Review

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Posted Date: 1 February 2024

doi: 10.20944/preprints202402.0042.v1

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Review

The Port Sector in Italy: Its "Keystones" for an Energy-Effective 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 by 2022 (Assoporti data Jan-Dec 2022) [1] is the key to guarantee this condition 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, decarbonization of the maritime sector and related infrastructural problems (e.g. Cold Ironing or alternative fuels, where the uncertainty about resources availability and related cost do not allow for an easy strategic planning by both the shipowner and the port authority), as well as policies such the Emission Trading System (ETS) will be analyzed. All these issues, if addressed with a critical review, could represent the driving force of the national port sector for its growth and its competitiveness at a global scale.

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" [2]. What stated by the historian Braudel almost forty years ago is still topical and summarizes the strategic importance of the Mediterranean Sea as current and future scenario for the transport of people and goods, so for the economic development of Europe, Africa and Middle East (10% of the global maritime traffic passes though the Mediterranean along with almost 30% of the total containers movements) [3].

Although in recent years the European strategy has favored the development of Northern Europe 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 since 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 in Mediterranean ports (e.g. Piraeus, Port Said, Tanger Med, Ambarli, Haifa, Valencia, Marseille, Vado), so confirming the importance of creating in the Mediterranean area a solid system as valid alternative to current preferential routes and as driving force of new commercial possibilities [4].

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 in terms of TEUs ports capacity) by 2026 (expected annual average +3,6%) more than the global average (+3,5%), and the increase in the Port Liner Shipping Connectivity Index (PLSCI) by over 20% since 2006 [5].

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 line traffic (SRM on World Shipping Council) and 30% of oil and gas north-south and east-west flows (including pipelines) [3].

Speaking of the Mediterranean, it is unavoidable thinking to 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-establish the economic and geopolitical centrality of the Mediterranean. But its development must necessarily consider the European/international regulatory framework which increasingly pushes towards green economy and decarbonization. As well known, shortly after the new administration of the European Commission took office in 2019, very ambitious environmental goals were set, summarized in the so-called *European Green Deal* [6]. 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).

To this aim, in March 2020 the European Commission adopted a new industrial strategy defined "*Sustainable and Smart Mobility Strategy*" [7] 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) or 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, as well as the transportation segment is responsible for approximately ¼ of global emissions capable of altering the climate [8]. 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.

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 resources availability and related cost do not allow for an easy strategic planning by both the shipowner and the port authority) and policies such as the Emission Trading System (ETS) for 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, then moving 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 word scale and then with reference to Italy. We performed a systematic review, focusing on the results more than on the method adopted, based on a comprehensive search and analysis of published studies on well-known online research database (Scopus, Web of Science, IEEE Xplore, ScienceDirect), sector studies or specialized technical magazines. A final discussion section concludes the 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 the global trade, seemed to come back under control towards the end of 2021, but became critical again at the beginning of 2022 due to the combined effect 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 [9].

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 [10].

The situation is different considering the container segment, where the pressure on maritime transport is now easing as a result of the weakening of demand due to the 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) [9].

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 towards the Cape of Good Hope. Estimates indicate that, currently, traffic towards 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 [11]. Clearly, this solution is more expensive: transit and fuel costs alone should 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 [12, 13, 14]. In [11], using "Marine Traffic" software, 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 hours at an average cruising speed of 12 knots (1,672 miles). The same ship, at the same speed, transiting the Horn of Africa, would take 44 days and 12 hours (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, the effects of the crisis in the Red Sea will soon also impact container prices in the main ports of Northern Europe. According to Drewry Supply Chain Advisors [15], in the week after 18th January 2024 the World Container Index (WCI) has increased by 23% (up to $ 3,777 per 40ft container) and by 82% when compared with the same week of 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 $ 1,069 to $ 6,282 per 40 ft equivalent unit).

According to data reported by Linerlytica, a total of 664 containerships 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 traveling between Europe and the US East Coast (12%); 123 were 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, were used respectively on voyages between the USA and the Middle East/ India and between Europe and Oceania [12]. Currently, since non-clear timeline for the resolution of the Red Sea crisis is foreseen, the number of containerships re-routed to the Cape option has risen to 354 units for 4.65 m TEU or 16.4% of the overall fleet as at 7th January 2024. Over the coming weeks, the consequence is a capacity shortfall expected up to 40% for departures from Asia to Europe and the US East Coast, and on freight rates as well [16].

2.1. The Italian Port System

Italian national seaports are divided into the following categories and classes:

a) category I: ports, or specific port areas, aimed at military defense and national security;

b) category II, class I: ports, or specific port areas, of international economic relevance;

c) category II, class II: ports, or specific port areas, of national economic relevance;

d) category II, class III: ports, or specific port areas, of regional and interregional economic relevance.

Ports, or specific port areas referred to in category II, classes I, II and III, have the following functions:

a) commercial and logistics;

b) industrial and oil services;

c) passenger service, including cruise passengers;

d) fishing vessel;

e) tourism.

The Legislative Decree n. 169/2016 (GU 31 August 2016) provides that the 62 ports of national relevance are coordinated by 16 Port System Authorities (AdSP), who are entrusted with a strategic role of direction, planning and coordination of the port system in their own area. The AdSP are the nodes of a logistics network that should integrates 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 (Logistics and Infrastructure, ITA, 2020; Corte dei Conti Europea).

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 254 billion euros, was transported by sea [1]). 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 Smr (research center connected to the Intesa Sanpaolo group) highlighted the recovery of commercial traffic in Italian ports which is returning to pre-Covid levels [3, 18, 19]. Recent data confirm a good trend in the third quarter of 2023 [1]: 360 million tons of goods 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; 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) [1, 20].

