativity in the next few years along the routes of the Mediterranean Sea, in particular in the West Mediterranean Sea, Adriatic Sea, Aegean Sea, Tyrrenian Sea and Balearic Sea, where that information is available (also for the ships still under construction). Some of the "green" sample Ferry, Ro-Ro and Ro-Pax ships equipped with scrubbers are also equipped with dual fuel engines, which allow to use alternative fuels such as LNG and methanol, as an alternative to heavier fuels (by putting in action the onboard scrubbers). Moreover, in the "green" sample almost 80% of the Ferry, Ro-Ro and Ro-Pax ships with Italian flag are equipped with scrubber, but without dual fuel engines. These Ferry, Ro-Ro and Ro-Pax ships are partly, however, equipped with batteries that allow to store energy to be used for both propulsion and onboard services. It deals with ships of Grimaldi Green, specifically those belonging to the 5th Generation-class (GG5G-class), almost all in service along routes of the Mediterranean Sea, and the new units currently under construction at the shipyard Hyundai Mipo Dockyard Co. Ltd. Some of the units of the "green" sample provided with scrubbers are also equipped with dual fuel engines, allowing to use alternative fuels such as LNG, methanol, as an alternative to heavier fuels (by putting the scrubbers on board). In this vein, it consists of the units operated from Brittany Ferries BAI SA and Stena Line Irish Sea Ferries along routes of the Europe North.

Due to the analysis conducted in this PhD thesis, more than 67% of ships belonging to the "green" sample operate and will enter into service mainly in the North Europe Area (North Sea, Baltic Sea, Norwegian Sea, Irish Sea, English Channel, Biscay Bay, Atlantic Ocean, Celtic Sea, Iceland). Furthermore, more than 65% of the new and green technological options and solutions aimed at mitigating the impact of the ship operations on the environment that have been analysed in the "green" sample are currently onboard on ferry, Ro-Ro and Ro-Pax ships and will be installed on units currently under construction that operate and will enter into service in the in the North Europe Area.

This trend is confirmed also considering the group owners of the ships belonging to the "green" sample, since almost 52% of these are of owned by group owners having domicile in North Europe Countries. Furthermore almost 50% of the innovative technical solutions and cutting-edge technologies for mitigating the pollution and reducing harmful emissions are installed and will be implemented onboard units owned by group owner with domicile in North Europe Countries.

The above-mentioned analysis confirmed the geographic coverage related to the systematic literature review conducted in the previous the fourth Chapter, from which it was found that the most investigated geographical area in the academic contributions was Northern Europe. This result is not surprising as Northern European countries are worldwide recognized as extremely advanced when it comes to environmental sustainability issues, also in shipping industry.

This trend of many North European stakeholders that is currently shaping the sustainability agenda and encouraged to identify related values and strategies for a sustainable future, is an example for other European and Mediterranean countries, enhancing the understanding of the divergent goals and complex processes associated with sustainable development, also considering the interplay between social, political, and economic issues and environmental concern.

Indeed, all the other nations in Europe are today in the running for towards the achievement of the environmental sustainability objectives of the countries typical of the north Europe countries, also in the context of the shipping industry. For this issue and for example not exhaustive, the NextGenerationEU or Recovery Plan or Recovery Fund set up by the European Council after the COVID-19 pandemic that represents a once in a lifetime chance to emerge stronger from the pandemic, transform the economies, create opportunities and jobs for the Europe. This fund has a value of € 750 billion approved in July 2020 and, consequently, integrated by additional complementary funds, according to the regulations of each country.

For example, in 2021 in Italy the Decree Law 6 May 2021 n. 59 was published in the Gazzetta Ufficiale, containing "Urgent measures relating to the complementary Fund to the PNRR and other urgent measures for investment". As a result of this decree, also the decrees of the Minister of Sustainable Infrastructure and Mobility (Ministro delle Infrastrutture e della Mobilità Sostenibili) n. 389 of 12 October 2021 and n. 290 of 21 September 2022 have been published in the Gazzetta Ufficiale, where the second one is an implementing decree of the first one. With these Ministerial decrees. Italian Ministry makes available 550 million euros for intervention and implementation of the construction or the refitting of new ships or naval units operating in Italian ports (tugs, etc.), in order to implement a plant of propulsion to reduce the environmental impact.

Among the green interventions mentioned in the n. 389 of 12 October 2021 decree, at article 5, subsection 2 (as shown in Figure 76), some of those are identify also in fifth and the sixth Chapters of this PhD thesis.

