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Cold Ironing and Energy Transition in Western Ligurian Ports: A Stakeholder-Driven Model for Sustainable Development

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Abstract

In a context of continuous technological and regulatory changes ports are now facing the energy and the ecological transition. To be achieved, these processes need a lot of effort in terms of investment and stakeholder involvement. The main instrument to achieve tangible change within the port and urban areas is cold ironing. The benefit of using CI is widely addressed by literature discovered in Chapter 2 since the aim of this analysis is not to discover environmental benefits but to make the service effectively possible. The analysis focuses on the Western Ligurian Sea Port Authority (AdSPMLO), which is the Genoa Port Authority, in change to manage four basins, namely the ports of Genoa, Prà, Savona, and Vado Ligure. To understand the development possibilities this thesis starts analyzing the context in which CI technology is used and how regulatory bodies are pathing the way for the energy transition. The stakeholder's cohesion is the base floor to build a real and reliable project to reshape how Ligurian ports manage energy, involving the community through Port Energy Communities (PRECs) will enhance the convenience for participants helping the spread of decentralized production from renewables. For what concerns the port as a whole, all the undergoing energy investments are evaluated to framework how the planning of the ports is changing. In this sense, the role of the new dam of Genoa represents a game-changer to completely revolutionize the availability of auto-produced energy inside the port. Different levels of internal capacity are considered and allow us to calculate a theoretical price at which auto-produced electricity may be sold by the AdSPMLO to port stakeholders, building a win-win model. The final part of the analysis uses the data coming from the DSFE software of all the maritime traffic registered in the last year in the four basins to evaluate the potential effect of auto production on the cost-effectiveness of cold ironing service.

Abstract in Italiano

In un contesto di continui cambiamenti tecnologici e normativi, i porti stanno affrontando la transizione energetica ed ecologica. Per raggiungere questi obiettivi, è richiesto un grande sforzo in termini di investimenti e di coinvolgimento degli stakeholders. Lo strumento principale per ottenere cambiamenti tangibili all'interno dei porti e delle aree urbane circostanti è rappresentato dall'elettrificazione delle banchine e il conseguente utilizzo del servizio di Cold Ironing (CI). I vantaggi dell'utilizzo della tecnologia di CI sono ampliamente trattati dalla letteratura approfondita nel capitolo II della tesi. Poiché lo scopo dell'analisi non riguarda strettamente i benefici ambientali del CI, l'elaborato si concerta su come far sì che il servizio sia economicamente conveniente per gli armatori, così da essere utilizzato. L'analisi si concentra sull'Autorità di Sistema Portuale del Mar Ligure Occidentale (AdSPMLO) che gestisce i quattro porti di Genova, Prà, Savona e Vado Ligure. Nello specifico, viene analizzato il contesto di utilizzo del CI, valutando come la normativa sta mettendo le basi per la transizione energetica. Vengono esplorati i ruoli delle comunità energetiche e delle comunità energetiche portuali, in particolar modo il loro contributo nella decentralizzazione e nell'avanzamento tecnologico della rete. Il porto, nel suo complesso, ha pianificato diversi investimenti legati all'approvvigionamento e all'utilizzo di energia che modificheranno strutturalmente il modo in cui il contesto portuale si alimenta. Il progetto della nuova diga foranea di Genova risulta essere un punto di svolta per autoprodurre energia all'interno del porto. L'analisi valuta diversi livelli di capacità interna che permettono di calcolare un prezzo teorico al quale l'elettricità autoprodotta potrebbe essere venduta dall'AdSPMLO agli stakeholder portuali, costruendo un modello favorevole per tutti i soggetti coinvolti. La parte finale dell'elaborato utilizza di dati di traffico delle navi per valutare il potenziale effetto dell'autoproduzione sulla convenienza in termini di prezzo del servizio di Cold Ironing.