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 850 thousand passengers transported in Italian ports with an increase of 9,3 million compared to 2022 and a total of 4,970 ship calls) and confirming its strategic role for Italian ports. The data exceeds that 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 [21].

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2.1.1. The Potential of Italian Ports as Sustainable Energy Hubs

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 and among these 76 are Italian. Specifically, the analysis focused on ISO certifications, Blue Flags and the perception of users [22]. 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: ISO 13687 and ISO 21406 (only 26% of Italian ports have one of these certifications). Even Bizzarri et Crea [23] 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 sensitivity of private shipping companies, which take charge of innovative projects and solutions. They also pointed out how Italian ports are negatively impacted by air pollution with a consequent risk of geographical impoverishment of places of very high cultural and social value.

However, Italian ports, as terminals of fossil and renewable energy, as well as outlets for energy pipelines coming from North Africa, and thanks to their proximity to highly energy-intensive industries, have a 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 Srm (research center connected to the Intesa Sanpaolo group) and Esl@Energy (research center of the Polytechnic of Turin) [24], confirms that the Italian port system has an 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 previously described: a port increasingly intended to make, also with the help of digital technologies, its energy consumption more efficient, to be at the service of ships that use alternative fuels and to equip themselves with docking infrastructures and equipment for the diversified bunkering of ships.

The report by Srm-Intesa Sanpaolo and the Polytechnic of Turin also highlights the role of biofuels in the decarbonization of the EU transport sector, representing 83% of the total renewable fuels used in 2020. Furthermore, in the Mediterranean region, 94,2% of total final energy consumption in the transport sector is currently covered by petroleum products (75,9% of petroleum product consumption is due to road transport). An estimate of the amount of electricity that would need to be produced to replace the consumption of petroleum products throughout the Mediterranean transport sector with synthetic fuels shows that 6,177 Twh/a would be needed, or more than three times the current total electricity generation throughout the Mediterranean region. If synthetic fuels were adopted for the decarbonization of the air transport sectors (both national and international) and maritime transport in the Mediterranean alone, the electricity requirement would be equal to 1,198 TWh/a, that means 58% of the current electricity production of the Mediterranean. The overall analysis shows that synthetic fuels cannot yet represent either an alternative to fossil fuels or a competitor to electricity.

However, it is worth mentioning that the Legislative Decree n. 50/2022 (known as “Aid Decree”), containing measures to support families and businesses to face the increase in energy costs, has recognized to Italian ports the possibilities of constituting “*energy communities*” to encourage and support a transition in these areas towards 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. those 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 (situation that well applies to the Italian port system), the impact of ports on the decarbonization process can be more than significant as demonstrated by

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several review and applied studies focused on factors and solutions for increasing ports' self-sufficiency using renewable energy sources [25-29].

In addition to environmental advantages, by attributing to port areas the status of *energy community*, the Aid Decree recognizes them a key role for developing the country's sustainability and economy. In this way, an effective promotion of green energy in port and backport areas is supported, including a substantial allocation of funds for this sector to help businesses heavily affected by the increase in the cost of raw materials, and thus encourages the effective implementation of the infrastructures/services necessary to achieve the energy goals.

3. Ecological Transition and Green Ports

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

The maritime transport represents 80% of global wholesale trade in goods and is responsible for at least 3% of global GHG emissions, assimilable to the largest countries CO_2 emitters globally, having produced 740 $MtCO_2$ in 2018 [30]. Analogous trend is detected in Europe [31]. Most of these emissions are CO_2 emissions (over 90%, which have increased by 32% over the last twenty years) and methane (CH_4), black carbon and nitrous oxide (N_2O) [32]. Wissner and Cames [32] effectively depict the CO_2 emissions development related to international maritime transport from 1990 to 2022 (based on historic emissions from IMO) and proposes an emission projection up to 2050 considering a business-as-usual (BAU) scenario. A significant 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, as for example the large cruise ships that burn heavy fuel oil (3,500 times more polluting than road diesel, 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 engine of over 130 kW output power irrespective of the tonnage of the ship onto which such engines are installed. Different levels (i.e. Tiers) of control are established based on the ship construction date [33]).

A Getting to Zero study [34] 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, in various port areas, also due to increasingly widespread protests by inhabitants and environmental movements, an environmental reconversion seems to have finally begun which would aim at the drastic reduction of emissions, in some cases using new technologies to also increase economic competitiveness (i.e. green ports: according to the definition proposed in 2009 [35], a port characterized by healthy ecological environment, reasonable utilization of resources, low energy consumption and pollution). This reconversion is focused on the containment of energy consumption in ports to make activities more sustainable, compatible with the urban realities close to the port areas and attentive to the naturalistic heritage and biodiversity.

Particularly active in the current energy/environmental conversion seem to be the ports with the highest traffic volumes (e.g. Rotterdam, Antwerp, Hamburg, which alone represent 47% of European container traffic): among other things, they are already equipped for the docking and the electricity supply from the docks of giants ships such as container ships of 14,000 TEU and more (close to 400 m in length) [36].

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

- electrification of docks (i.e. on-shore power supply or cold ironing), to power the docked ships with electricity;
- alternative fuels and 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. On-Shore Power Supply (Cold Ironing)

3.1.1. Definition and Requirements

On-shore power supply (OPS), also named as shore-side electricity technology or ‘‘Cold Ironing”, is based on replacing the auxiliary diesel engines of the ships with electricity power supplied from shore; the aim is to reduce carbon emissions during berthing periods.

