

Review

The Port Sector in Italy: Its Keystones for Energy-Efficient Growth

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Abstract: Italy has been defined as the “logistics platform” of the Mediterranean Sea. The Italian port system, with 11.6 million TEUs handled and 61.4 million passengers in 2022 (Assoport data January–December 2022), is the key to fulfilling this title through adequate levels of reliability, safety, and sustainability. This contribution addresses port logistics and shipping, focusing on primary issues related to the energy sector with a specific focus on what can be observed in the Italian context. Specifically, the decarbonization of the maritime sector and related infrastructural problems (e.g., cold ironing or alternative fuels, where the uncertainty about resource availability and related costs do not allow for easy strategic planning by both the ship owner and the port authority), as well as policies such as the Emission Trading System (ETS), will be analyzed. All these issues, hereafter addressed with a systematic critical review of the existing literature and other relevant sources, could represent the driving force of the growth of the national port sector toward its competitiveness at a global scale. The review was performed through a wide search and analysis of studies published in well-known online research databases (Scopus, Web of Science, IEEE Xplore, ScienceDirect), sector studies, or specialized technical magazines. The review focuses on the results of each analyzed contribution rather than on the analysis method adopted with the final aim to identify useful hints and innovative ideas for further studies on the topic.

Keywords: cold ironing; alternative fuels; Emission Trading System; Italian port system



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1. Introduction

“The Mediterranean is honeycombed with sea and land routes, so that towns, small towns, medium-sized towns, and great cities, are linked together. And all these routes form a system for the movement of traffic” [1]. What was stated by the historian Braudel almost forty years ago is still topical and summarizes the strategic importance of the Mediterranean Sea as the current and future route for the transport of people and goods; so, the Mediterranean Sea is crucial for the economic development of Europe, Africa, and the Middle East (10% of global maritime traffic passes through the Mediterranean along with almost 30% of the total containers movements) [2].

Although in recent years, the European strategy has favored the development of northern European ports and relations with Eastern countries, the Mediterranean is still at the center of geopolitical and economic interests (e.g., energy, trade). The strong demographic and economic growth of the African continent, with particular attention to its northern coast, plays a key role. China, which has been pursuing a commercial–infrastructural positioning strategy in Africa for a few years, has turned its attention to the Mediterranean port system as a sorting and branching hub into Europe for the supply chains that run along the Silk Road. Large Chinese companies have already acquired important parts of Mediterranean ports (e.g., Piraeus, Port Said, Tanger Med, Ambarli, Haifa, Valencia,

Marseille, and Vado), thus confirming the importance of creating a solid system in the Mediterranean area as a valid alternative to current preferential routes and as a driving force of new commercial possibilities [3].

With regard to the container shipping sector, the renewed importance of the Mediterranean is demonstrated by the expected growth (i.e., compound annual growth rate measured as the port capacity in TEUs) by 2026 (expected annual average +3.6%) compared to the global average (+3.5%) and the increase in the Port Liner Shipping Connectivity Index (PLSCI) by over 20% since 2006 [4].

Moreover, although the Mediterranean area covers only 1% of the world's seas, it accounts for 20% of global shipping traffic, 27% of container shipping traffic, and 30% of oil and gas transfers from north to south and from east to west (including pipelines) [2].

When discussing the Mediterranean, it is unavoidable to think of Italy which, thanks to its geographical position and its geomorphological conformation, represents the backbone and the crossroads of all maritime routes.

The Italian port system is crucial to re-establishing the economic and geopolitical centrality of the Mediterranean. However, its development must necessarily consider the European/international regulatory frameworks which increasingly push toward a green economy and decarbonization. As is well known, shortly after the new administration of the European Commission took office in 2019, a series of very ambitious environmental goals were set, summarized in the so-called *European Green Deal* [5]. Among others, these goals include reducing net greenhouse gas (GHG) emissions by at least 55% by 2030 (compared to 1990 levels) and by 90% by 2050 (Europe aspires to become the first climate-neutral continent by 2050) [5].

To this aim, in March 2020, the European Commission adopted a new industrial strategy defined as the *"Sustainable and Smart Mobility Strategy"* [6], which should promote and accelerate the green transition by investing in digital transformation and technological tools, considered essential enabling factors. Sustainability and digitalization are seen as complementary ideas. Several legislative initiatives detailed this new strategy, such as the new Circular Economy Action Plan (March 2020), the Digital Compass 2030 (March 2021), the European Climate Law (June 2021), and the legislative *"Fit for 55"* (July 2021), where it is explicitly said that *"the adoption of digital solutions and the use of data will contribute to the transition towards a climate neutral, circular and more resilient economy"*.

At the same time, the infrastructural sector is identified as the production field which, in the last twenty years, has experienced the lowest level of innovation and technological development among all the main industry sectors. In addition, the transportation sector is responsible for approximately $\frac{1}{4}$ of global emissions capable of altering the climate [7], and the port system is inevitably involved in this scenario.

Like every other *"industry"*, the port sector needs to address the challenges of technological innovation and modern organizational policies in its production chain and must face the globalization of its markets, as well as geopolitical events that can strongly impact market requests and the energy supply.

Paper Structure and Review Methodology

This contribution addresses port logistics and shipping, focusing on primary issues related to the energy sector with a specific focus on what can be observed in the Italian context. Specifically, the paper will review the main decarbonization strategies (such as cold ironing (CI) or alternative fuels, where the uncertainty about resource availability and related costs do not allow for easy strategic planning by both the ship owner and the port authority) and policies such as the Emission Trading System (ETS) in the context of the growth and competitiveness of the Italian port sector at a global scale.

The paper is structured as follows: Section 2 analyzes the geo-political framework influencing the maritime sector and then moves to a description of the Italian port system. Section 3 deals with ecological transition, green ports, and related decarbonization strategies and policies. Every theme is analyzed at a global scale and then with reference

to Italy. A systematic critical review was performed, focusing on the results more than on the analysis method adopted, based on a comprehensive search and analysis of studies published in well-known online research databases (Scopus, Web of Science, IEEE Xplore, ScienceDirect), as well as other and relevant sources, such as sector studies, governmental reports, or specialized technical magazines. A final Discussion Section concludes the study by proposing a critical interpretation of the most relevant elements identified throughout the bibliography review.

2. The Geo-Political Framework Influencing the Maritime Sector

After the COVID-19 pandemic, the situation of maritime transport, which carries a large part of global trade, seemed to come back under control toward the end of 2021 but became critical again at the beginning of 2022 due to the combined effects of the outbreak of war in Ukraine (which resulted in the blockade of ports in the Black Sea and sanctions on Russia, leading to a change in trade models) and new lockdowns imposed in China, which led to new blockades in ports and delays in the delivery of goods [8].

At the end of 2022, profound uncertainty characterized world markets due to the notable fluctuations in energy costs, restrictive monetary policies aimed at containing inflation, the crisis in agri-food supplies, and the consequent social tensions.

The effects of the Russia–Ukraine conflict on the shipping costs of goods were significant, especially referring to the freight rates for small oil tankers between the Black Sea and the Mediterranean, whose prices in March 2022 have increased by 96% compared to pre-existing values. The freight rates of grain and cereal cargo ships, with regional routes transiting the Black Sea, increased by over 100% compared to pre-COVID values [9].

The situation is different when considering the container segment, where the pressure on maritime transport is now easing as a result of the weakening of demand due to global uncertainty. Compared to November 2021, on average, a container that follows the Asian route from the port of Shanghai to Genoa costs over 70% less (even if the cost is still far from pre-crisis levels) [8].

The general inflationary effects due to the increase in costs of some key raw materials, including all fossil fuels and some major cereals, continue to affect purchasing power and contribute to the weakening of consumer demand, leading to the slowdown of global trade and the consequent needs to identify new strategies and port logistics models.

In this context, a new major threat to the maritime sector of the Mediterranean comes from the recent conflict between Israel and Hamas.

The escalation of maritime raids by the Houthis against commercial ships of countries affiliated with Israel, in continuous and rapid evolution, worries shipping companies which, in ever-increasing numbers, are considering the possibility of not transiting the Suez Canal in an east–west direction. Despite the US-led task force (*Prosperity Guardian mission*) and other similar initiatives, established with the aim of strengthening maritime defense in the Red Sea and ensuring safety for commercial ships, shipping companies whose ships have remained trapped in the region, between the Houthis in the south and the costly Suez Canal transit in the north, are continuing to divert their fleet toward the Cape of Good Hope. Estimates indicate that, currently, traffic toward the Suez Canal (12% of the total world traffic) has decreased by 48% in favor of the circumnavigation of Africa, chosen in more than 78% of cases [10]. Clearly, this solution is more expensive; transit and fuel costs alone exceed 2 million dollars per ship. Furthermore, transit from the Cape of Good Hope takes, on average, at least two weeks longer than sailing through the Red Sea (i.e., transit time would increase by around 30%), with unavoidable indirect operating costs, higher price for goods transport, and less profits [11–13]. In [10] the authors simulated the time needed to sail from the port of Jeddah (South Arabia) to the port of Taranto (Italy); the route through the Suez Canal would take approximately 5 days and 20 h at an average cruising speed of 12 knots (1672 miles). The same ship, at the same speed, transiting the Horn of Africa would take 44 days and 12 h (11,371 miles).

Considering that the Red Sea trade route is strategically significant because it connects the Mediterranean Sea to the Indian Ocean, providing a shortcut for ships traveling between Europe and countries in Asia and Africa, this situation marks a daunting start to strategic planning for the year 2024. Likely, soon, the effects of the crisis in the Red Sea will also impact container prices in the main ports of northern Europe. According to Drewry Supply Chain Advisors [14], in the week after 18 January 2024, the World Container Index (WCI) increased by 23% compared to the previous week (up to \$3777 per 40 ft container) and by 82% when compared with the same week in 2023. Considering the freight rates between Rotterdam and Shanghai, Drewry indicates an increase by 50% (from \$323 to \$975 per 40 ft container). Likewise, freight rates for travelling from Shanghai to Genoa grew by 21% (from \$1069 to \$6282 per 40 ft equivalent unit).