Figure 76. Eligible interventions onboard ships.

a) Installazione di nuovi apparati/equipaggiamenti ed impiantistica associata in modo da rendere la nave con motori in grado di utilizzare uno/due combustibili, tra cui almeno uno basso impatto ambientale (GNL, BioGNL, metanolo, idrogeno, ammoniaca NH_3);
b) Installazione di gruppi di batterie, in modo che l'unità navale quando in prossimità dei porti possa staccare i motori ed effettuare le manovre di avvicinamento, di approdo, sosta in porto, e viceversa utilizzando le batterie installate;
c) Installazione di celle a combustibile (Idrogeno, metanolo, GNL) ed impiantistica associata per la propulsione della nave;
d) Installazione di motori elettrici ad alta efficienza e a velocità variabile ed impiantistica associata, sostituzione dei motori elettrici con altri di classe energetica superiore e, ove possibile, con motori elettrici a velocità variabile ed in grado di adattarsi al carico;
e) Miglioramento idrodinamico (bulbo di prora, appendici di carena, applicazioni di pitture a basso impatto ambientale e/o ad alte prestazioni, sostituzione delle eliche o delle pale delle eliche);
f) Lubrificazione ad aria della carena;
g) Sistemi ibridi calibrati su specifiche esigenze operative;
h) Installazione dell'equipaggiamento necessario per l'alimentazione elettrica da terra (cold ironing);
i) Illuminazione, sostituzione dei corpi illuminanti con altri a basso consumo energetico (LED);
j) Installazione di dispositivi di recupero energetico, installazione di impianti di recupero dell'energia dai gas di scarico per produzione di energia elettrica;
k) Installazione di sistemi di pulizia dei gas di scarico, scrubber, abbattitori di emissioni NO_x (SGR, EGR) o interventi di miglioramento delle performance degli stessi;
l) Installazione di apparecchiature per il recupero ed immagazzinamento dell'anidride carbonica (CO_2);
m) Installazione di pannelli solari per la produzione di energia elettrica in ausilio ai generatori di bordo;
n) Installazione di sistemi per lo sfruttamento dell'energia del vento (wing sails, kites, cilindri eolici ad effetto magnus) di ausilio alla propulsione;
o) Monitoraggio dei consumi, Installazione di sistemi per la raccolta sistematica e l'elaborazione dei dati relativi ai consumi di bordo, al fine di limitare i consumi;
p) Installazione di sistemi di monitoraggio delle prestazioni e manutenzione predittiva basati sull'intelligenza artificiale;
q) Interfaccia innovativa tra layout portuale e progetto nave per migliorare la logistica di imbarco e sbarco (adeguamento nave ad esempio portelloni);
r) Riduzione della rumorosità in aria e in acqua;
s) Sistema di propulsione integrato tra timone ed elica da permettere di minimizzare le perdite vorticose;
t) Motori a controllo elettronico della combustione;
u) Installazione di software di ottimizzazione della rotta e dell'assetto nave;
v) Intelligenza artificiale-digitalizzazione della gestione e della operatività nave;
w) Installazione di generatori asse reversibili PTO/PTI dotati di inverter;
x) Impiego di convertitori di frequenza sulle utenze elettriche di grande potenza;
y) Installazione di refrigeranti a scafo per evitare l'installazione e l'uso continuato di pompe acqua mare.

Source: Ministry decree n. 389 of 12 October 2021 (Article 5, subsection 2).

This demonstrates and confirms that the implementable investment options aimed at reducing emissions and, in general, the environmental impacts of the Ferry, Ro-Ro and Ro-Pax industry, which are identified at a scientific and academic literature (the fifth Chapter "Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the art") are the same as those considered “eligible” by the above-mentioned decree and correspond to those detected in the samples elaborated in this PhD thesis (the sixth Chapter “Green investment options in Ferry, Ro-Ro and Ro-Pax industry: state of the play”), considering the group owners strategies at European level.