Indeed, ships are generally equipped with two different engine types: the main engines, used as ship main engine, and the auxiliary ones used to provide uninterrupted power to run the electrical devices and appliances of various systems on board (i.e., to supply the essential loads, such as hoteling/kitchen, communication devices, alarm systems). The main engines are switched off when the ship berths in a port, while the auxiliary ones continue 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 harbour territory. Such externalities become particularly evident when ports are located close to the urban areas.

Establishing an OPS connection necessitates investments by both ship owners (for updating ship technologies) and port authorities or terminal operators (in the form of either a retrofit of existing technological and physical infrastructures or construction of new ones). The ship needs an additional electrical switchboard along with cables for its connection to the ship’s main switchboard, and, in many cases, a step-down transformer. The port requires a substation with breakers and disconnectors, an automated earthing switch, a transformer, protection equipment such as transformer and feeder protection relays, communications equipment to link ship and shore, and in most cases a frequency converter to adapt the frequency of electricity from the local grid to match that of each vessel. Further, a cable-management system is needed for either the port or the ship [37].

3.1.2. Current OPS Development

OPS has been implemented in different ports in the United States, Belgium, China, Canada, Germany, Sweden, Finland and the Netherlands [37, 38]. The port of Long Beach, California, opened the first cruise terminal around the world equipped with an OPS in 2009. All container terminals of Long Beach seaport applied Cold Ironing technology. Well-known examples of seaport using OPS are the port of Shanghai and the port of Vancouver, whereas in Europe the port of Gothenburg (Sweden) and the port of Hamburg (Germany).

Through the Directive 2014/94/EU, the European Union (EU) has required European ports to provide facilities to enable Cold Ironing use by 2025. Afterwards, the European Regulation 2023/1805/EU on the use of renewable and low-carbon fuels in maritime transport has established additional zero-emission requirements for energy used at berth which impose, starting from 2030, that a ship moored at the quayside 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 Member State shall connect to OPS and use it for all its electrical power demand at berth (from 2035 also to ports of call not covered by Article 9 of Regulation 2023/1804/EU).

In Italy OPS is promoted by the National Cold Ironing Plan, started in July 2021 and ending in June 2026, which aims to reduce carbon dioxide emissions in the port areas. 755 million euros, of which 700 are 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 paragraph 3), which

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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: the technical and economic feasibility study about the electrification of its docks has started at the beginning of 2023. In the North-West, also the port of Genoa is starting a process of 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, amount of power sufficient to allow all on-board activities for a ship at dock without need of auxiliary diesel engines [39]. 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) [40].

In addition to the high investments required for the development of OPS, which cover cost for on-shore power facilities, power capacity expansion and 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 the electrical characteristics of the grid, which in turn depend on the regulations of the country where the port is located. This aspect is one of the key factors cited in feasibility studies for ports and shipping companies which prevent the adoption of OPS. However, according to [37], universal electrical standards are on the verge of being ratified by the three main bodies responsible for developing standards for the electrical industry around the world: 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 CO_2 Reduction

Several studies focused on quantifying the impact of OPS on the carbon emissions from shipping. Innes and Monios [41] applied a mixed methodology to quantify the annual savings of CO_2 emissions for small to medium ports and to produce the best system design for meeting the particularly challenging needs of a specific port. The methodology mixes quantitative methods to calculate energy demand, costs and emissions savings, and qualitative methods based on expert interviews. The study reported an annual savings of CO_2 emissions of about 4.767 tons in the port of Aberdeen, a medium sized port with several small berths. In Yun et al. [35], a simulation model is established to cope with complex stochastic processes in container terminals without real energy consumption data. It found that applying OPS cannot save carbon emissions due to the source of electricity, which is generated by coal power, whereas reduced auxiliary time at berth can help in decreasing emissions from ships at berth significantly. Thus, increasing the working efficiency for port equipment is suggested as the most powerful action; at the same time, since emissions from ships in waterway account for the largest part (about 68% in a container terminal) of their total ones, additional measures are recommended such as the use of LNG instead of diesel for both waterway channels and at berth and the adoption of reduced speed in waterway channels.

Zis [42] presented a methodology to assess the implications of providing OPS to ships during their hoteling activities and evaluated the environmental saving based on a comparison between the emission factors of the ships under study (a small Ro-Ro ship, a large cruise ship, an ultra large container vessel and a Panamax ship) and of the electricity grid.

Herrero et al. [43] investigated the integration of a CI system in the port of Santander, demonstrating as its efficacy is influenced by the ship type, with the outcome of Ro-Ro, ferries, and cruises being the best target for OPS implementation (with a reduction of about 38% of total emitted tons of CO2 during the period of study). Even in Hall [44], emission savings are function of the ship type and of the call frequency in ports, with an estimate of around 29% on average.

Stolz et al. [45] estimated the auxiliary power demand at berth for 714 major ports in the European Economic Area (EEA) and the United Kingdom (UK). Annual emissions of 3 Mt (/ 5 Mt) CO_2 could be avoided if the auxiliary power demand at berth would be supplied from national grids (/ from CO_2-neutral electricity). This equals an average reduction of overall shipping emissions by

2.2%/3.7% respectively for the EEA and the UK, and requires only 0.2% (or 6.4 TWh) of the current electricity generation capacity. Using shore-side electricity from the grid can also contribute to substantial annual local air pollution reductions of 86,431 t NO_x, 4,130 t SO_x, 1,596 t PM10, 4,333 t CO, 94 t CH_4, 4,818 t NMVOC, and 235 t N_2O.