According to data reported by Linerlytica [11], a total of 664 container ships are used along the routes passing through Suez: 234 are used for the Asia–northern Europe route (43% of the total capacity); 159 are the units used along the connection services between Asia and the Mediterranean (23%); 84 ships are traveling between Europe and the US East Coast (12%); 123 are used between Europe, the Middle East, and the Indian subcontinent (11%); while 48 and 16 ships, equal to 4% and 2% of the overall capacity, are used on voyages between the USA and the Middle East/India and between Europe and Oceania [11], respectively. Currently, since an unclear timeline for the resolution of the Red Sea crisis is foreseen, the number of container ships re-routed to the Cape option has risen to 354 units for 4.65 m TEU or 16.4% of the overall fleet as of 7 January 2024. Over the coming weeks, the consequence is an expected capacity shortfall of up to 40% for departures from Asia to Europe and the US East Coast and on freight rates as well [15].

2.1. The Italian Port System

In this paragraph, a brief description of the Italian port system is provided to understand strengths and weaknesses of the current organization of Italian maritime sector. A quantification of Italian maritime traffic volumes is proposed too, to better appreciate the size and the economic impact of the matter. Finally, The Potential of Italian Ports as Sustainable Energy Hubs Section focuses on the potential of Italian ports as promoters of eco-sustainable solutions for the energy efficiency of the sector.

Italian national ports are classified as follows:

- First category: for military defense and national security;
- Second category, class I: of international economic relevance;
- Second category, class II: of national economic relevance;
- Second category, class III: of regional and interregional economic relevance.

Ports that fall into the second category have the following functions depending on the class:

- Commercial and logistics;
- Industrial and oil services;
- Passenger service, including cruise passengers;
- Fishing vessel;
- Tourism.

The Legislative Decree n. 169/2016 (GU 31 August 2016) states that the 62 ports of national relevance are coordinated by 16 port system authorities (AdSPs), who are entrusted with a strategic role of the direction, planning, and coordination of the port system in their own area. The AdSPs are the nodes of a logistics network that should integrate maritime, land, and air transport, in continuity with the TEN-T Corridors (i.e., the trans-European transport network defined in the European Regulation 1315/2013/EU) that connect Italy to Europe, from the Baltic to the Atlantic, and to the Mediterranean networks [16].

According to Eurostat [17], in 2021, Italy was the European country that transported the majority of goods on short-distance routes (314 million tons, around 15% of European maritime trade over short distances). Compared to the previous year, there was an increase

of 9.7%, one of the largest among EU countries. Moreover, in Italy, over 50% of foreign trade uses maritime transport (in the first 9 months of 2023, 37% of Italian import–export, approximately EUR 254 billion, was transported by sea [18]). Ports are crucial for the Made in Italy industries, for the supply of raw materials, and for the essential supplies of gas and oil. The Italian Maritime Economy reports published over the last three years by the SRM (research center connected to the Intesa Sanpaolo group) highlighted the recovery of commercial traffic in Italian ports, which is returning to pre-COVID levels [2,19,20]. Recent data confirm a good trend in the third quarter of 2023 [18]: 360 million tons of goods were handled with only a slight drop of 3% compared to the third quarter of 2022; +0.6% for ro–ro transport in the same period; and excellent performance for passengers and cruises (+16.4% and +54.4%). Nevertheless, it should be pointed out that over the last ten years, the Italian port system has not exceeded around 10–11 million TEUs and around 480–490 million tons of goods per year (the port of Rotterdam alone handles 12–14 million TEUs) [18,21].

Although economic uncertainties may cause slowdowns, current data on passenger traffic are encouraging after years of standstill. The cruise segment continues to grow even beyond forecasts, setting an historical record in 2023 compared to the last 30 years (over 12 million and 850 thousand passengers transported in Italian ports with an increase of 9.3 million compared to 2022 and a total of 4970 ship calls) and confirming its strategic role for Italian ports [22]. The data exceed those of the pre-COVID era (12.3 million in 2019), which had already set a record, and the ranking of the top 20 ports in the Mediterranean includes 8 Italian ports [22].

The Potential of Italian Ports as Sustainable Energy Hubs

Indeed, even in Italy, ports are increasingly becoming hubs of industrial and energy development. Actually, so far, the Italian port system cannot boast great results in terms of sustainability, as revealed by a recent study by the University of Genoa which analyzed 255 tourist ports in the Mediterranean, among which 76 are Italian. Specifically, the analysis focused on ISO certifications, Blue Flags, and the perception of users [23]. The study found that only half of the ports analyzed have an ISO 9001 (quality management system) or ISO 14001 (environmental management system) certification. Other specific certifications for the quality of ports are almost absent, such as ISO 13687 and ISO 21406 (only 26% of Italian ports have one of these certifications). Even Bizzarri and Crea [24] highlighted that, at present, all actions aimed at reducing the environmental impact of port navigation in Italy were not able to promote a significant change and are too often delegated to the responsibility of private shipping companies, which take charge of innovative projects and solutions. They also pointed out how Italian ports negatively impact air pollution with a consequent risk of the geographical impoverishment of places of very high cultural and social value.

However, thanks to their proximity to highly energy-intensive industries, Italian ports, as terminals of fossil and renewable energy as well as outlets for energy pipelines coming from North Africa, have relevant strategic and economic value and a high potential to become virtuous examples in terms of environmental sustainability.

The fourth MED & Italian Energy Report, written by the research center SRM, as previously mentioned, and EST Lab@energycenter (research center at the Polytechnic University of Turin) [25], confirms that the Italian port system has important energy potential. The top five Italian “energy ports” concentrate approximately 70% of traffic (i.e., Trieste, Cagliari, Augusta, Milazzo, and Genoa). They aim at imitating the more advanced port model of northern Europe, as previously described. These northern European ports increasingly intend to make their energy consumption more efficient, with the help of digital technologies, to be at the service of ships that use alternative fuels and to equip themselves with docking infrastructure and equipment for the diversified bunkering of ships.

The report by SRM and the Polytechnic University of Turin [25] also highlights the role of biofuels in the decarbonization of the EU transport sector, representing 83% of the

overall renewable fuel options recorded in 2020. Furthermore, in the Mediterranean area, petroleum products (75.9% of petroleum consumption is attributable to road transport) currently compose around 94.2% of total energy consumption in the transport sector. The amount of electricity produced through synthetic fuels that would be needed to replace petroleum products for the transport sector in the Mediterranean is estimated to be around 6177 Twh/a, more than three times the current total electricity generation throughout the Mediterranean region [25]. If synthetic fuels were adopted for the decarbonization of air transport sectors (both national and international) and maritime transport in the Mediterranean alone, the electricity requirement would be equal to 1198 TWh/a, which represents 58% of the current electricity production of the Mediterranean. Overall, the analysis demonstrates that synthetic fuels cannot yet compete with either fossil fuels or electricity [25].

However, it is worth mentioning that the Legislative Decree n. 50/2022 (known as the “Aid Decree”), containing measures to support families and businesses facing increased energy costs, has recognized Italian ports and the possibilities of forming “*energy communities*” to encourage and support a transition in these areas toward energy from renewable sources. *Energy communities* are new models of collective self-consumption through which local communities, businesses, and citizens (such as, for example, the inhabitants of the same condominium or the same neighborhood) can produce and share electricity deriving from systems powered by renewables.

Thus, the establishment of an energy community involves an aggregation of *Prosumers* (i.e., consumers who are themselves producers) who are willing to share renewable energy production systems and, therefore, the energy itself. The proximity between the point of consumption and the production plant from renewable sources is a key factor for the success of an *energy community*. Especially for ports in proximity to urban areas (a situation that applies well to the Italian port system), the impact of ports on the decarbonization process can be more than significant, as demonstrated by several reviews and applied studies focused on factors and solutions for increasing the self-sufficiency of ports using renewable energy sources [26–30].

In addition to environmental advantages, by attributing to port areas the status of *energy community*, the Aid Decree recognizes them a key stakeholder in developing the sustainability and economy of Italy. In this way, an effective promotion of green energy in port and proximity areas is supported, including a substantial allocation of funds for this sector to help businesses that are heavily affected by the increase in the cost of raw materials. Thus, this decree encourages the effective implementation of the infrastructure/services necessary to achieve the energy goals.

3. Ecological Transition and Green Ports

Ports, being complex infrastructures that also serve the urban context, urgently pose significant environmental issues: energy supply (e.g., the production of renewable energy through wind platforms or alternative sources), the electrification of docks (i.e., cold ironing), diesel refuel for ships, the transformation of maritime infrastructures into a defense against rising waters, erosion, and hydrogeological risk.

Maritime transport represents 80% of global wholesale trade in goods and is responsible for at least 3% of global GHG emissions, similar to the countries that are the largest CO₂ emitters globally, having produced 740 Mt CO₂ in 2018 [31]. An analogous trend is detected in Europe [32]. Most of these emissions are CO₂ emissions (over 90%, which have increased by 32% over the last twenty years), methane (CH₄), black carbon, and nitrous oxide (N₂O) [33]. Wissner and Cames [33] effectively depict the CO₂ emissions development related to international maritime transport from 1990 to 2022 (based on historic emissions from the IMO) and propose an emission projection up to 2050 considering a business-as-usual (BAU) scenario. A noticeable increase in emissions in 2050 compared to the current status is expected.

In this sense, one of the main problems to be solved concerns the dependence on hydrocarbons. Until a few years ago, naval and port industries, even in Europe, have used almost exclusively fossil fuels, and often the most polluting and climate-altering ones. For example, the large cruise ships that burn heavy fuel oil are much more polluting than transportation that uses road diesel, due to the fact that the sulfur content allowed until 2020, according to the ISO 8217 international standard, could reach 3.5% compared to the less sulfurized fuel oil for vehicles, where the sulfur content is generally limited to 0.001% [34]. This aspect is particularly relevant when also taking into account the absence of particulate filters or selective catalytic converters, which were standard technologies only for cars and trucks before IMO regulation 13.8 about nitrogen oxides NO_x control requirements, which has imposed an Engine International Air Pollution Prevention (EIAPP) Certificate and the subsequent demonstration of in-service compliance. This regulation applies to installed marine diesel engines of over 130 kW output power, irrespective of the tonnage of the ship where such engines are installed. Different levels of control are established depending on the ship construction date [35]. However, it is worth mentioning that the sulfur limit for heavy fuel oil was reduced to 0.5% by the IMO 2020 regulation as an amendment of the “*International Convention for the Prevention of Pollution from Ships—Annex VI*” (MARPOL), decision that surely helps to reduce ships’ environmental impact.