I. Introduction

In the last two centuries, energy consumption has increased according to the need to feed the world's economies, energy is in everything that is used, in itself a service but treated as an economic good. In particular, electricity does not exist in nature, everything that is powered by electricity works through a conversion of energy, from one form to another. The most common way to produce electricity is to burn fossil fuels, coal, or natural gas to power industrial turbines. This process has a problem that is becoming increasingly significant in the 21st century, that is the emission of pollutants. Renewables are not able to satisfy the loads that will continue to increase in the next years, due to the electricity storage, transportation constraints, and the natural sources' instability. Thinking about the contribution that this sector may give to global development; shipping is a key element to ensure the sustainable movement of goods.

To promote sustainable development towards economic growth, the United Nations created the Agenda 2030, a strategy to achieve many different Sustainable Development Goals (SDGs) by 2030. These promote socio-economic development including goals about poverty, climate change, and inequality. Agenda 2030 represents a key element to understanding the development strategy that nations share. If the aim of each goal is different, is important to underline that all the seventeen SDGs deal with energy. No advancements can be carried out without energy. The International Energy Agency (IEA) forecasts a stable energy consumption for European countries in the next thirty years, this ambitious pledge will be fulfilled only if Member States (MS) achieve internal policies in terms of energy efficiency. According to the "The State of European Transport 2024" report of March 2024, the European transport sector has been decarbonizing more than three times slower than the rest of the economy (The State of European Transport 2024). In this context of increasingly integrated globalization, the role of maritime transport is crucial both in terms of energy raw materials transportation and energy consumption by the transport sector itself. According to the European Environmental Agency (EEA), in 2021, the transport sector was responsible for around 24% of total Co2 European emissions (EEA 2022) while road transport covered 72% of the transportation sphere and the shipping sector accounted for 7% of total EU emissions. Due to the ship's capacity, fuel consumption, and high cargo volumes, shipping is the most economical and the most environmentally friendly means of transportation (World Shipping Council, 2024). If the maritime sector way may be seen as feasible thinking about new energy vectors, the remaining part of the intermodal supply chain needs many different efforts to be ready.

Within the maritime sector, cruises stand out because of their carbon footprint-they are very large and extremely energy-intensive ships. The environmental impact of cruise ships is enormous, is estimated by the transport and environment organization that in 2020, cruise ships in Europe polluted more than 4.4 times all the continent's cars (Transport and Environment, 2023). During their routes, ships burn fuel to run their main engine and the auxiliary systems, with a top fuel consumption of 20.000 liters per hour while sailing, which decreases to 2.800-3.000 liters per hour to maintain the auxiliary engines operating while at berth. Cruise ship's impact comes in different ways, setting aside the economic one, the remaining two are social and environmental impacts. Nowadays a percentage of 80% to 90% of the goods traveling worldwide are transported by ship, according to IEA, in 2022 international shipping accounted for about 2% of global energy-related CO2 emissions. This percentage doesn't seem much, but it is slightly less than the total European emissions (IEA, 2022). In line with the Paris Agreement, all the commercial European authorities must provide measures to make the CO2 reduction possible, in this sense, many different normative regulatory bodies are trying to define the proper laws to achieve the SDGs of the Agenda 2030 and the long term zero emission level in 2050. Since the Kyoto Protocol was signed in 1997, the focus on greenhouse Gas (GHG) emissions has been increasing and is now essential. At the European level many regulations have been promulgated in order to reduce emissions, the IMO in this sense took charge even earlier, in 1978 with the promulgation of MARitime POLlution (MARPOL). Subsequently with the various annexes various regulations and indices have been introduced to define and measure the reduction of pollution from ships. The last annex of the MARPOL promoted by IMO was the 6th of 2005. The matter is that every docked ship needs energy, mainly to have electricity and to keep the onboard systems operational. Bulk ships need energy to run their boilers, generate electricity, and make the pumps operational. Nowadays ships burn conventional fuels, mainly HFO and LSFO. Considering only the price of the bunker and the price of electricity coming from the national grid burning ship fuel is more convenient. Moving to a macro perspective this convenience immediately lapses. From a social point of view exploiting fossil fuel and consequently polluting the environment cannot be considered convenient at all, even if the freight prices will rise due to the mandatory cold ironing use. This is why public entities like the European Commission and the IMO are defining measures in order to decrease European emissions. The possibility of the management transition is the most successful one due to the vertical integration of the derived product through innovation processes.