Despite OPS contribution in reducing the amount of emissions, the huge amount of energy required from the shore side can act in generating electricity congestion on the electricity grid. According to Iris and Lam [27], ferries can have an energy demand between 1 MW and 3 MW, cruises up to 10 MW and container ships up to 1 MW; thus, the contemporary presence of several ships in the port requires a local energy production for both peak shaving of the main grid, and to increase the energetic self-sufficiency of the port infrastructure.

3.1.4. Microgrids and Hybrid Renewable Energy Systems

The main results of the European project introducing OPS as an appealing alternative towards greener ports are summarized in Mertikas et al. [46], which explore the opportunities of turning the ports as smart energy hubs and discuss potential renewable energy sources for OPS.

Indeed, traditionally, the energy demand is satisfied by electricity form the national grid, but CI technology requires the port to develop a local energy production system, thus increasing the energetic self-sufficiency of the port area and reducing the pressure on the national grid. This way the port area can be considered an autonomous microgrid, characterized by both energy producers and consumers, and required to manage efficiently multiple energy resources while meeting seaport energy demand.

Ahamad et al. [47] studied the integration of microgrid technologies in conventional seaports and optimized the photovoltaic/wind/energy storage system to the use of OPS. Kumar et al. [48] proposed an innovative design concept of the harbor area smart grid and validated the performance to supply the ships for CI purpose, but also to support future technologies in hybrid ships. Misra et al. [26] detailed the benefits of implementing microgrids based on renewable energy resources and suitable energy storage technologies to achieve sustainable port energy management and concluded that suitable energy storage systems are able to provide 60% of the port's total daily electricity requirements [49]. stressed that CI can ensure locally a high level of local pollutants abatement, but globally the overall environmental impact depends on the quality (in terms of energy sources) of the energy purchased from the electricity grid. In fact, the higher the quality of the grid energy mix, the higher the abatement efficiency. In case of similar CO_2 emissions, substituting on-board engines with systems taking the energy form the grid simply leads to a shift of the polluting source from the port to the place where the energy is produced. They proposed a numerical optimization model aiming to return the best sizing of a photovoltaic plant and the capacity of an energy storage system located in the port area, so that the CI system is powered by means of electricity locally produced. The case of the ferry ships in the port of Ancona (Italy) has been taken as a case study, proving that a local energy production, from renewable sources, can be a good self-sufficiency in supplying the energy demand of berthed ships.

The energy demands in seaports can also be satisfied by a hybrid renewable energy system (HRES), which consists of wind energy, on-shore power supply, energy storage and conventional power [47]. To satisfy the energy demands of ships at berth, HRESs always account for photovoltaic system, energy storage system, on-shore power supply, and on-board diesel generators. Many researchers have focused on identifying the optimal design of a HRES for ships.

Wang et al. [50] proposes a two-stage framework for the optimal design of a 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 OPS at each berth is the same under different emission limitations and wind speeds.

Buonomano et al. [51] modelled and optimized the port of Naples (South- Italy) as a sustainable energy hub, considering several alternative renewable energy sources for fulfilling different port users demands, such as OPS. The energy hub includes an anaerobic biodigester for producing biogas

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from the organic waste of docked cruise ships, photovoltaic panels and marine power generators. Results showed that a very high rate of renewable energy produced on-site (up to 84%) can be exploited by certain port facilities, ensuring increasing independency from utility power grid (self-sufficiency index up to 40%).

3.1.5. Perspectives of OPS

Storage capacity limitation of electricity, electricity price, possible financial rewards, but also of the characteristics of maritime traffic each port is able to accommodate are the major aspect able to affect development perspectives of OPS.

Indeed, capacity limitation of electricity requires to be taken into account for a sustainable development of emission reduction strategies such as OPS.

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 electricity supplies and specific modern infrastructures (e.g. high voltage transformation and conversion cabins, cables), but also ships specially prepared for the electricity supply (even if temporary). On this front, despite the 800 million euros 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 OPS installing investment, according to Peng et al. [52] port operators have to pay for high investment and operation costs when the price of electricity provided to ports is higher than 0,3 $/Wh. The government should offer financial rewards to ports and shipping companies which install OPS systems or undertake part of investment costs to offset the initial economic disadvantages of OPS solutions. Besides, the electricity price for OPS systems should be limited within a certain level to avoid unbearable operation costs for ships and ports. Even in a recent study by Enel X and Legambiente [53] has clearly highlighted the need for public intervention to support the reduction of the price of electricity. The costs for producing electricity in port are currently around 0,11 €/KWh for container ships and cruises, and 0,14 €/KWh for Ro-Ro and Ro-Pax ships; they become approximately 0,15 €/KWh if the energy comes from the national electricity grid (therefore approximately 60% produced with fossil fuels) and reaches approximately 0,18 €/KWh if it is formally green energy [36]. Renewable energy produced by wind and photovoltaic systems would lower the price to just 0,06 €/kWh according to the European Commission [54].

Focusing on the ship operators' perspective, Zis [42] concludes that CI investment is not beneficial for vessels considering their usual lifecycle (10 years) when the fuel cost is very low, but with different scenarios the investment could be desirable.

Regarding the maritime traffic, there is broad consensus that the major potential beneficiaries of the CI are specific ship types: Cruise ships, Ro-Ro vessels [41, 55] and container vessels [56] with special mention to those vessels with reefer cargoes [57]. This is due not only to the environmental effects they generate (with particular reference to high energy consumptions in port with medium berthing times), but also because these ship types regularly call at the same ports.