A Getting to Zero Coalition study [36] reveals that to adapt international maritime transport to the objectives of the Paris Agreement on Climate (2015–2016), it is essential that zero-emission fuels represent at least 5% of the fuel used in international maritime transport by 2030.

In recent years, also due to increasingly widespread protests by inhabitants and environmental movements, in various port areas, an environmental reconversion seems to have finally begun. This would aim at the drastic reduction in emissions, in some cases using new technologies to also increase economic competitiveness. This reconversion is focused on the containment of energy consumption in ports to make activities more sustainable, less risky for the urban realities close to the port areas and attentive to naturalistic heritage and biodiversity (i.e., green ports: according to the definition proposed at the United Nations Climate Change conference in 2009 [37], *a port characterized by a healthy ecological environment, reasonable utilization of resources, and low energy consumption and pollution*).

Regarding the Italian context, Castellano et al. [38] evaluated the environmental performance of ports in correlation with their economic efficiency when green port measures are adopted. A total of 24 Italian ports were assessed through a multistep approach which proposes two new parameters as indicators of the impact of port activities on environmental quality and the commitments of port authorities to assume proactive environmental measures. Surprisingly, the study demonstrates that the more numerous the proactive environmental policies, the higher the operating and economic efficiency of the port, suggesting that to properly judge environmental performance, a comprehensive framework of the overall port activities, infrastructure, and regulations is needed.

From an international perspective, ports with the highest traffic volumes seem to be particularly active in the current energy/environmental conversion (e.g., Rotterdam, Antwerp, and Hamburg, which alone represent 47% of European container traffic); among other things, they are already equipped for docking and receiving the electricity supply from the docks of giant ships such as container ships of 14,000 TEU or more (close to 400 m in length) [39].

The energy and environmental reconversion of ports simultaneously aims at three main types of solutions [39]:

- The electrification of docks (i.e., onshore power supply or cold ironing) to power the docked ships with electricity;
- Alternative fuels and the production of a large part of the electricity consumed with renewable sources (e.g., wind, photovoltaic);
- Policy measures with regard to the level of general emissions by ships.

3.1. Onshore Power Supply (Cold Ironing)

The following subsections delve into various aspects of onshore power supply (OPS) systems: first, their functioning and the fundamental requirements asked for ships and port infrastructures for their operation are described; Section 3.1.2. proposes a framework of their current implementation, with reference to the Italian context; then, the potential of OPSs as a promising instrument for reducing CO₂ emissions is investigated, exploring various methodologies proposed in the literature for assessing OPS contributions toward green ports, also in combination with microgrids and hybrid renewable energy systems; finally, future perspectives for OPSs are discussed, pointing out the importance of pricing mechanisms and specific investments to support OPS adoption.

3.1.1. Definition and Requirements

Onshore power supply (OPS), also named shore-side electricity technology or “cold ironing”, is based on replacing the auxiliary diesel engines of ships with electricity power supplied from the shore; the aim is to reduce carbon emissions during berthing periods [40,41]. Indeed, two different types of engines are usually equipped in ships: the main engine, used for moving; and the auxiliary engine, used to uninterruptedly supply electrical devices and appliances located on board (i.e., the supply of essential loads, such as hoteling/kitchen, communication devices, and alarm systems). The main engine is switched off when the ship berths in a port, while the auxiliary one continues to stay on to satisfy the above-mentioned complementary services. Usually, auxiliary engines are diesel ones, thus generating significant gas emissions and air pollutants within the harbor territory [41]. Such externalities become particularly evident for ports located close to urban areas.

Establishing an OPS connection necessitates economical and technical efforts by ship owners (for updating ship technologies), as well as port authorities and/or terminal operators (for implementing existing technologies and infrastructures or constructing new ones). Beyond the main switchboard, ships need an additional electrical switchboard that must be connected through cables to the main one and, usually, a step-down transformer. At the same time, ports must be equipped with a substation complete with breakers and disconnectors, an automated earthing switch, a transformer, protection equipment (e.g., transformers and feeder protection relays), communications equipment between the ship and the shore, and a frequency converter (to make compatible the electrical frequency of the local grid with that of each ship type). Additionally, both ports and vessels require a cable management system [42].

3.1.2. Current OPS Development

OPSs have been implemented in different ports in the United States, Belgium, China, Canada, Germany, Sweden, Finland, and the Netherlands [42,43]. The first OPS was installed in the cruise terminal of Long Beach port (California) in 2009. Not long after, the container terminals of Long Beach port also applied CI technology. Other noticeable examples of ports equipped with OPSs are Shanghai and Vancouver, whereas in Europe, Gothenburg (Sweden) and Hamburg (Germany) have employed their use.

Through the Directive 2014/94/EU, the EU has required European ports to provide facilities to enable CI use by 2025. Afterward, the European Regulation 2023/1805/EU on the use of renewable and low-carbon fuels in maritime transport made additional zero-emission goals mandatory for ships at berth, which implies, starting from 2030, that a ship berthed in a port of call which is covered by Article 9 of Regulation 2023/1804/EU (on the deployment of alternative fuels infrastructure) and which is under the jurisdiction of a European member has to use OPSs to satisfy its entire electrical power need at berth (from 2035, these regulations will apply also to ports of call not covered by Article 9 of Regulation 2023/1804/EU).

In Italy, OPSs are promoted by the National Cold Ironing Plan, which started in July 2021 and ends in June 2026, which aims to reduce carbon dioxide emissions in port areas. A total of EUR 755 million, of which 700 million is covered by the National Complementary

Fund, will fund projects for around 50 ports. This initiative is part of a broader scope strategy called “Green Ports” (see Section 3), which provides for interventions on renewable energy and energy efficiency in ports financed by the National Recovery and Resilience Plan (NRRP).

The port of Civitavecchia (close to Rome) is currently implementing an OPS; a technical and economic feasibility study about the electrification of its docks started at the beginning of 2023. In the northwest, the port of Genoa is also starting the process of the electrification of docks to support electric boating; likewise, the port of La Spezia has begun the electrification of the Garibaldi pier, which will be able to provide a power of 16 megawatts, an amount of power that is sufficient to allow all on-board activities for a ship at dock without the need of auxiliary diesel engines [44]. Additional Italian ports with allocated funds for electrification are Catania, Palermo and Termini Imerese (Sicily), Cagliari, Porto Torres and Santa Teresa di Gallura (Sardinia), Livorno and Piombino (Tuscany), Marghera (Veneto), and Ravenna (Emilia Romagna) [45].

In addition to the high investments required for the development of OPS, which cover the costs of onshore power services, power capacity extension, and the operations of electricity provided by the grid, another critical issue that can make OPS implementation and spreading difficult is the lack of standardization of power frequency and voltage worldwide. Currently, different ships operate with different voltages and frequencies which often do not comply with grid electrical features, which in turn depend on the regulations of the country where the port is located. This aspect is one of the most mentioned factors in feasibility studies for ports and shipping companies which presents as an obstacle to the adoption of OPSs. However, according to [42], global electrical standards shall be ratified by the three main international bodies in charge of developing standards for the worldwide electrical industry: the Institute of Electrical and Electronics Engineers (IEEE), the International Organization for Standardization (ISO), and the International Electro-Technical Commission (IEC).

3.1.3. OPS as a Mitigation Strategy for CO₂ Reduction

Several studies have focused on quantifying the impact of OPSs on the carbon emissions from shipping. Innes and Monios [46] applied a mixed methodology to quantify the annual savings in CO₂ emissions for small- to medium-sized ports and to create the best system design for meeting all the specific requirements outlined by each single port. The methodology mixes quantitative methods to determine energy request, costs, and emissions savings and qualitative methods based on expert interviews. The study reported an annual savings in CO₂ emissions of about 4.767 tons in the port of Aberdeen, a medium-sized port with several small berths. In Yun et al. [47], a simulation model is established to deal with complex stochastic processes that apply to container terminals without real energy consumption data. The authors found that applying OPSs is not enough for saving carbon emissions since the source of electricity is coal power, whereas shortening the time at berth can considerably decrease emissions from ships. Thus, increasing the working efficiency of port equipment is suggested as the most powerful action; at the same time, since emissions from ships in waterways represent the major contribution (about 68% in a container terminal) of their total emissions, additional measures are recommended, such as the use of liquified natural gas (LNG) instead of diesel for both waterway channels and at berth and the adoption of reduced speed in waterway channels.

Zis [48] proposed a methodology to evaluate consequences for ships related to OPS adoption while providing hotel services and evaluated the environmental savings through a comparison between the emission factors of all the ships considered in the evaluation (a small ro-ro ship, a large cruise ship, an ultra large container vessel, and a Panamax ship) and those of the electricity grid.

Herrero et al. [49] examined the integration of a CI system in the port of Santander, demonstrating that its efficacy is influenced by the ship type, with the outcome of ro-ro ships, ferries, and cruises as the best ship types for OPS implementation (with a reduction

of about 38% of overall CO₂ emissions during the time interval considered). Even in the study by Hall [50], emission savings are a function of the ship type and of the call frequency in ports, with an estimate of around 29% on average.

Stolz et al. [51] estimated the auxiliary power requested at berth for 714 European and United Kingdom ports. Each year, around 3–5 Mt of CO₂ could be saved if national grids using CO₂-neutral electricity would supply the auxiliary energy requested at berth. Such a measure would imply an average reduction in total shipping emissions of around 2.2% and 3.7% for Europe and the United Kingdom, respectively, and needs simply 0.2% (i.e., 6.4 TWh) in terms of the current generation capacity of electricity. The use of energy coming from the national grid would also result in a significant yearly air pollution reduction in the territory around the port area (i.e., expected reductions of 86,431 t NO_x, 4130 t SO_x, 1596 t PM10, 4333 t CO, 94 t CH₄, 4818 t NMVOC, and 235 t N₂O).

Despite OPSs contributions to emissions reduction, the enormous quantity of energy required from the shore side can result in generating electricity congestion on the electricity grid. According to Iris and Lam [28], ferries can ask for between 1 MW and 3 MW, cruises up to 10 MW, and container ships around 1 MW; thus, considering the contemporary presence of several ships in the port, the local shore energy production must satisfy both the peaks of the main grid and the energy required by port infrastructures for self-sufficiency.

3.1.4. Microgrids and Hybrid Renewable Energy Systems

Mertikas et al. [52] explore the opportunities to convert ports into smart energy hubs and discuss potential renewable energy sources for OPSs, summarizing the most relevant findings of the plan promoted by the European Union to introduce OPS as an attractive option for the development of greener ports.