I.1 European Directives

The European Union specifically issued two main regulations that include the shipping sector emissions the FuelEU and the AFIR. According to the AFIR (Alternative Fuels Infrastructure Regulation), by 2030 every Member State is required to offer at a minimum of 90% of the total port calls done by more than 5.000GT the electricity at berth. Since at least two years are required to build a CI infrastructure, from the project to the operating phase, aligning is crucial. One internal constraint according to many European Ports Authorities is how to calculate port calls. The article 9th of the AFIR package doesn't include a common metric to evaluate the number of calls, the main trend is the implementation of software based on AIS (Automatic Identification System) to be able to track marine traffic. According to the International Council on Clean Transport (ICCT) report of 2019, in the EU area, there are 51 ports in 15 different member states that are capable of providing onshore power supply, granting 309 MW of electricity. In this sense, the energy to be installed in ports was estimated by measuring an average of the energy required to satisfy an average number of ships docked at the same time. The ICCT estimates that to achieve the environmental goals the EU should triplicate or quadruplicate the power capacity, it also stresses, the need to include more ships in the regulation, lowering the tonnage threshold to 400GT (ref. Discussion Table ESPO Members May 2024).

The FuelEU package, by the European Commission has been published to accelerate renewable energy projects, through the revision of RED III (Renewable Energy Directive) and to increase the share of renewable energy to 42.5% in 2030. In the transport sector, member states can choose between a binding target of a 14.5 percent reduction in GHG intensity in transport through the use of renewable energy by 2030 or a binding target of a renewable energy share of at least 29% of final energy consumption by 2030.

Many aspects are in between the AFIR and the FuelEU directive, the article 5th supports the AFIR, defining that every ship moored directly fall in the article 9th of the AFIR directive. The way to operate is wide, the main concern of the regulator is to ensure to all the stakeholders a proper management of the transition. Doing that, the discussion table was open to many consultations with the aim of including every stakeholder's category point of view in the discussion. Implementing these directives, the EU has the goal to become more sustainable without limiting economic growth.

The TEN-T network is undergoing development. The acronym stands for EU's trans-European Transport Network Policy, and is a strategic instrument that comes with a specific structure, core network, comprehensive network, and a more recent layer, the extended network. The core is planned to be fully operational in 2030, while the comprehensive will be operational in 2050, and the extended will be an intermediate milestone to complete before 2040 (EU Commission, 2023). On the other reducing GHG emissions by up to 0,4 percent in 2050, it will be crucial to focus on the transportation of large consignments using trains and inland waterways, as well as the implementation of hybrid and electric cars with the highest construction standards regarding emissions and efficiency. The TEN-T turns the spotlight on freight and passenger transport logistics within the European space. Some Italian ports, which perform a key function for the Italian economy, such as the port of Genoa, are called upon to ensure high performance for the successful creation of the TEN-T network.