The 2023 IMO Strategy on Reduction of GHG Emissions from Ships, presented also at the recent UN Climate Change Conference COP28 held in Dubai, United Arab Emirates [58] and adopted unanimously by Member States in July, foresees reaching net zero GHG emissions for the shipping sector by 2050. It marks the reduction pathways towards net zero, namely by reducing emissions by at least 20%, striving for 30%, by 2030, and by at least 70%, striving for 80%, by 2040.

In this sense, to ensure that international shipping can continue to play its pivotal role for global trade, while ensuring a clear course to net zero shipping, an impact assessment of the tangible proposals for measures that will ask for the gradual reduction of GHG intensity of marine fuels, in combination with a global maritime GHG emission pricing mechanism, is required. To this aim and with reference to OPS, a workshop package for use by port stakeholders has been developed by the IMO-GreenVoyage2050 project, in collaboration with the International Association of Ports and Harbours, IAPH [59]. The package supports the use of OPS to reduce ship emissions in ports by explaining how ports can use OPS, in line with the objectives of IMO resolution MEPC.366(79) which encourages voluntary cooperation between port autorithies and shipping sectors to contribute to the reduction of GHG emissions from ships. It includes the analyses required to assess feasibility and potential usage, specifically: fleet and port call analyses, grid analysis and the importance of grid characteristics, energy consumption and OPS emissions analysis.

3.2. Future Fuels in Shipping

3.2.1. Alternative Fuels for Maritime Sector

The latest IMO strategies, presented at the 72nd session of the Marine Environment Protection Committee (MEPC 72) in April 2018, aim to reduce 70% of the CO2 emissions and 50% of the GHG emissions from maritime activities by 2050, compared to 2008 levels. As stated in paragraph 1.1, also the EU has set up goals to reduce GHG emissions by at least 55% by 2030, compared to 1990, and achieve net-zero GHG emissions by 2050. The UK aims to achieve even more than 68% GHG emission reduction by 2030 and net-zero GHG emissions by 2050.

In this perspective, alternative fuels represent a key mitigation strategy for carbon emissions from port operations/shipping and are essential for reaching the goal of “green port”. Alternative fuels cover all aspects related to replacing marine fuel oils with alternative energy, such as liquefied natural gas (LNG), methane, biofuels, methanol, hydrogen and ammonia

3.2.2. Impacts of Alternative Fuels

Several studies in the literature analyze the effects of alternative fuels on CO_2 emissions reduction. Most of them stressed the need for a Life Cycle Assessment (LCA) when evaluating the environmental impact of a fuel change.

In Bengtsson et al. [60] four fossil fuels are compared: heavy fuel oil (HFO), marine gas oil, gas-to-liquid (GTL) fuel, and LNG. The alternatives with GTL result in the highest global warming potential during the whole life cycle of a ship, whereas the use of LNG does not decrease the global warming potential by more than 8–20%. Similar values can be found in the study of Yun et al. [35] where, considering a container terminal, authors demonstrated that, the use of LNG can reduce carbon emissions from ships by about 11% and from port operations and ship by about 8%. Even Styhre et al. [61] reported that, adopting LNG, CO_2 emissions are about 25% lower compared with fuel oils; moreover, LNG leads to significant reduced emissions of NO_X, SO_2 and particulate matter.

Methane has a high global warming potential: 86 times more powerful than CO_2 in a 20-year perspective and 34 times more powerful from a 100-year perspective [62]. The differences for the two-time horizons are due to differences in residence times and reactivity of CH_4 and CO_2 in the atmosphere [61].

Bouman et al. [63], through a review of several studies, found that high reduction potentials of CO_2 emissions can be reached adopting biofuels; however, if indirect effects, such as land use change, are considered in the assessment, biofuels would produce more CO_2 emissions.

In the study of Brynolf et al. [64], LNG, liquefied biogas (LBG), methanol and bio-methanol are compared. Authors found that, despite LNG or methanol produced from natural gas would significantly improve the environmental performance in terms of emissions, the overall impact on climate change is not dissimilar to that of using heavy fuel oil. Among the two fuels, the production and combustion of methanol causes lower emissions of CO_2- equivalents (per energy unit of the fuel) than LNG in a time horizon of 100-year, but it performs worse than LNG in a 20-year time horizon. LNG and methanol mainly reduce local air pollutants. From the perspective of combustion, the emission reduction capacity by adopting LNG can reach 20%~30% [65].

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

In Calise et al. [66] 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 CO_2 emissions reduction are obtained.

Tomos et al. [67] 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 potential emission reduction respectively of 74–81%, 87%, and 85–94% compared to heavy fuel oil. In Zhang et al. [68], considering a large cruise ship sailing in Oceania and in the Caribbean as a case study, the application of hydrogen, ammonia, methanol, and natural gas, indicated that more than 60% of greenhouse gas emissions can be reduced by replacing conventional fossil fuels with alternative fuels. With regard to ammonia, it has to be known that, from its combustion, emitted nitrogen and sulphur oxides are more harmful for the marine ecosystem due to their acidification and eutrophication impacts [69]. In Wang H. et al. [70] the comparison of hydrogen fueled vessels with ships driven by diesel generators demonstrate the benefits of using hydrogen for maritime transportation: over 80% emission reduction and around 60% life cycle cost savings.

However, all the analyses demonstrate that additional measures, such as low H_2 price and high carbon credit, are required in the next future to push industry to adopt new alternative fuels.