Indeed, the national grid usually satisfies the energy request, but CI technology needs the development of a complementary energy production system located in the port and specifically designed for guaranteeing the energetic self-sufficiency of port activities, thus being able to burden the national grid less. Such a solution would make port areas autonomous microgrids, with both producers and consumers, and would require the efficient management of several energy sources for satisfying port energy demand.

Ahamad et al. [53] explored how to integrate microgrids for conventional ports and renewable energy storage systems (such as photovoltaic and wind) to optimize OPS solutions. Kumar et al. [54] created a new design for the port area where the smart grid should be located and verified its capability to adequately sustain CI systems for supplying ships currently in service, as well as future ships potentially equipped with hybrid technologies. Misra et al. [27] detailed the benefits of implementing microgrids based on renewable energy sources and adequate energy storage systems, a solution that would guarantee the much more sustainable energy management of port activities. They found that with appropriate energy storage systems, around 60% of the port electricity per day is covered. Colarossi and Principi [55] stressed that CI can ensure locally a significant reduction in pollutants, but globally, the overall environmental impact mainly depends on the quality (measured as energy source type) of the electricity coming from the grid; the more various the sources, the higher the reduction capability. In the case of similar CO₂ emissions, substituting on-board engines with systems taking the energy from the grid simply means the polluting source changes (from the port to the area where energy is produced). They proposed a numerical optimization model to properly design a photovoltaic plant and the related energy storage system able to power the CI system through electricity produced nearby. The case study of Ancona (Italy) was proposed as a positive example of local energy production from renewable sources to power ferry ships when berthed.

Hybrid renewable energy systems (HRESs), which include wind energy, onshore power supply, energy storage, and conventional power, represent a further option for satisfying port energy needs [53]. For ships at berth, HRESs always account for a photovoltaic system, an energy storage system, an onshore power supply, and an on-board diesel

generator. Many researchers have focused on identifying the optimal design of an HRES for ships.

Wang et al. [56] propose a two-stage framework for the optimal design of an HRES for port application, and the main findings can be summarized as follows: (i) the difficulties in balancing energy supply and demand in seaports can be solved through energy storage systems; (ii) the optimal installation capacity of OPSs at each berth is the same under different emission limitations and wind speeds.

Buonomano et al. [57] modelled and optimized the port of Naples (Italy) as a sustainable energy hub, considering several alternative renewable energy sources for fulfilling different port user demands, such as OPS. The energy hub consists of an anaerobic biodigester (that produces biogas from organic wastes coming from berthed cruise ships), photovoltaic panels, and marine power generators. Results demonstrate that certain port facilities use a high share of renewable energy produced on-site (up to 84%), strengthening the self-sufficiency from the national grid (self-sufficiency index up to 40%).

3.1.5. Prospects of OPSs

The storage capacity limitation of electricity, electricity price, possible financial rewards, and also the characteristics of maritime traffic that each port is able to accommodate are the major aspects able to affect the development prospects of OPSs.

Indeed, the capacity limitation of electricity must be taken into account for the sustainable development of emission reduction strategies such as OPSs.

In particular, the electrification of docks can allow docked ships to turn off their engines, thus reducing GHG and air/noise pollution. The transfer of energy from high voltage lines to port docks, and from there to ships, requires the availability of adequate electrical supplies and specific modern infrastructure (e.g., high-voltage transformation and conversion cabins, cables), as well as ships that are specially prepared for the electricity supply (even if temporary). On this front, despite the EUR 800 million allocated by the NRRP for the renewal of fleets and green ships, strong resistance persists from shipowners, both due to the higher costs of electricity and the investments necessary for ship adaptation.

In terms of the OPS installation investment, according to Peng et al. [58], when the cost of electricity for ports is higher than 0.3 USD/Wh, port operators must sustain a significant financial outlay. In this sense, governments should promote the installation of OPSs with financial rewards to ports and shipping companies or cover part of the costs to counterbalance the initial economic efforts required for OPS solutions. For the same reason, the price of electricity for OPS systems should be limited to avoid unbearable costs for ships operations and port activities. Even a recent study by Enel X and Legambiente [59] has clearly highlighted the need for public intervention to support a reduction in the price of electricity. The costs of producing electricity in port are currently around 0.11 EUR/kWh for container ships and cruises and 0.14 EUR/kWh for ro-ro and ro-pax ships; they become approximately 0.15 EUR/kWh if the energy comes from the national electricity grid (therefore, approximately 60% produced with fossil fuels) and reach approximately 0.18 EUR/kWh if it is formally green energy [39]. Renewable energy produced by wind and photovoltaic systems would lower the price to just 0.06 EUR/kWh, according to the European Commission [60].

Considering the ship operator's point of view, Zis [48] found that CI investment is not convenient for ships when the fuel cost is very low, as the initial investment cannot be depreciated over a ship's usual lifecycle (10 years); however, under different scenarios, the investment could be desirable.

Regarding maritime traffic, there is broad consensus that the major potential beneficiaries of the CI are specific ship types: cruise ships, ro-ro vessels [46,61], and container vessels [62], with special mention to vessels with reefer cargoes [63]. This is due not only to the environmental effects they generate (with particular reference to high energy consumption in port with intermediate berthing durations) but also because these ship types usually berth at the same ports.

The 2023, the IMO Strategy on the Reduction of GHG Emissions from Ships, presented also at the recent United Nation Climate Change Conference COP28 held in Dubai, United Arab Emirates [64] and adopted unanimously by Member States in July, foresees reaching net-zero GHG emissions for the shipping sector by 2050. It marks the reduction steps toward the expected result (i.e., emissions reduction of at least 20%, striving for 30%, by 2030 and of at least 70%, striving for 80%, by 2040).

In this sense, to guarantee a key role of international shipping for global trade without renouncing the net-zero emissions goals, an impact evaluation of substantial measures that are adoptable to gradually reduce GHG amounts from ships fuels, along with the implementation of an international GHG emission pricing mechanism in the maritime sector, is required. To this aim, and with reference to OPS, the IMO GreenVoyage2050 project, in conjunction with the International Association of Ports and Harbors, developed a workshop package for port stakeholders [65]. The package promotes OPSs by showing how ports can use these systems to reduce GHG emissions, as also asked by IMO resolution MEPC.366(79), which hopes for cooperation initiatives between port authorities and shipping operators. The package also includes feasibility and potential usage analysis, specifically regarding the following: fleet and port call analysis, grid analysis and the analysis of the importance of grid features, energy consumption, and OPS emissions.

3.2. Future Fuels in Shipping

This section explores the use of alternative fuels for maritime transportation, perceived as essential instruments for answering the challenging goal of net-zero GHG emissions in the maritime sector. Through the analysis of the existing literature on the topic, the effects of various types of alternative fuels, such as biogas, liquid natural gas, hydrogen, ammonia, methanol, and waste-derived biofuels, was addressed in terms of environmental impact reduction. After this introductory overview, the paragraph focuses on the implementations required both in port infrastructure and ships to guarantee the adequate supply of alternative fuels. Finally, evaluations on the potential development of the main alternative fuels as valid alternatives to fossil fuels are proposed, stressing the importance of common international regulations to standardize the technologies and procedures, as well as financing instruments and economic incentives, that support the shift toward new innovative systems.

3.2.1. Alternative Fuels for Maritime Sector

In the last decade, IMO strategies pushed more and more toward the adoption of important measures for reducing ships' environmental impacts. At the 72nd session of the Marine Environment Protection Committee (MEPC 72) in 2018, the IMO prescribed a 70% reduction in the CO₂ emissions and a 50% reduction in the GHG emissions from maritime activities by 2050, compared to 2008 levels. Afterward, these limits were revised with the adoption of the new IMO Greenhouse Gas Strategy presented at the Marine Environment Protection Committee (MEPC 80) in 2023; the ambition is to reach net-zero GHG emissions in the international shipping sector by 2050. Such a goal implies the adoption of near-zero GHG fuels by 2030 and intermediate checkpoints in 2030 and 2040 for monitoring the emissions reduction trend.

As stated in the Paper Structure and Review Methodology Section, the European Union has also established challenging goals to reduce GHG emissions by 2030 (by at least 55% compared to 1990) and achieve net-zero GHG emissions by 2050 [5]. The United Kingdom hopes for more than 68% GHG emissions reduction by 2030 and net-zero GHG emissions by 2050.

From this perspective, alternative fuels represent a key mitigation strategy for carbon emissions from port operations/shipping and are essential for reaching the goal of a "green port" system. Alternative fuels (such as LNG, methane, biofuels, methanol, hydrogen, and ammonia) answer many of the concerns related to fuel oils used in the maritime sector.

3.2.2. Impacts of Alternative Fuels

Several studies in the literature analyze the effects of alternative fuels on CO₂ emissions reduction. Most of them stress the need for a life cycle assessment (LCA) when evaluating the environmental impact of a shift in fuel type.

In Bengtsson et al. [66] four fossil fuels are analyzed: heavy fuel oil (HFO), marine gas oil, gas-to-liquid (GTL) fuel, and LNG. The solutions using GTL result in the highest global warming potential considering the entire ship's lifecycle, whereas the use of LNG could decrease the global warming potential by not more than 8–20%. Similar values can be found in the study of Yun et al. [47] where, considering a container terminal, the authors demonstrated that the use of LNG can reduce carbon emissions from ships by about 11% and from port operations and ships by about 8%. Even Styhre et al. [67] reported that by adopting LNG, CO₂ emissions could be about 25% lower compared with fuel oils; moreover, LNG significantly reduces emissions of NO_x, SO₂, and particulate matter.

Huang et al. [68] evaluated a case study, through an LCA, quantifying GHG emission performance of a very large crude carrier travelling between the Middle East and China. The impact of alternative fuels (i.e., LNG, methanol, and ammonia) was compared to the impact generated using fuel marine oil. Various scenarios of supply and production options were considered: no effects in terms of emissions using fossil energy-based methanol and ammonia were detected. Benefits were evident only when full solar and battery-based methanol and ammonia were used, with the latter being more efficient than the former.

The same results were confirmed through a similar case study (a 12,000 gross tonnage ferry operating in the Republic of Korea) [69]. Also, this study stressed the importance of the energy sources for producing alternative fuels as fundamental factors in determining emission levels.