I.2 Cold Ironing Relevance

Asking for high levels of functioning of the port's infrastructures, one of the main issues is the sustainable development of the port and port areas, many difficulties to be faced by those who manage the port concern bureaucracy (Gervasi 2023). Bureaucratic barriers have a heavy impact on port planning choices. In Italy, planning is done through the *Piano Regolatore Porutale,* (PRP), which is the port master plan, this document contains the port development strategy for the following years. The social, political, and geographical contexts are the main drivers influencing the investments contained in the PRP. The economic and social value of this document is crucial to enable stakeholders to understand how and why the port is moving in a certain direction. Many different efforts in terms of investments can be included in the PRP, and technologies vary according to the strategy adopted by management, for Italian ports, decisions are taken by the *Autorità di Sistema Portuale* (Assoporti 2020) which are Italian port authorities. The main one of these technologies for reducing emissions is cold ironing or onshore power supply. It is a mature technology widely adopted by larger ports, already from Article 4 of Directive 2014/94/EU (European Commission) the European Commission lays the foundations for undertaking the adoption of the CI by ports. Each member state is free to choose how and how to be compliant with the legislation. Some realities, such as the Olso port, have already implemented this technology at full capacity, while others, as in the case of Italian ports, are experiencing a slower process that requires a long development process.

Different studies show that CI is one of the most effective ways to address the environmental and public health problems posed by ship emissions in port areas. Reducing the use of engines during docking helps mitigate the risks associated with air pollution, such as respiratory and cardiovascular diseases, which disproportionately affect communities living near ports (Coppola 2024). In addition, switching to shore power can help port operators comply with increasingly stringent regulations on sulfur content in fuels and emission standards set by organizations such as the IMO. As evidenced by several case studies, the CI significantly reduces the noise generated by ships at the docks with a consequent positive impact on the surrounding environment(G. G. Olszewski 2018), for society, and also for the marine ecosystem.

I.3 Alternative technologies

There are many strategies to enhance maritime decarbonization, those involve different stakeholders and different efforts to be completed. Since emissions come from fossil fuel combustion, the very first reason may be to switch to alternative fuels. This implies the reduction of ship emissions and a number of environmental positive impacts in and around the ports. It is estimated that 70% of ships' emissions occur within 400 km of land (D. Toscano, 2023). As emission gas pollutants, these can be spread over the territory beyond the port. The port macro-impact should include not only port areas, routes, railways, and intermodal nodes but also this extension in terms of pollution and negative externality. For this reason, to reduce port emissions becomes even more important.

Encouraging the use of alternative fuels for ports vehicles and equipment, such as liquefied natural gas (LNG) or hydrogen is fundamental for decarbonization, nevertheless, LNG is not emission-free but it's a feasible way to reduce shipping's impact. At the moment, the maritime decarbonization path through alternative fuels follows three lines: light-weight gasses, heavy-weight gasses, then finally the use of biological and synthetic liquid fuels in the further part of the decarbonization transition. These lines of development envisage possible solutions in the short, medium, and long term. The first line includes the use of LNG because it's a ready and technologically mature solution supported by a growing stakeholder network that makes its use feasible on a large scale.

This category also includes ammonia, which is one of the alternative fuel options. Like LNG, ammonia is a gas that can be stored and transported in liquid form, but has the advantage of not containing carbon, therefore, during combustion, it does not emit CO_2 emissions. Ammonia is already widely used in industries such as agriculture, so it has a certain reliability in terms of existing infrastructures, which are insufficient if you think of it as an alternative on a large scale, this aspect, combined with the high toxicity (H. Jang 2024) of the element, make it an expensive investment to be adopted by ports and shipowners. In 2021, the European Union funded the ENGIMMONIA project aimed at promoting the use of ammonia as a fuel for bunkering and assessing the potential of a range of clean energy solutions, already used on land, and onboard ships. The protagonist of this project is the Rhine-Alps connection which sees the port of Genoa as the protagonist of this project. This project includes many applications such as the study of dual-fuel ships (Katsikas, Serafeim), which will be studied in order to promote the use of ammonia.

Heavy gases, which are the second-line, such as liquefied petroleum gas (LPG), and alcohols have been already tested as ship fuels but those cannot rely on a supporting demand as LNG can. LNG's potential for use is manifold, and it also presents fewer problems than some rival fuels such as hydrogen and ammonia. LNG, unlike hydrogen, does not explode but ignites, to date, the greatest risk for the use of LNG in the naval sector concerns pool fires, caused by cryogenic leaks (Deptken 2024) which have the least risk of occurring. For this reason, shipowners are investing in this solution, as evidenced by the ships' order book.