3.2.3. Applicability of Alternative Fuels

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

From the ship point of view, the technical solution for adopting LNG often includes a dual-fuel engine that can run on either LNG or fuel oil, and which always uses a minor amount of fuel oil for ignition when using LNG. Thus, LNG is increasingly adopted as a marine fuel, and from 2010 to 2022 there has been a significant increase in the number of LNG-fueled vessels, both through new builds and retrofit projects [71]. It is obvious that ships working in regions with an established infrastructure for LNG will more easily adopt LNG as fuel. However, the uncertainty about the availability and accessibility of LNG, that depends on geopolitical factors such as supply disruptions or political tensions in LNG-producing regions, can deeply influence the choice.

Methanol is in an earlier state of introduction with respect to LNG, but full-scale tests have been started in Sweden. Methanol is a liquid at room temperature, thus it is easier to store and distribute than LNG. Instead bio fuels are far from being realized [61].

Thus, the most effective alternative fuels are currently not produced at a sufficient 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 [67]. This calls for a need of accelerated investments in new and retrofit ships, as well as on new fuel supply chains.

Hydrogen-ammonia fuels, i.e. the most commercially promising zero-carbon fuels, in addition to high investment and maintenance costs, presents 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 also increases the difficulty of application and genealogy of these new power systems [72]. Similar considerations are found in Wu et al. [73], where a structured review to systematically collect and analyze carbon reduction policies is reported along with related technical, regulatory, and economic measures in international shipping. Results show that, while hydrogen, ammonia and green methanol fuels and ship wind power have a high potential to advance emission reduction, they are still limited by technology, regulation, cost and support. Moreover, the use of hydrogen as a fuel in shipping requires significant infrastructure development and technological advances in hydrogen production, storage and transportation. In addition, cost and availability of hydrogen fuel remain the main barriers to its widespread adoption in shipping [74].

Additional weaknesses depend on the ship type, since various navigation loads and strict space limitations are usually overlooked when designing the ships' energy systems incorporating alternative fuels, which include internal combustion engines, fuel cells, energy storage technologies, and other relevant equipment [68]. 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.

3.2.4. Prospective of Alternative Fuels

The maritime industry, being one of the sectors mainly responsible for GHG emissions, is highly committed in 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 International Maritime Organization (IMO), which are introducing 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 become essential. In the meantime, bunkering services and port authorities must ensure all the necessary investments to face the technical feasibility of new fuel solutions guaranteeing adequate terminal infrastructures and continuous availability of the product in order to avoid any inefficiencies in the service [75].

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 the emissions locally. Methanol, which can also be produced from renewable sources such as biomass or water electrolysis (green methanol), is under test. 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, it is the case of hydrogen, may have a lower energy density than fossil fuels, which could impact performance and autonomy of ships.

Given all the above-mentioned aspects, the substitution of fossil fuels clearly represent a challenge for both ports and shipowners, since all the potential solutions, being still in the development and large-scale production phase, have currently high costs and a lack of infrastructures for production, storage, distribution and supply [76].

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 the Naples Shipping Week 2022 [77], 61% of all purchase orders in the first half of 2022 relate to ships using alternative fuels and the adoption of alternative fuels covers about 5% of the global fleet (in terms of tons).

Many container carriers are investing in alternative fuels, for examples [78]: the Chinese Cosco Shipping has ordered 12 dual-fuel methanol container ships (24,000 TEU each) for a value of approximately 2,9 billion dollars 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 containerships with a capacity of 17 thousand TEUs. The new units, to be delivered in 2025, will be additional to others of the same type that the Danish group has recently commissioned, and that will be received in the same year (19 units in total). France's CMA CGM announced that it has placed orders for 10 dual fuel LNG container ships and 6 methanol-fueled ships, bringing its order book to 69 ships. The Swiss liner MSC has placed a maxi order for 28 LNG container ships with a total cost of almost 3,5 billion dollars which is added to a further order for 3 LNG-powered cruise ships that is worth 3 billion euros. The first delivery took place in October 2022: the MSC World Europa is the first cruise ship in the world to be equipped with the brand-new LNG fuel cell technology.

In terms of "green" infrastructure, the same report by SRM [77] 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 with hydrogen in the long term. For example, the Italian shipowner specialized in the Ro-Ro segment, Grimaldi, has planned an investment of 1 billion euros for the construction of 10 ships powered by ammonia with a transport capacity of 9,000 vehicles each.

The centrality of ports in this process is clear as demonstrated by the approximately 4 billion euros 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 paragraph 2.1.1, 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 association of shipowners), underlines the need for uniform interpretations at international levels of IMO recommendations and guidelines [79]. 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, shipping companies), especially for production and distribution infrastructures that are strongly influenced by the existing regulatory framework. From the shipowners' point of view, the decarbonization process will involve: *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 consumption of the existing fleet and increasing shares of eco-compatible fuels such as bio-fuels. Another important element underlined by the shipowners concerns costs for new ships and alternative fuels: financing instruments have to be suitable for allowing the adoption of the technologies actually available and consistent with the timing required for realizing the related projects, considering the production chain of the global shipbuilding industry [79].

The new challenge of Italian ports could be becoming energy transition hubs for the storage and/or production of LNG, biofuels and hydrogen [80]. In 2021, the Blue economy in Italy exceeded 52.4 billion euros, growing by over 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 Quatar, 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 north Africa and North Europe through Italy and aimed at passing around 50 billion cubic meters of LNG and up to 90 billion of gas (full regime) for a total of 140 billion of fuel. Agreements have been signed between Italy and Quatar and Italy and Algeria, for example, to give concrete implementation to the project. These agreements involve also other actors. In July 2022, Italian oil company Eni, the American Occidental and the French Total signed a 4 billion $ oil and gas production sharing contract with Algeria's state-owned Sonatrach, which will supply to countries like Italy significant volumes of natural gas. With similar aim, QatarEnergy and Eni signed a long-term LNG sale and purchase agreement for the supply of up to 1 million tons per annum of LNG from Qatar to Italy. LNG shipments, expected to start in 2026 for a term of 27 years, will be delivered to a floating storage and regasification unit located in the port of Piombino (Tuscany Region).