Considering a nearshore ferry operating in the Republic of Korea (i.e., 170 gross tonnage) does not appear able to change what was found in the previous studies [70]. The hydrogen showed the highest global warming potential due to the high quantity of pollutants emitted during the hydrogen production process.

On the contrary, using alternative fuels for fishing vessels appears more effective in determining benefits in terms of emissions: an LCA and LCCA were performed by Perčić et al. [71], showing methanol as the most convenient solution compared to a usual diesel fuel.

Methane has a high global warming potential that is 86 times higher than CO₂ in a 20 year life span and 34 times higher in a 100 year life span [72]. The differences between the two durations considered are attributable to differences in residence times and the reactivity of CH₄ and CO₂ in the atmosphere [66].

Bouman et al. [73], through a review of several studies, found that a high potential for reductions in CO₂ emissions can be reached by adopting biofuels; however, if indirect effects, such as land use change, are considered in the assessment, biofuels would produce more CO₂ emissions.

Krantz et al. [74] studied biofuels by also considering marginal emissions for predicting the impacts of large-scale fuel transitions. Unexpectedly, biofuels showed equal or even higher marginal GHG emissions if compared to standard fuel oils. In fact, although they do not emit a lot when they operate, their current low availability counterbalances the positive effects and makes them climate inefficient.

In the study of Brynolf et al. [75], LNG, liquefied biogas (LBG), methanol, and bio-methanol are compared. The authors found that despite the fact that LNG or methanol produced from natural gas would substantially improve emissions savings, the overall impact on climate change is not dissimilar to that of using heavy fuel oil. Among the two fuels, producing and utilizing methanol implies lower CO₂ emissions than LNG in a time life span of 100 years, but the performance is worse than LNG when considering a 20 year duration. LNG and methanol mainly reduce local air pollutants. In terms of combustion, the adoption of LNG can promote an emission reduction capability up to 20–30% [76].

However, by only using LBG and bio-methanol, the global warming can be reduced.

In Calise et al. [77], a dynamic simulation model for the production of liquefied biomethane by anaerobic digestion is presented and applied to the islands of the Gulf of Naples. Significant energy savings (about 50% compared to the existing fleet equipped using internal combustion diesel engines) and CO₂ emissions reduction are obtained.

Tomos et al. [78] compared hydrogen, ammonia, methanol, and waste-derived biofuels and found that green hydrogen, waste-derived biodiesel, and bio-methanol have the best decarbonization potential, with possible reductions in emissions by 74–81%, 87%, and 85–94% compared to heavy fuel oil, respectively. Lee et al. [79] paid attention to the economic relevance of different production pathways of alternative fuels (e.g., LNG, ammonia, methanol, and biofuels) by evaluating the life cycle carbon pricing of each fuel pathway, while considering environmental effects. Data show biomass-based FT-diesel, e-methanol, and e-ammonia as the most effective in terms of environmental sustainability, with reductions in GHG emissions by 92%, 88.2%, and 86.6%, respectively. Nevertheless, the economic analysis demonstrated that the use of such fuels does not determine cost savings and is not financially sustainable in the current life cycle carbon pricing scenario.

In Zhang et al. [80], by analyzing the case study of a large-sized cruise ship in Oceania and in the Caribbean area, the adoption of hydrogen, ammonia, methanol, and natural gas showed a more than 60% reduction in GHG emissions by shifting from conventional fossil fuels to alternative fuels. With regard to ammonia, it has to be known that from its combustion, emitted nitrogen and sulfur oxides are more harmful for the marine ecosystem due to their acidification and eutrophication impacts [81]. In Wang H. et al. [82], the comparison between hydrogen-fueled vessels and ships with diesel engines showed significant advantages of using hydrogen, with a more than 80% decrease in emissions and almost 60% lifecycle cost savings.

However, all the analyses demonstrate that additional measures, such as low H₂ price and high carbon credit, are required in the near future to push the industry to adopt new alternative fuels.

3.2.3. Applicability of Alternative Fuels

Moving to alternative fuels requires appropriate supply infrastructures. A port must be prepared for the possibility of fuel supply to all the ships visiting the port or, at least, to the ships that visit the same port several times during a year. This latter case happens in areas characterized by few supply points, and, as a consequence, only the “main clients” (i.e., ships frequently berthing to these ports) have the potential to shift fuel usage metrics. It is clear that strategic decisions on alternative fuels are strictly interconnected with ship types, port infrastructures, land areas supplied, and, consequently, maritime routes.

From the ship point of view, the technical solution for adopting LNG often involves a dual-fuel engine able to run on either LNG or fuel oil, and which usually consumes a lower quantity of fuel oil for ignition when using LNG. Thus, LNG is increasingly adopted as a marine fuel, and from 2010 to 2022, the number of LNG-fueled vessels has considerably increased, considering both new builds and retrofit projects [83]. It is obvious that ships working in areas with a consolidated infrastructure for LNG will more easily adopt LNG as fuel. However, the uncertainty about the availability and accessibility of LNG, which depends on geopolitical aspects such as supply disruptions or political/military troubles in LNG-producing regions, can deeply influence the choice.

Methanol is at a first stage of introduction with respect to LNG, but full-scale trials have been started in Sweden. Methanol is a liquid at room temperature; thus, it is easier to store and distribute than LNG. In contrast, biofuels are still far from being realized [66].

Thus, the most effective alternative fuels are currently not produced at a sufficiently large scale to supply the potential demand; at the same time, the change to alternative fuel ships is too slow to meet the strategic objectives of emission reduction by 2050 [81]. This calls for a need for accelerated investments in new and retrofit ships, as well as in new fuel supply chains.

Hydrogen–ammonia fuels, i.e., the most commercially promising zero-carbon fuels, in addition to high investment and maintenance costs, present several drawbacks mainly related to the hydrogen fuel storage systems on ships, the safety of ammonia, and the need for more in-depth research about their combustion. Moreover, the lack of relevant technical specifications and regulatory systems makes it more difficult to apply these new power solutions [84]. Similar considerations are found in Wu et al. [85], where a structured systematic review and analysis of carbon reduction measures is presented along with related technical, regulatory, and economic policies adopted in the international maritime shipping sector. Results show that although hydrogen, ammonia, and green methanol fuels, as well as ship wind power, can significantly support emission reduction, their potential is still limited by technology, regulation, and costs. Moreover, using hydrogen as a fuel implies non-negligible infrastructure investments as well as technological improvements for its production, storage, and transportation. Additionally, hydrogen cost and accessibility are still unsolved issues that mainly present as obstacles to the widespread use of such a solution in shipping [86].

Additional weaknesses depend on the ship type, since ship loads and dimensions must be limited within a certain range, whereas currently, ships' energy systems incorporating alternative fuels still need heavy and large equipment (e.g., internal combustion engines, fuel cells, energy storage technologies) [80]. Thus, guidance for the utilization of alternative fuels as a function of the ship type is required, in order to identify the optimal ship-integrated energy systems solutions.

The same concerns were expressed by Notteboom and Haralambides [87] who analyzed in-depth the advances, opportunities, and challenges for the adoption of hydrogen as an alternative to fossil fuels. They carefully describe the potential of *green hydrogen* (the one obtained through electrolysis) to support the decarbonization of the maritime sector; green hydrogen does not generate carbon impacts, since the energy which powers electrolysis is mainly derived from renewable sources (e.g., wind, water, and solar). Despite the undoubted benefits, the study points out also the implications related to placing a green hydrogen system in an existing port context (e.g., changes in the port landscape due to the need for new massive physical infrastructure for production and storage, new cargo handling, and facilities for handling liquid hydrogen and ammonia and electrolyzers, such as pipelines, transformers, dryers, compressors, and a good connectivity to a high-capacity electricity grid). Furthermore, the document also highlights the fundamental importance of governments, port authorities, and shipping operators in anticipating the actions that are useful for clarifying the regulatory framework (such as the "*hydrogen strategy*" launched by the European Commission in 2020, which established the steps, from research and development to real-scale production and infrastructure, that are required for adopting green hydrogen in a large-scale dimension), promoting a reduction in the cost investment and supporting green hydrogen as a valuable solution for the energy transition.

Chen et al. [88] addressed the problem more from the port infrastructure point of view rather than hydrogen production and storage capability, stressing the fundamental role of port infrastructure and regulations for the good functioning of the hydrogen system supply chain. Although the study found that ports are not yet ready for hydrogen adoption and further efforts will be necessary such as implementing infrastructure and risk management measures and regulations, results showed that liquid hydrogen, ammonia, methanol, and LOHCs are suitable for international trade; moreover, they identified twenty ports as potential pioneers (i.e., twelve exporting ports and eight importing ports) for starting the decarbonization of ports through the adoption of hydrogen.

3.2.4. Prospects of Alternative Fuels

The maritime industry, being one of the sectors that is mainly responsible for GHG emissions, is highly committed to the decarbonization strategy which, among other measures, involves the progressive substitution of fossil fuels. As already highlighted, this strategy is promoted by international organizations, such as the IMO, which are introduc-

ing more stringent rules and regulations to limit GHG emissions and improve the energy efficiency of ships and port operations/infrastructures.

In this context, to reduce the risk of compromising the competitiveness of Italian/European ports, the identification of which alternative fuels may be most suitable for environmental impact purposes, as well as the understanding of their availability on the market, becomes essential. In the meantime, bunkering services and port authorities must ensure the availability of all the necessary investments to face the technical feasibility of new fuel solutions, guaranteeing adequate terminal infrastructures and the continuous availability of the product in order to avoid any inefficiencies in the service [89].

However, as described in the previous paragraph, a technology able to completely replace fossil fuels has not yet been identified. LNG is widely used and is considered a cleaner alternative to conventional fossil fuels, but as previously reported, it mainly works on reducing emissions locally. Methanol, which can also be produced from renewable sources such as biomass or water electrolysis (green methanol), is undergoing tests. Green methanol is of particular interest, but it still requires investments to become a practical large-scale solution, especially because it is highly flammable and requires special precautions for its handling, storage, and refueling. Green hydrogen is considered a promising option, as its combustion only produces water, but it presents significant challenges in terms of storage, distribution, and supply infrastructure. Other alternative fuels, such as the case of hydrogen, may have a lower energy density than fossil fuels, which could impact the performance and autonomy of ships.