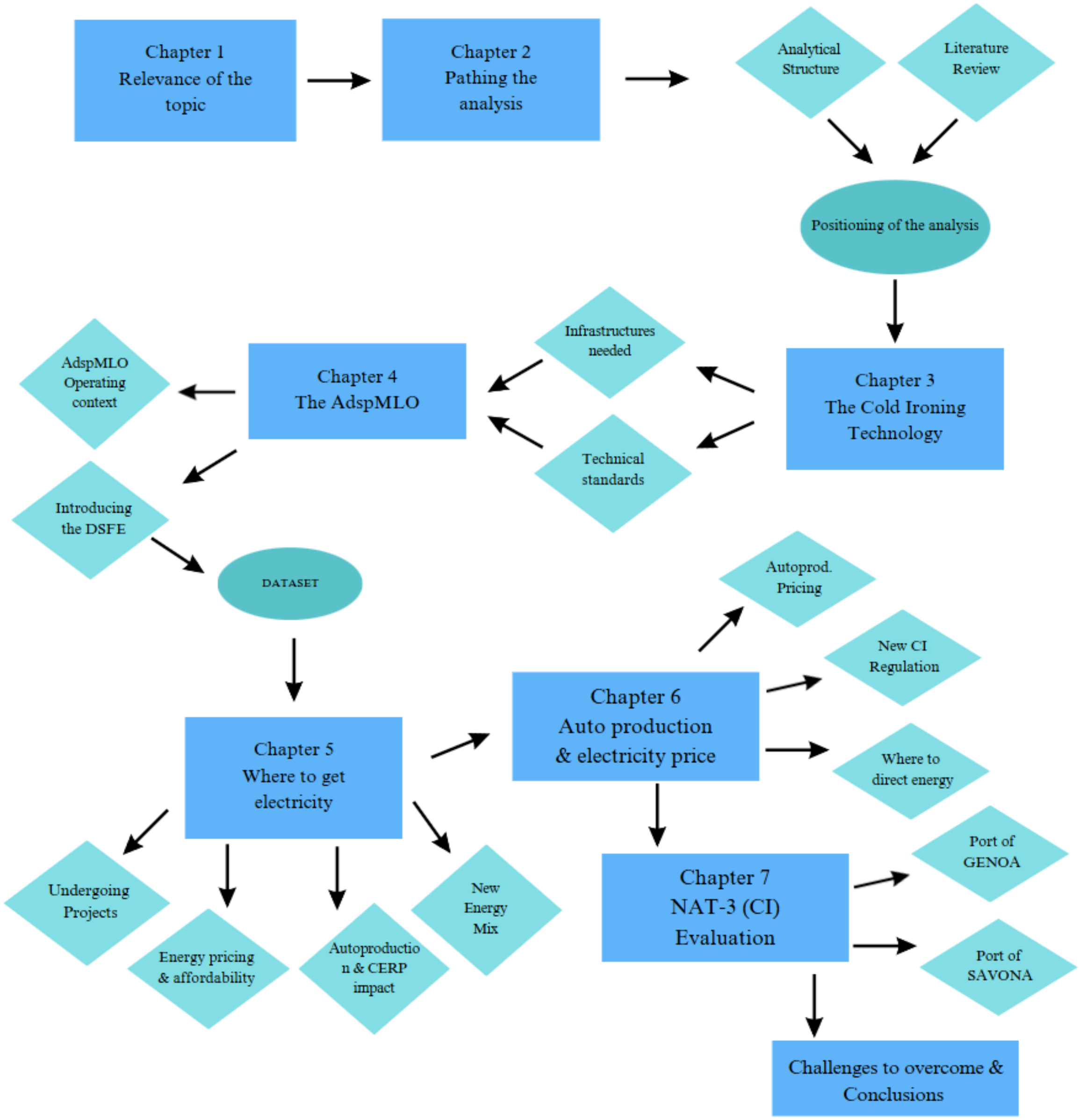
The third line is the most ambitious, carbon-friendly fuels without doubt the most challenging advancement able to reverse the impact of big ships. Moreover, using biofuels contributes to developing a greener economy, finally making the environmental transition a priority also for those who pursue only economic convenience. The main obstacle is the costs related to these elements, the technology and the network's immaturity are reflected in very high prices for those set biofuels outside of the market. The situation in this sense, may vary according to the considered geographical area, there are many countries that are moving differently belong internal strengths and weaknesses in terms of energy vehicles.