The theoretical framework that is proposed in this PhD thesis is tested empirically through a solid methodological approach, paving on a multiple case study analysis of the adoption of main green strategies and investment options by major Ferry, Ro-Ro and Ro-Pax companies. In order to achieve the RO.1, this PHD thesis focused on the classification of environmental impacts according to a comparison of several reports and studies proposed by international institutions and academic researchers (Author’s elaboration on EMSA, 2021; Jägerbrand et al., 2019; Walker et al., 2019; Joumard et al., 2011; OECD, 2011.). In this context, it was necessary to acknowledge theoretical constructs such as Corporate Social Responsibility (CSR) and Stakeholder Relationships Management (SRM) paradigms (Carroll, 1991; Freeman, 2010), in order to reshape the future strategic objective of shipping companies operating in Ferry, Ro-Ro and Ro-Pax industry. As green strategies in the Ferry, Ro-Ro and Ro-Pax industry still remain an underexplored topic in extant literature, this PhD thesis has further developed the academic knowledge on this matter. In this vein, an ad-hoc conceptual framework addressing viable green investment options in the segment domain is studied and developed in this PhD thesis. These steps constituted a pre-condition for investigating available green investment options, such as technologies, assets and equipment which allow Ferry, Ro-Ro and Ro-Pax companies to reduce their environmental impact (RO.2). In order to pursue the RO.2 of this PhD thesis, the proposed ad-hoc conceptual framework is applied to major Ferry, Ro-Ro and Ro-Pax companies in order to assess the current state of the art in the industry as well as the real commitment of companies in pursuing green strategies.

The PhD thesis attains interesting anecdotal evidence regarding diverse approaches currently adopted by Ferry, Ro-Ro and Ro-Pax companies in order to make the industry green and sustainable, and it contributes to common knowledge by addressing a topic which is rarely deepened by academics through an original contribution. More in detail, the research outcomes provide updated and cutting-edge insights concerning the range of green solutions, strategies and investment options which are shared by the entire shipping sector and ones that differentiate Ferry, Ro-Ro and Ro-Pax companies from other shipping companies. In fact, the results obtained constitute an original contribution that helps to fill a gap in the literature on the green, sustainability and environment-related issues and to energy efficiency, emission and environmental impact reduction in the industry, delving into topics that have so far been scarcely investigated. Furthermore, the results obtained may generate significant managerial implications, as they may provide indications to support the strategic decisions of shipping professionals regarding the most suitable green strategies and solutions to the industry. The results of this PhD thesis also contribute to extant literature by applying a technical and pragmatic approach to bridging some knowledge gaps concerning the role of green strategies in Ferry, Ro-Ro and Ro-Pax industry. For this reason, the green investment options in ferry, Ro-Ro and Ro-Pax industry thoroughly examined in this PhD thesis is particularly timely and of extreme importance, both because of the increase of the scholars and academics' contributions on this matter, both since the continuous pursuit by European countries towards the sustainability objectives and emission reductions also in the ferry, Ro-Ro and Ro-Pax industry.

Despite providing valuable insights for both academics and practitioners concerning the strategies and approaches adopted by Ferry, Ro-Ro and Ro-Pax companies towards green investments and solutions, it is deemed necessary to highlight certain limitations of the study within this PhD thesis, that might open further research opportunities for future investigations. The main limitations envisaged within this PhD thesis are the small number of analysed companies, the high level of confidentiality that characterizes the shipping sector and the reliability of the future strategies. Both the amount of information and its attainability has limited the study conducted in this PhD thesis. In some cases, few information and data were found about the green and sustainable attitudes and practices that are conducted by Ferry, Ro-Ro and Ro-Pax companies, operating in Europe, while, in other cases, such information does not seem truthful but only published to attract the attention of customers and stakeholders. It was therefore difficult to identify which of the available sources could be less reliable than others.

This thesis opens the doors for further analysis and research, including the world of green finance solutions. Considering the high capital intensive of green strategies aimed at improving the environmental performance of the shipping industry, with a specific focus on the Ferry, Ro-Ro and Ro-Pax industry, each company had to find new and more accurate funding mechanism to collect the financial resources necessary for the effective implementation of the green strategy. In this context, green finance solutions can function as valuable solutions, as they are designed to simultaneously allow the funding of investments form businesses and the pursuit of environmental goals. As for the green strategies and investment options, also the thematic related to the use of finance tools aiming at supporting such green investments from shipping companies is still scarcely investigated by academics (Sustainability-linked Bonds, Green Bonds, Sustainability-linked Loans, Green Loans). This issue also lays the foundations, for examples, for the subsequent architecture of a more detailed conceptual framework able to support industry players in selecting and activating the most suitable green finance solutions to finance their projects to improve the company's environmental performance. Also considering the increasingly stringent international and EU legislation and the ambitious green strategies that companies operating in the Ferry, Ro-Ro and Ro-Pax industry are pursuing, the volume of the green and investments carried out from these companies has grown remarkably in the last years and is destined to grow more and more in future. This is also due to recent guidelines at European level, the specific conditions of competition and the new needs expressed by the market. Moreover, precisely because of the preferential conditions of cost of capital that the green financing instruments offer to the achievement of certain sustainability objectives, the use of these financial instruments by companies will increase more than appreciably in the coming years.

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