Given all the above-mentioned aspects, the substitution of fossil fuels clearly represents a challenge for both ports and shipowners, since all the potential solutions, still being in the development and large-scale production phases, currently have high costs and a lack of infrastructure for production, storage, distribution, and supply [90].

Nevertheless, according to the ninth annual Italian Maritime Economy report presented by the SRM (i.e., Intesa Sanpaolo group) at the Congress Center of the Naples Maritime Station as part of Naples Shipping Week 2022 [91], 61% of all purchase orders in the first half of 2022 relate to ships using alternative fuels, and alternative fuels have been adopted in about 5% of the global fleet (in terms of tons).

Several container carriers are making important investments in alternative fuels [92]: Chinese COSCO Shipping has ordered 12 dual-fuel methanol container ships (24,000 TEU each) for a value of approximately USD 2.9 billion divided between its transport units, i.e., OOCL and COSCO Shipping Lines (7 and 5 ships ordered, respectively). Danish Maersk announced an order for 6 dual-fuel methanol container ships with a capacity of 17 thousand TEUs. These new units, expected by 2025, will be in addition to another 19 similar units that the Danish group has recently ordered. French CMA CGM has purchased 10 dual-fuel LNG container ships and 6 methanol-fueled ships, for a total of 69 new ships. The Swiss liner MSC has placed a maxi order for 28 LNG container ships (overall cost: USD 3.5 billion) in addition to a further order for 3 LNG-powered cruise ships (cost: EUR 3 billion). The first units were delivered in October 2022 and included the MSC World Europa, the first cruise ship equipped with the brand-new LNG fuel cell technology worldwide.

In terms of “green” infrastructure, the same report by the SRM [91] shows 148 ports active for LNG worldwide (and 95 planned structures). According to the analysis, a progressive replacement of LNG with bio-methane and ammonia is expected in the medium term, and replacement with hydrogen is expected in the long term. For example, the Italian shipowner specializing in the ro-o segment, Grimaldi, has planned an investment of EUR 1 billion for the construction of 10 ships powered by ammonia with a transport capacity of 9000 vehicles each.

The centrality of ports in this process is clear, as demonstrated by the approximately EUR 4 billion allocated by NRRP for the development of maritime accessibility and resilience, the development of cold ironing, and the development of the digitalization of the logistics chain for increasing competitiveness. Moreover, as described in The Potential of Italian Ports as Sustainable Energy Hubs Section, Italian ports are recognized as *energy*

communities by the Aid Decree of the Council of Ministers of May 2022, thus facilitating their transition to the use of renewable forms of energy.

The Italian RINA committee for the decarbonization of the maritime industry, with the participation of Assarmatori and Confitarma (Italian associations of shipowners), underlines the need for uniform interpretations at international levels of IMO recommendations and guidelines [93]. Clear and homogeneous regulations and authorization systems are fundamental for the standardization of technologies and procedures that, in turn, can streamline and facilitate the actions undertaken by the stakeholders involved in the process (i.e., e.g., port authorities, service operators, and shipping companies), especially for production and distribution infrastructures that are strongly influenced by the existing regulatory framework. From the shipowner's point of view, the decarbonization process will involve the following: (i) orders for new ships (or major conversions) which can fully benefit from new technologies and alternative fuels that the industry is gradually making available; (ii) techniques for reducing the consumption of the existing fleet and increasing shares of eco-compatible fuels such as biofuels. Another important element underlined by the shipowners concerns the costs of new ships and alternative fuels; financing instruments have to be suitable for allowing the adoption of the technologies that are actually available and consistent with the timing required for realizing the related projects, considering the production chain of the global shipbuilding industry [93].

The new challenge of Italian ports could be becoming energy transition hubs for the storage and/or production of LNG, biofuels, and hydrogen [94]. In 2021, the blue economy in Italy exceeded EUR 52.4 billion, growing by over EUR 10 billion in 10 years, with 228 thousand companies and 914 thousand workers. For several years, LNG supply in Italian ports mainly depended on small methane tankers and barges coming from Spain. Recently, other sources from Qatar, Algeria, and West Africa were activated.

Considering these new supplies, it is estimated that it will take 5 years to make Italy the Mediterranean gas bridge through 7 gasifiers near ports and 5 gas pipelines connecting northern Africa and northern Europe through Italy, which aim to transport around 50 billion cubic meters of LNG and up to 90 billion cubic meters of gas (full regime) for a total of 140 billion cubic meters of fuel. Agreements have been signed between Italy and Qatar and Italy and Algeria, for example, to give concrete implementation to the project. These agreements also involve other actors. In July 2022, the Italian oil company Eni, the American Occidental, and the French Total company signed a contract with Sonatrach (state-owned Algerian company) for producing and sharing oil and gas. The agreement (for a total value of USD 4 million) will supply significant amounts of natural gas to countries like Italy. With a similar aim (annual supply of around 1 million tons of LNG from Qatar to Italy), QatarEnergy and Eni signed a long-term contract for selling and purchasing LNG. LNG shipments, expected to start in 2026 and lasting 27 years, will be sent to a floating storage and regasification feature located in the port of Piombino (Italy—Tuscany).

However, developments also go beyond the extraction of gas and oil. For example, the pipeline between Italy (Italy—Sardinia) and Algeria (that of GALSI) will be completely new compared to existing ones and will allow the transport of natural gas but also hydrogen and/or ammonia. The ports of Southern Italy, especially, can play a key role in the energy sector; these represent 48% of the country's oil supplies and exports by sea and are the terminal of important pipelines from North Africa and Asia.

3.3. European Emission Trading System: Challenge and Opportunity

Below, the paper addresses the extension of the European Emission Trading System (EU ETS), already adopted in other production fields, to the maritime sector: first, the operating mechanisms of this significant novelty for ship transportation are described; then, economic implications of its adoption are discussed, while also analyzing the possible consequences of ETS effectiveness in reducing GHG emissions. As a further reference, an overview of the additional instruments adopted by the European Union for promoting the decarbonization of the maritime sector closes the section.

The beginning of 2024 marked the entry into force of the measure which extends to the maritime sector the EU ETS (Directive 2003/87/EC), adopted by the European Union to reduce greenhouse gas emissions and to align the maritime transport industry with the 55% reduction target of EU net greenhouse gas emissions by 2030 compared to 1990 levels.

Based on the EU ETS, from 1 January 2024, shipping companies must progressively purchase and transfer allowances (“EUAs”) for each ton of CO_{2eq} (carbon dioxide equivalent) emissions released into the atmosphere during the year.

Basically, a “cap” (i.e., a threshold) is set on the total amount of certain greenhouse gases that each company/operator can emit. The cap is reduced over time, at a fixed interval, in order to limit total emissions and comply with EU climate targets (reduction in the GHG emissions by 62% from 2005 to 2030). The cap is quantified in emission allowances (i.e., one allowance gives the right to emit one ton of CO_{2eq}) [95,96].

Each year, a company receives emissions allowances (consistent with the cap). Operators are not allowed to generate more GHG emissions than their allowances can cover. If, during the year, the company needs further allowances to cover its emissions, it can purchase them from other companies that did not use the entire amount of their allowances (they can save the spare allowances to cover possible future needs or sell them to other companies through secondary markets). Currently, the price of the allowances, which should be determined by supply and demand, appears to be quite volatile due to the bidding nature of purchasing. Based on what has been said by many of the major carriers, the price should probably be revised on a quarterly basis. If companies generate more emissions than what is covered by their allowances, heavy fines are imposed. By leveraging the payment of GHGs, the ETS should incentivize companies to reduce their emissions.

For all the companies covered by the EU ETS (not only limited to the maritime sector), the Union Registry, established in 2012, records allowances corresponding to their verified emissions and any transfer/transaction performed by account holders. The Union Registry is an electronic centralized database of emissions/allowances that works similarly to a bank account with money. Consequently, each company/operator that must comply with the EU ETS has to open an account in the Union Registry. All transactions between accounts are automatically checked and authorized by the European Union Transaction Log (EUTL) to ensure that all transfers comply with EU ETS rules. Therefore, starting from January 2024, the Maritime Operator Holding Account (MOHA) has been included in the Union Registry [97].

The opening of an MOHA will be possible within 20 days of the publication by the EU, in February 2024, of the official list of shipping companies and their member states. For all new companies/operators, the opening of an MOHA must occur within 65 days of the first trip.

The maritime industry’s inclusion in the EU ETS will occur through a step-by-step approach (i.e., phased-in implementation), with 40% of emissions covered by the system during 2024, 70% in 2025, and 100% in 2026. This new system is currently applied to cargo ships and passenger ships above 5000 GT, but it will also gradually concern other vessels, as listed below [95,96]:

- Offshore ships above 5000 GT, according to the EU Regulation 2015/757, will be included in the EU MRV European Monitoring, Reporting and Verification system to report CO₂ emissions from ships starting from 2025, and they will be included in the EU ETS starting from 2027;
- General cargo vessels and offshore ships between 400 and 5000 GT will be included in the EU MRV starting from 2025, and their inclusion in the EU ETS will be reassessed in 2026.

To fully quantify the EU ETS implications in the maritime transport industry, an essential element is the definition of which emissions are considered for the evaluation of each company’s ETS balance [97]:

- 50% of the emissions from vessels departing from a port under the jurisdiction of Europe and arriving at a port outside the jurisdiction of Europe and vice versa (international routes);
- 100% of emissions from intra-EU routes (i.e., vessels departing from a port under the jurisdiction of Europe and arriving at a port under the jurisdiction of Europe);
- 100% of emissions from vessels at berth in a port under the jurisdiction of Europe.

To this extent, during the drafting of the ETS regulation, critical concerns about its real effectiveness and the competitiveness of European ports, including their entire supply chain, arose, particularly regarding the risk of cargo diversion and a change in how shipping companies approach and plan their voyages (i.e., stops at additional and/or alternative ports to minimize the overall amount of GHG emissions and the related financial liability) [98,99].

In fact, GHG emissions that the EU ETS takes into account are only those between the last and the next port of call.

As a consequence, the EU ETS legislation has redefined a “port of call” (i.e., the one from where the voyage starts or ends when accounting for emissions) as a port where ships stop only for bunkering and/or obtaining supplies. Therefore, any “*neighboring container transshipment port*” (NCTP) does not qualify as a port of call for container ships and is not eligible for the purpose of calculating GHG emissions [95]. In order to be qualified as an NCTP, a port must fulfill the following criteria:

- It must be located in a country which does not apply measures equivalent to the EU ETS;
- It must be located in a country outside the jurisdiction of Europe, but within 300 nautical miles to a European port;
- 65% or more of its traffic of containers (during the last year for which relevant data are available) must concern transshipment containers.