Increasing efficiency using the Scrubber system helps also to reduce ship emissions, which are designed to clean exhaust gases and reduce emissions. Around 5% of the global fleet, or 5,000 ships, are equipped with scrubbers, and these ships account for approximately 25% of global heavy fuel oil consumption. (DNV 2022). While new ships use low-sulfur fuels and don't need scrubbers, this technology remains essential for existing ships, especially after the MARPOL law. Another development solution is the SETH system, which captures emissions from ship smokestacks while docked. However, its implementation requires complex infrastructure, making it a transitional technology, similar to LNG, while awaiting more sustainable options

Analyzing what a port can actually do, among the available technologies, the CI turns out to be the most effective. In Italy, the pressure exerted on Port System Authorities is very high, stakeholders are waiting to know which direction in terms of reducing emissions will be taken. For this reason, the attention to the development of port areas is constant, for greater cohesion, national organizations such as Assoporti and international organizations such as ESPO and IAPH are constantly working in order to seek the most optimal solutions. In principle, after a macroscopic analysis of the chosen technology or fuel, each port must come to terms with its own geography, with the means to invest in infrastructure, and with the authorities involved. In general, as analyzed by (Kelmalis 2024), CI aided by the production of electricity from renewable sources or the use of high-energy fuels, would be the ideal solution to contribute to the maximum both on the ship side and on the quay side. This technology is the specific object of this research which aims to investigate the use of cold ironing in the ports of Genoa.

The port of Genoa is the most important port in Italy, this has the highest volume of traffic and has also commissioned the largest project of the Italian PNNR. The various projects related to energy production and energy efficiency of *the Port Authority of the Western Ligurian Sea* (AdSPMLO) lay the foundations for being able to study how an Italian port can achieve sustainable development while maintaining high levels of operation. For this reason, the analysis focuses on the case study of the AdSPMLO which manages the four basins of Genoa, Prà, Savona and Vado Ligure. The particular historical period sees the ports of Genoa evolve giving the opportunity to study how the self-production of energy can influence an innovative context for the realities of Italian ports. In this sense, both technical and economical constraints are analyzed to investigate ports development according to the European regulatory direction.

I.2 The workflow diagram



1 The work flow diagram (Source: Our Elaboration)

The diagram represents the structure of the analysis, it follows the classic scheme that contains the flow of reasoning followed during the drafting of the paper.

I. The first chapter introduces the argument, specifically answering why it was considered relevant to carry out this analysis.

II. The second chapter deepens and contextualizes the analysis, through a review of the literature it was possible to understand the positioning of this research and the most debated paths among the authors.

III. The third chapter deals with offering a complete view of the cold ironing infrastructure, the chapter deals in detail with the standard technology for the construction of a plant of this type.

IV. In the fourth, the case study of this analysis is presented, as addressed in the introduction, it is emphasized that each port has its own internal and contextual characteristics, defined by the macro-environment in which it operates. The data obtained from the DSFE software used to build the empirical analysis of Chapter VI, are also presented.

V. The fifth chapter, directly answers the question "where to get electricity", the issue of satisfying the required consumption calculated by the DSFE software in the previous chapter is addressed. Of particular importance are the issues of smartgrids within port areas and the role of Port Energy Communities (PREC). In this chapter, the current energy mix and the projects being developed concerning the port's energy self-sufficiency are explored.