However, it also goes beyond the extraction of gas and oil, for example the pipeline between 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. Especially the ports of Southern Italy 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

The beginning of 2024 marked the entry into force of the measure which extends to the maritime sector the European Emission Trading System (EU ETS, Directive 2003/87/EC), adopted by the

 doi:10.20944/preprints202402.0042.v1

European Union to reduce greenhouse gas emissions and to align the maritime transport with the 55% reduction target of EU net greenhouse gas emissions by 2030 compared to 1990 levels.

Based on the EU ETS, from January 1, 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 fixed interval, in order to limit total emissions and comply with EU’s climate target (reduction in the GHG emissions by 62% from 2005 to 2030). The cap is expressed in emission allowances, (i.e. one allowance gives the right to emit one ton of CO_{2eq}) [81, 82].

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 keep the spare allowances to cover its future needs or sell them to other companies through secondary markets). Currently, the price of the allowances, that should be determined by supply and demand, appears quietly volatile due to the bidding nature of purchase. Based on what said by many of the major carriers, probably the price should be revised on a quarterly basis. If companies generate more emissions than what 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: it 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 (MOAH) is included in the Union Registry [83].

The opening of MOAH 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 the MOAH 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 concern gradually also other vessels as below [81, 82]:

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

To fully quantify EU ETS implications in the maritime transport, an essential element is the definition of which emissions are considered for the evaluation of each company ETS balance [83]:

- 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 regard, 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: 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 for minimizing the overall amount of GHG emissions and the related financial liability) [84, 85].

In fact, GHG emissions that EU ETS takes into account are only those between the last and/or 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 to account for emissions starts or ends) as a port where ships stop only for bunkering and/or obtaining supplies. So that, any "*neighboring container transshipment port*" (NCTP) does not qualify as a port of call for containerships and are not eligible for the purpose of calculating GHG emissions [81]. In order to be qualified as a NCTP, a port must fulfill the following criteria:

- it must be located in a country which does not applies measures equivalent to the EU ETS;
- it must be located in a country outside the jurisdiction of Europe, but within 300 nautical miles from a European port;
- 65% or more of its traffic of containers (during the last year for which relevant data is 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 for 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 a 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, EU before entering the EU continent, as well as ships that have just left Europe could call the first nearest port just after leaving [84, 85, 86].

Further, in case of vessels avoid calling at EU ports or NCTPs, it may happen that cargo could be dropped off at a transshipment port outside EU regulations, and thereafter distributed via smaller feeder vessels to EU ports. The consequence would be a larger volume of smaller vessels into EU ports who 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 those European ports close to third countries 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 demonstrate by Lagouvardou and Psaraftis [84] that performed a cost-benefits analysis focused on the impact of the EU ETS inclusion in the maritime transport sector. They showed that replacing European transshipment hubs with nearby non-European competitors would lead to revenue loss for the EU ETS and penalization of the European transshipment hubs in close proximity with hubs outside Europe, thus posing a threat to their economic activity and 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 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) [87]. As a result, to date, container companies of different trades have announced new surcharges for the first quarter of 2024 [88, 89].

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 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 [87]. The ETS should considered also 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 aspect usually not within the control of shipping companies, with particular reference to all those long and complex administrative processes often required to dock. Procedures that surely require a heavy bureaucratic streamlining also with the view to minimizing the overall environmental impact linked to port activities.

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3.3.1. Green Measures Complementary to 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 to make sure that a fair price (equivalent to the carbon price of domestic production) has been paid for the embedded carbon emissions generated in the production of certain goods imported into the EU. The introduction of this measure, that is aligned with the phase-out of the allocation of free allowances under the EU Emissions Trading System (ETS), should protect EU green regulations from being undermined by countries with lower carbon targets and encourage cleaner industrial production also in non-EU countries [90, 91].

The European strategy for the decarbonization of the maritime transport sector includes also other initiatives such as the FuelEU Maritime Regulation that should set an emission intensity standard from 2025 onwards [92]. The average GHG intensity of the energy used for shipping activities must 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 compared to the EU ETS, it is not limited to the evaluation of CO2 emissions (also CH4, N2O and upstream emissions are 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 [93]. It should guarantee that the exemption of fuels used in the EU maritime transport (including in-land navigation) is phased out from 2023. Alternative fuels from renewable sources will not be taxed for 10 years, as well as on-shore power supply in ports. Other measures part of the European “Fit for 55” package presented by the European Commission on July 2021 are the Alternative Fuels Infrastructure Regulation (AFIR [94]) and the Renewable Energy Directive (RED [95]), which are intended to push alternative fuels and on-shore power supply.

Moreover, the International Maritime Organization (IMO) has already introduced the Carbon Intensity Indicator (CII) and the associated CII rating, that will be reviewed in 2026, along with the Energy Efficiency Existing ships Index (EEXI) and the Energy Efficiency Design Index (EEDI - for new vessels), which measures a ship energy efficiency.

These measures are part of IMO's commitment expressed in its “*Initial Strategy on Reduction of GHG Emissions from Ships*” developed in 2018 to reduce carbon 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 in a short-term perspective.

EEXI applies to each ship and each ship that has undergone a major conversion, whereas CII applies to ships of 5,000 GT and above.