To date, the EU ETS has designated only two ports as NCTPs: East Port Said (Egypt) and Tanger Med (Morocco). The list of NCTPs will be next updated by the end of 2025 and every two years thereafter. This designation removes the potential competitive advantage of these ports and puts them behind ports that are not considered NCTPs. Companies and operators could elect another non-EU port of call for the purposes of the EU ETS which is not an NCTP.

Despite these precautions, shipping companies may decide to completely avoid using EU transshipment ports (shipping routes could be re-planned so as to engage with ports of call outside of the EU, which are not NCTPs), or ships coming from long voyages could decide to call into a port near, but outside, the EU before entering the EU continent. As well, ships that have just left Europe could call the first nearest port just after leaving [98–100].

Further, in the case of vessels that avoid calling at EU ports or NCTPs, it may happen that cargo could be dropped off at a transshipment port outside of EU jurisdiction and thereafter distributed via smaller feeder vessels to EU ports. The consequence would be a larger volume of smaller vessels into EU ports, which might not be equipped to deal with much more traffic and operation.

This scenario would significantly reduce the effectiveness of the EU ETS with no benefits in terms of total GHG emissions. In addition, economic negative effects for all the European ports that are close to countries that are not covered by the EU ETS legislation and to the supply chain related to them could subsequently occur (e.g., negative impact on employment and business activity depending on how this cost will be distributed across the value chain), as demonstrated by Lagouvardou and Psaraftis [98], who performed a cost–benefit analysis focused on the impact of the inclusion of the EU ETS in the maritime transport sector. They showed that replacing European transshipment hubs with nearby non-European competitors would imply disadvantages for the EU ETS and a negative impact for the European transshipment hubs located close to hubs outside Europe, thus posing a risk to their economic activities and future development.

A specific report published by Alphaliner indicates that globally, 37% of the container ship fleet will be affected by the new EU ETS regulation (around 10.5 million TEUs). Routes that are the most affected by the EU ETS will be the ones between the Far East and Europe (for a total of 5.7 million TEUs) followed by the transatlantic and intra-European routes (for a total of 1.1 million TEUs each) [101]. As a result, to date, container companies of different trades have announced new surcharges for the first quarter of 2024 [102,103].

Although according to Alphaliner, expected ETS costs will be relatively lower for companies compared to other major expenses such as fuel, port fees, and transit fees, to correctly quantify the total impact in terms of the emissions of each ship/vessel and, consequently, in terms of costs, the analysis cannot be limited to the type of fuel and the distance traveled between the port of departure and the port of arrival [101]. The ETS should also consider indirect costs related to navigation speed and waiting times to enter the port and to dock at the quay. These are all variables that depend on various aspects that are usually not within the control of shipping companies, with particular reference to all the long and complex administrative processes that are often required to dock. These procedures surely require heavy bureaucratic streamlining, with the goal of minimizing the overall environmental impact linked to port activities.

Green Measures Complementary to the EU ETS

The EU ETS is not the only green measure being implemented. The EU Carbon Border Adjustment Mechanism will also assist in minimizing carbon leakages and ensuring that a fair price (similar to the carbon cost of domestic production) is recognized for the carbon emissions related to the production of specific goods imported into the EU. The introduction of this measure, which is aligned with the phase-out of the allocation of free allowances under the EU ETS, should protect EU green regulations from being undermined by countries with lower carbon targets and promote cleaner industrial production also in non-EU countries [104,105].

The European strategy for the decarbonization of the maritime transport sector also includes other initiatives such as the FuelEU Maritime Regulation that should set an emission limit from 2025 onwards [106]. The average limit of GHG related to the energy necessary for shipping activities has to decrease every 5 years (by 2% in 2025 and by 80% in 2050 compared to 2020 levels). Although the FuelEU Maritime Regulation faces the same issue as the EU ETS, it is not limited to the evaluation of CO₂ emissions (CH₄, N₂O, and upstream emissions are also accounted for).

The Energy Taxation Directive, commonly known as ETD, is included in the European regulations for the taxation of energy products including electricity, motor, and a variety of heating fuels [107]. It should guarantee that the exemption of fuels used in European maritime shipping (including in-land navigation) is phased out from 2023. Alternative fuels from renewable sources will not be taxed for 10 years, as well as onshore power supply in ports. Other measures that are part of the European “Fit for 55” package presented by the European Commission on July 2021 are the Alternative Fuels Infrastructure Regulation [108] and the Renewable Energy Directive [109], which are intended to push alternative fuels and onshore power supply.

Moreover, the IMO has already introduced the Carbon Intensity Indicator (CII) and the associated CII rating, which will be reviewed in 2026, along with the Energy Efficiency Existing Shipships Index (EEXI) and the Energy Efficiency Design Index (EEDI—for new vessels), which measure a ship’s energy efficiency.

These measures are part of the IMO’s commitment expressed in its “*Initial Strategy on Reduction of GHG Emissions from Ships*” developed in 2018 to reduce carbon emission intensity from all ships. They are part of the IMO technical and operational amendments MEPC.361(79) presented at the “*International Convention for the Prevention of Pollution from Ships—Annex VI*” (MARPOL), and they require ships to improve their energy efficiency, thus reducing their greenhouse gas emissions from a short-term perspective.

EEXI applies to each ship and each ship that has undergone a major conversion, whereas CII applies to ships that are 5000 GT and above.

The EEXI of a ship quantifies its energy efficiency with respect to a certain threshold: the current EEXI is compared to an EEXI calculated through a reduction factor expressed as a percentage of the Energy Efficiency Design Index (EEDI). EEXI has to be calculated for ships of 400 GT and above, taking into account the ship types and size categories. To guarantee the achievement of a minimum energy efficiency standard, current EEXI values for each individual ship must be lower than the required EEXI.

The CII, expressed in grams of CO₂ emitted, links the GHG emissions to the cargo-carrying capacity and to the nautical miles travelled as follows:

$$\text{CII} = \frac{\text{annual fuel consumption} \cdot \text{CO}_2 \text{ factor}}{\text{annual distance travelled} \cdot \text{capacity}} \cdot \text{correction factors}$$

It represents the annual reduction factor of carbon emissions. Lower CII values ensure the continuous improvement of a ship's operational carbon intensity.

The comparison of the current CII with a required CII determines the environmental carbon intensity rating, which qualifies a ship as A (highest rate—major superior performance level), B (minor superior performance level), C (moderate performance level), D (minor inferior performance level), or E (lowest rate—inferior performance level). The rate is recorded in a “*Statement of Compliance*” (that is required to be kept on board for five years) to be further elaborated in the Ship Energy Efficiency Management Plan (SEEMP). A ship rated D for three consecutive years, or E for one year, must propose a corrective action plan to achieve a CII of C or above. The rating thresholds will become increasingly stringent toward 2030.

Clearly, ships that use a low-carbon fuel will be characterized by a better CII than ships with fossil fuels. Moreover, apart from the type of fuel, a number of measures can improve a ship's rating (e.g., speed optimization, routing adjustments, low energy light bulbs, auxiliary renewable source energy power, hull cleaning to reduce the potential risk of friction with the seabed).

4. Discussion and Final Remarks

This final section seeks to bring together the elements illustrated in the previous sections, proposing a critical interpretative key of the main aspects that emerge from the bibliography review, but without claiming to provide an innovative methodology or a technical analysis of what was previously described. Overall, this paper aims to organically systematize the vast existing literature on the topic and harmonize the large amounts of information available, often found randomly, thus being able to constitute a reference compendium for easily identifying scientific studies on each specific aspect for further in-depth analyses.

Starting with an assessment on a global scale, attention is then focused on what is happening at a European level, to finally focus on the dynamics taking place in Italy. The final objective is to provide insights for stimulating further thoughts and ideas on the topic of decarbonization in the maritime sector and related infrastructural problems.

In recent years, environmental sustainability has acquired growing and growing attention and represents an undisputed and urgent priority on the global political agenda.

What was described in the previous paragraphs illustrates the efforts and potentials of the maritime sector to provide its contribution for the reduction of its environmental impact and for counteracting climate change. The transformation underway and the further developments that could take place thanks to research and innovation, both in terms of physical infrastructures and technological development, demonstrate an epochal revolution for the naval sector which involves both shipowners and operators, as well as government authorities.

Regarding the maritime sector, as extensively illustrated, fossil fuels adopted to power ships and related services have a terrible impact on air pollution. The possibility of using

alternative fuels, produced through vegetal or synthetic processes, is one of the prospects in which the sector is investing the most for lowering emissions into the atmosphere. However, studies conducted so far demonstrate that a long way is still ahead for research and technological applications to succeed in the complete replacement of fossil fuels. The heterogeneity of alternative fuels available today is one of the aspects that is slowing down their development; both the emissions and technologies to make them work are different from propellant to propellant. Their use is also influenced by raw material availability, costs, and the lack of adequate physical infrastructure for production and distribution. In the short-to-medium term, biofuels probably represent the most practical solution, and according to many studies, they are currently the most convenient alternative fuel for shipping. Furthermore, ammonia and hydrogen will likely prevail over other solutions from a long-term perspective. For achieving the decarbonization goal, every type of alternative energy efficiency measure that promotes fuel savings and the reduction of CO₂ emissions surely must be taken into consideration. In addition, collaboration between everyone is needed to guarantee the sector the necessary leverage to start a new phase of development.

In this sense, as shown in the previous paragraphs, the increased number of orders for ships capable of running on alternative fuels demonstrates that shipowners are making important investments to test different fuel formulas for their ships that are more sustainable but, at the same time, not excessively penalizing in terms of costs. At the same time, governments will have to promote measures and policies that encourage the massive adoption of alternative fuels. However, to date, an efficient and competitive technology capable of completely replacing oil fuels in the maritime sector has not yet been identified.