VI. In the sixth chapter, the economic analysis is carried out to identify the benefits coming from the institution of a PREC. Moreover, the chapter introduced the new regulation proposed about CI Italian regulatory framework. In the last part theoretical price for auto-produced electricity is performed through a scenario analysis made using different levels of auto production.

VII. The final chapter deals with a specific evaluation of the NAT-3 project which is the latest CI investment made by the AdSPMLO. This chapter faces the empirical calculation of how the price of the CI service per berth will be diminished by the auto production share of electricity available.

II. Pathing the Analysis

II.1 Literature Review

The literature focuses on the study of cold ironing by addressing environmental, social, and economic aspects. CI is also often called *Alternative maritime Power, Onshore Power Supply, or Shoreside electricity*. The topic in question is mainly analyzed in two ways, a macro view that encompasses the global fleet and the benefits for the planet, while a second micro view focuses on individual ports or specific routes by analyzing local benefits. The main driver of the literature regarding cold ironing has remained the same over the years, namely its proven environmental benefits (Martínez-López, 2021), (Winkel, 2015). The study of this technology is very extensive, the literature suggests several evidence regarding the benefits of CI, the reduction of CO_2, NO_x, SO_x and PM represents the main strength, followed by the reduction of noise emitted by ships and air quality (Jonson, 2020). In a context in which the maritime transport of goods is constantly growing, with the expectation of increasing its percentage in the coming years, for the regulator it is necessary to develop protocols so that emissions from the shipping sector are reduced.

Some studies underline how the technical-logistical gap is one of the biggest obstacles to overcome, specifically, naval architecture and logistics, or suppliers of engines for ships and the design of port infrastructures (Davarzani, 2019). In general, it is reflected that naval gigantism, both in freight and passenger transport, creates significant barriers to development, especially for second-comer ports. Large ships need deep water and plenty of space for maneuvering, which is not always possible to guarantee, especially in city ports (Haralambides, 2021). If on the one hand naval gigantism reduces costs for shipowners, on the other hand, it reverses them on port infrastructures (CargoExchange, 2022). From this scenario, it is possible that only the most important ports will be able to keep up with the enlargement of ships and their consequent consumption of energy and pollution.

Another aspect on which the literature focuses concerns the difference between the objectives set by governments and the efforts actually put in place by ports. (Iris, 2019). Some of the ambitious goals set by the 2030 Agenda in terms of energy efficiency and pollution reduction are not reflected in the operational and logistical difficulty of an infrastructure such as a port (Diniz, 2024), this is why the simplification of legislation and the support of national regulatory bodies is vital. If it is true that regulation is fundamental, the initiative of individual ports is no less, a good example is represented by the MAGPIE project of the Port of Rotterdam, which involves the study of ten pilot projects aimed at verifying their applicability on a large scale, these are tests in order to innovate the port areas of Northern Europe (Flikkema, 2023). Similarly, the PIONEERS project led by the Port of Antwerp-Bruges aims to succeed in effectively reducing the environmental impact of ports (Pioneers-ports.eu, 2024). Both projects were funded through the Horizon 2020 project, a European Union funding program, now replaced by Horizon Europe 2021-2027. There is no coincidence that both projects are led by ports in northern Europe, the literature underlines a situation of gap between the ports of northern and southern Europe (Bouazza, 2024). Italian, Spanish and French ports, for example, have much more cruise ship-focused traffic while northern European ports work mainly with commercial cargo.