The EEXI of a ship indicates its energy efficiency compared to a baseline: current EEXI is compared to a required EEXI calculated through a reduction factor expressed as a percentage of the Energy Efficiency Design Index (EEDI). EEXI must be calculated for ships of 400 GT and above, taking into account ship types and size categories. To ensure the ship meets a minimum energy efficiency standard, current EEXI value for each individual ship must be lower than the required EEXI.

The CII, expressed in grams of CO_2 emitted, links the GHG emissions to the cargo-carrying capacity and to the nautical mile travelled as follows:

$$CII = \frac{annual\ fuel\ consumption \cdot CO_2 factor}{annual\ distance\ travelled \cdot capacity} \cdot correction\ factors$$

It represents the annual reduction factor of carbon emissions. Lower CIIs ensure continuous improvement of ships 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*"

 doi:10.20944/preprints202402.0042.v1

(that is required to 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 towards 2030.

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

4. Discussion and Final Remarks

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

What described in the previous paragraphs illustrates efforts and potentials of the maritime sector to provide its contribution for the reduction of the environmental impact and for contrasting the 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 needed for research and technological applications to succeed in the complete replacement of fossil fuels. 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, organization of ports, logistics operations, logistics services, and on-shore logistics chains. In this sense, the electrification of dock 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 OPS 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. limited energy storage capacity, lack of systems for producing enough energy from renewable sources to cover the entire energy demand for ships berth in port).

Although some issue 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: not just cold ironing, but the use of electricity for powering vehicles handling between port infrastructures, energy efficiency of buildings, smart grids, virtual power plans, automation and digitalization, ship-rail multimodality.

Ports renewal means ports are no longer a place exclusively for docking ships, but a hub of modern logistics, whit the potential of becoming 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 electrification of public and private transport, 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 right precautions and adjustments over time, it undoubtedly represents on opportunity for incentivizing and supporting 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

 doi:10.20944/preprints202402.0042.v1

up 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 of investments for developing new technologies for ships, as well as ports and terminals able to provide alternative fuel hubs to facilitate smooth bunkering operations.

This is the international framework 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 (whose 16 belong to the central TEN-T network) distributed over almost 7,500 km of coastline. As well explained by Pavia in [96], too many stopovers compared to port concentration of Northern European countries (i.e. Hamburg, Rotterdam, 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 digitalization of logistics operations, production processes and services for passengers and operators, aspects which make Italian ports perceived as inefficient and unreliable. 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 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 reduced trip times that Italian ports could guarantee.

The consequent high logistics costs on national companies (around 11% higher than the European ones) significantly reduce the country's competitiveness (deficit on industrial turnover estimated at approximately 12 billion euros). 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. As well as the intense urbanization and the consequent strong contamination between port areas and the urban context, which severely limits the process of delocalization and expansion of port capacity. While the ports of the Northern Range have undergone significant decentralization processes, detaching themselves from urban centers (Hamburg, Rotterdam, 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 to integrate different ways of transport, from railways to waterways, but also production and service areas [96]. Consequently, it is difficult to.

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 the maritime transport.

All these factors (i.e. geographical, administrative, cultural and technological context) makes 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 of 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 such as solar and wind power to meet the growing demand for electricity. On the contrary, lack of foreign investment inflows in energy-dependent economies such as Italy particularly contributed to this negative gap [5].

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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.

4.1. Future Prospective for the Italian Port System

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 [97]. The resources made available for the 2021-26 period are significant and involve a variety of actions:

– fleet renewal and green ships (800 million €);
– maritime accessibility and resilience of port infrastructure to climate change (1,470 million €);
– selective increase in port capacity through dredging works and new piers and platforms (390 million €);
– development of rear-port areas, last/penultimate rail/road mile (250 million €);
– energy efficiency (50 million €);
– electrification of docks, i.e. cold ironing (700 million €).

Overall, 3,660 million euros 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: 46,9% of investments go to the ports of Southern Italy, 37,7% to those of the North and the remaining 15,4% to those of Central Italy. At a regional level, the ports of Liguria and Sicily are the main beneficiaries: around 2,7 billion euros have been allocated to Liguria (whose 600 million euros for the new breakwater in Genoa), and around 1,1 billion to Sicily [98, 99].

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. simplification of procedures for strategic planning, awarding of port areas, faster authorizations for cold ironing systems, digitalization of logistic operations, implementation of a single customs desk, organization of port activities, 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 (630 million euro for 71 interventions, whose: 33 for last mile projects in ports and related industrial areas, 30 for logistics and urbanization, 8 for 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 not only linked to its maritime accessibility (a new breakwater located 500 m further off-shore 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 for 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 towards the Nuremberg logistics platform [100]. In this case, rapid progresses are expected thanks to the virtuous process undertaken with international logistics operators (Hamburg port, Nuremberg interport, Danish logistics services company DFDS) and with the Friuli Venezia Giulia Regional Administration and its territory.

This current condition of “minority” compared to the Norther Range and other realities 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 [101], the instruments related to the European Green Deal and the new commercial choices of many companies due to the 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: the future prospective must aim at ports integrated into large logistics digitalized systems organized around rear port areas and interports.

Being able to provide a coordinated offer of port services at an interregional level, both in the western and eastern arc of the peninsula, capable to satisfy 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.

Author Contributions: Responsible for the ideation, Marialisa Nigro and Massimo De Domenico; literature search, Marialisa Nigro and Arianna Stimilli; writing—original draft preparation, Marialisa Nigro and Arianna Stimilli; review and supervision, Tiziana Murgia. All authors have read and agreed to the published version of the manuscript.".

Funding: This research received no external funding.

Data Availability Statement: Data sharing is not applicable.

Conflicts of Interest: "The authors declare no conflicts of interest.".

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