Concurrently, other solutions must be explored bearing in mind that the challenges related to the renewable energy supply chain are not limited to technological improvements for ships. The achievement of environmental sustainability goals must necessarily pass through a rethinking of the entire port system that must include terminals, infrastructures, the organization of ports, logistics operations, logistics services, and onshore logistics chains. In this sense, the electrification of docks surely represents one of the major changes in the approach to provisioning ships when they are docked. The replacement of auxiliary diesel engines during berthing periods for complementary services would guarantee significant advantages in terms of emissions and energy savings. Nowadays, still, few ports are equipped for OPSs as not only ships but also port infrastructures require significant adaptations and, consequently, huge monetary investments to meet the new “greener” needs. In addition, current OPS technologies in port areas are not able to fully meet needs (e.g., due to limited energy storage capacity and a lack of systems for producing enough energy from renewable sources to cover the entire energy demand for ships berthed in port).

Although some issues are still unsolved, the electrification of docks must be seen as an opportunity and placed in a broader perspective that must include the support of artificial intelligence, including not only cold ironing but also the use of electricity for powering vehicles travelling between port infrastructures, the energy efficiency of buildings, smart grids, virtual power plans, automation and digitalization, and ship–rail multimodality.

Ports renewal means ports are no longer a place exclusively for docking ships but a hub of modern logistics with the potential to become an energy hub.

The port can represent a key factor in the modernization of mobility for urban contexts as well as inland territories, in accelerating the process of the electrification of public and private transport, and in the diffusion of digitalization and automation.

This renewal is easier to implement if promoted at a regulatory level, as the introduction of instruments such as the EU ETS would aim at.

Even though the adoption of the EU ETS could cause initial uncertainty and issues for EU ports, with the right precautions and adjustments over time, it undoubtedly represents an opportunity to incentivize and support the growing market of alternative fuels (e.g., LNG, methanol, and ammonia). The EU ETS can bring broad changes to fuel strategies in Europe, forcing shippers to weigh the cost–benefit analysis of purchasing carbon allowances

versus lowering emissions (also considering that shippers transporting cargo on “green” services do not have to pay for the allowances). To meet the European regulations and reduce costs, many shipping companies are expected to work for the decarbonization of their fleet with the consequent need for investments for developing new technologies for ships, as well as for ports and terminals able to provide alternative fuel hubs to facilitate smooth bunkering operations.

This is the international framework that the Italian port system must deal with. Italy, due to its geographical position in the center of the Mediterranean, where around 30% of maritime transport is concentrated, boasts a strategic condition: a platform overlooking the sea, close to major shipping routes. Nevertheless, Italian ports are still unable to exploit their full commercial potential; port infrastructures appear too distributed and extremely fragmented.

As previously described, the Legislative Decree 169/2016 established 16 port system authorities that coordinate 58 ports (of which 16 belong to the central TEN-T network) distributed over almost 7500 km of coastline. As was well explained by Pavia in [21], there are too many stopovers compared to the port concentration of northern European countries (i.e., Hamburg, Rotterdam, and Antwerp intercept 70% of their countries’ maritime transport).

In addition, Italian ports pay the price of an extremely complex and slow bureaucracy and the lack of the digitalization of logistics operations, production processes, and services for passengers and operators, aspects which cause Italian ports to be perceived as inefficient and unreliable. The times and costs of ground services and connections with production/consumption centers are too high, as well as docking, embarkation/disembarkation, and cargo handling times. In these circumstances, operators tend to favor the greater predictability of other countries, which allows for better and more effective logistics planning. Generally, the reliability of the service prevails over other evaluation elements such as, for example, a potential advantage in terms of the reduced trip times that Italian ports could guarantee.

The consequent high logistics costs of national companies (around 11% higher than the European ones) significantly reduce the country’s competitiveness (the deficit on industrial turnover is estimated at approximately EUR 12 billion). Furthermore, physical characteristics such as the depth of the seabed, the extension of the docks and the lack of operational spaces for the movement of goods further worsen the potential of Italian ports. In addition, Italy is undergoing intense urbanization and the consequent strong contamination between port areas and the urban context, which severely limits the process of delocalization and the expansion of port capacity. While the ports of the northern range have undergone significant decentralization processes, detaching themselves from urban centers (Hamburg, Rotterdam, and Antwerp are located on large estuaries that facilitate expansions and relocations), Italian ports are incorporated within a highly urbanized territory, both on the inland side and along the coast, with consequent difficulty in integrating the different methods of transport, from railways to waterways, and in integrating production and service areas [110]. Consequently, it is difficult to develop Italian ports.

The privileged geographical position of Italy is not able to compensate for the above-mentioned issues. Not even the orography of the country (the Alps in the north and the Apennines longitudinally), which have a strong negative impact on the internal mobility of goods, has encouraged maritime transport.

All these factors (i.e., geographical, administrative, cultural, and technological context) make it extremely difficult for Italian ports to compete for global trade routes to and from Europe compared to the northern range ports.

The comparison with other countries in the Mediterranean is equally alarming. The countries on the southern shore of the Mediterranean have made important investments in their port systems, acquiring significant market shares to the detriment of Italian ports. In the last decades, they have welcomed massive port and inland infrastructure investments by foreign partners, such as China, with particular regard to the establishment of new transshipment hubs in strategic locations. This development strategy has also focused

on renewable energies (e.g., solar and wind power) to answer the increasing demand for electricity. On the contrary, the lack of foreign investment inflows into energy-dependent economies such as Italy has particularly contributed to this negative gap [4].

Important port investments are also being made in some eastern European countries, such as Slovenia, which is strengthening its Adriatic ports, and Romania, which has invested in the development of the port of Constanta.

Future Prospects of the Italian Port System

This subsection focuses on the predictable prospects for the Italian port system. Starting from the analysis of the investments currently planned for the sector, a final analysis is proposed for overcoming the present critical situation with respect to other European and international realities.

The Italian Legislative Decree no. 59/2021 on “Urgent measures to the National Complementary Plan (NCP) and to the National Recovery and Resilience Plan (NRRP) and other urgent measures for investments” outlined the overall framework of the future development policies of the port system [111]. The resources made available for the 2021–26 period are significant and involve a variety of actions:

- Fleet renewal and green ships (EUR800 million);
- Maritime accessibility and the resilience of port infrastructure to climate change (EUR 1470 million);
- Selective increase in port capacity through dredging works and new piers and platforms (EUR 390 million);
- The development of rear port areas, last/penultimate rail/road mile (EUR 250 million);
- Energy efficiency (EUR 50 million);
- The electrification of docks, i.e., cold ironing (EUR 700 million).

Overall, EUR 3660 million will be invested, almost the entire amount of resources foreseen by the NRRP for national ports and integrated logistics. Interventions are planned in 47 ports located in 14 regions and under the responsibility of the 16 port system authorities. A total of 46.9% of investments go to the ports of southern Italy, 37.7% go to those of the north, and the remaining 15.4% goes to those of central Italy. At a regional level, the ports of Liguria and Sicily are the main beneficiaries; around EUR 2.7 billion has been allocated to Liguria (of which EUR 600 million are allocated to the new breakwater in Genoa), and around EUR 1.1 billion has been allocated to Sicily [3,112].

A certain part of the funding will be allocated to the approval, monitoring, and control procedures defined by the Italian Government and are intended to support the reforms necessary for the modernization of the sector (e.g., the simplification of procedures for strategic planning, the awarding of port areas, faster authorizations for cold ironing systems, the digitalization of logistic operations, the implementation of a single customs desk, the organization of port activities, the attribution to ports of the qualification of “energy communities”) and the digitalization of passenger and goods transport services.

Also, infrastructural investments for the development of special economic zones (SEZs) will receive significant funds for port areas (EUR 630 million for 71 interventions, of which 33 are last mile projects in ports and related industrial areas, 30 are logistics and urbanization projects, and 8 are focused on increasing the resilience of ports to climate change).

Two cities will be the major recipients of the funds provided: Genoa and Trieste. The related projects are aimed at promoting these two ports as logistical hubs serving Europe. The development of the Genoa port is linked not only to its maritime accessibility (a new breakwater located 500 m further offshore than the existing one, to allow access for the new mega container ships) but also to the completion of the Third Crossing and the Monte Ceneri tunnel, essential to the functionality of the Rotterdam–Genoa corridor. In Trieste, the most advanced Italian port in terms of ship–railway intermodality, it is crucial to implement relations with the Cervignano interport as an exchange hub toward the Nuremberg logistics platform [16]. In this case, rapid progress is expected thanks to the virtuous process undertaken with international logistics operators (Hamburg port,

Nuremberg interport, and Danish logistics services company DFDS) and with the Friuli Venezia Giulia Regional Administration and its territory.

This current condition of “minority” compared to the northern range and other entities in the Mediterranean could be overcome by reorganizing the ports into a few multiport systems, taking advantage of the “opportunity” given by the new strategy for building the TEN-T network by 2030 [113], the instruments related to the European Green Deal, and the new commercial choices of many companies due to so-called *near-shoring* (i.e., companies shifting their manufacturing and production operations closer to their main markets) with the consequent re-evaluation of Mediterranean routes. Future work must aim at ports integrated into large logistics digitalized systems that are organized around rear port areas and multimodal hubs.

Being able to provide a coordinated offering of port services at an interregional level, both in the western and eastern arcs of the peninsula, capable of satisfying the logistics needs expressed by companies at lower costs and with greater levels of efficiency would certainly increase the reaction capacity of the Italian system to interact and compete with the northern range.

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Nomenclature

AdSP	Port System Authorities
BAU	Business-As-Usual
CI	Cold Ironing
CII	Carbon Intensity Indicator
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ships Index
ETS	Emission Trading System
EU	European Union
EUA	European Allowances
EUTL	European Union Transaction Log
GHG	Greenhouse gas
GTL	Gas-To-Liquid
HFO	Heavy Fuel Oil
HRES	Hybrid Renewable Energy Systems
IEC	International Electro-Technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LBG	Liquefied Biogas
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
LNG	Liquefied Natural Gas
LOHC	Liquid Organic Hydrogen Carriers
MEPC	Marine Environment Protection Committee
MOAH	Maritime Operator Holding Account
MRV	Monitoring, Reporting and Verification
NCP	National Complementary Plan

NCTP	Neighboring Container Transshipment Port
NRRP	National Recovery and Resilience Plan
OPS	On-shore Power Supply
PLSCI	Port Liner Shipping Connectivity Index
Ro–Pax	Roll-on/roll-off Passengers
Ro–Ro	Roll-on/roll-off
TEN-T	Trans-European Transport
TEU	Twenty-foot Equivalent Unit
US	United States
WCI	World Container Index

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