Given the size of ships and port infrastructure, which are labor-intensive, and the proximity if not total integration of ports with cities, reducing the pollution that arises from a port is considered a public utility. Evidence shows that citizens are the real beneficiaries of the CI service (Peddi K. P., 2024). Studies in this sense deepen the issue, also considering methods to reduce the environmental impact even at sea (Dong, 2020), mainly through alternative fuels and on-board energy production through wind turbines and solar panels. If the CI system is used, it guarantees a reduction in emissions with the consequent benefits, however, it must be emphasized that the precise percentage of reduction and therefore of the associated benefit depends on the emission factor of the auxiliary engines and the structure of how the energy is supplied. Studies delve into the use of decentralized production and renewable electricity production systems (Liu, 2023), therefore, another line of study focuses on how to provide energy in the most *environmentally friendly* way possible. This approach includes reasoning regarding the difference between the characteristics of the plants, renewable sources usually produce electricity in DC, while the electricity from the national grid and ships is in AC with a well-defined frequency. Many ports and terminals are looking to improve energy efficiency due to rising energy prices over the years and climate change, which has become a key focus for the port industry (Iris, 2019). This growing attention is due in part to the need for ports to evolve in the sense of green ports (Zhang, 2024). Efficiency calls directly to digitalization and data collection, the availability of data is the first instrument to monitor properly and start the path toward an efficiency incremental process.

II.2 Research Objectives

In this context, this thesis aims to study the current context of the Cold Ironing (CI) system in the Ports of Genoa by investigating the already installed systems and studying the economic and social feasibility, the investments needed, and the efficiency to introduce smart grid and decentralized generation. The role of port energy communities (PREC) in the creation of a smart grid is also explored, as has already happened in the port of Savona. The implementation of new components inside of the grid has to be evaluated by different aspects considering technical, economic, and socio-environmental analysis. The whole system can be considered feasible only if it will be exploited by stakeholders. Moreover, the economic analysis is based on energy prices and self-consumption studying the port authority as a prosumer. In this sense, the role of data collection and digitization will also be addressed in the conduct of the analysis.

The best way for the port of Genoa to evolve into an innovative green port is to ensure a large amount of self-generation of energy. Specifically, the analysis investigates how and how much energy can be produced from renewable sources within the port areas. The direct link between auto production and self-consumption appears to be the key to achieving the ecological transition. In this context, the design of the new dam in Genoa is crucial to exploit the possibility of generating electricity from wave power. The analysis concludes with an empirical evaluation of the electricity price that the AdSPMLO could sell to the final customers of the CI service which are ship owners. An energy cost price is estimated to reflect production capacity and investment. Lastly, an empirical analysis is carried out to exemplify how self-handling can become the key to getting the CI to be used by the ships at berth.

III. Cold ironing technology

The cold ironing (CI) or onshore power system (OPS) or Alternative Power Supply (APS) is a technology that allows to supply of electricity to a ship at berth. It is a key element not only for the energy transition but also for the consequences that it brings out. The CI is a system with different components, from the grid to onboard systems the electricity has to flow in heavy cables that end with an iron plug usually moved using a crane. In 2004, China Shipping's container ships in Los Angeles were among the early adopters of cold ironing (ENVIRON, 2004), plugging into a dedicated port barge near the berth. The goal is to improve air quality near ports and reduce carbon emissions, contributing to a greener shipping industry. In the port area, ships that are ready to use the cold ironing service are no less than 10% percent of the total (ESPO data form working, 2024), the largest percentage and represents cruise ships, in second place container ships, and in third place Ro-Ro ferries. The last ship generation comes with the predisposition to host the plug and exploit the grid power during the berth stationing while the old ones have to be retrofitted. The cost to update the onboard systems has been esteemed by the American Association of Port Authorities which calculated a value between \$300.000 and \$2.000.000 while some estimations are between \$300.000 and \$1.500.000 (Wang, A bilevel hybrid economic approach for optimal deployment of onshore power supply in maritime ports, 2021). This expense may vary according to the ships' characteristics.

The first element of differentiation concerns the frequency of the electricity supplied, most ships use 60 Hz systems while the other part, numerically relevant, is at 50 Hz. For this reason, an upstream transformer is needed to modify the frequency of the current coming from the national grid, it is also necessary to implement a downstream frequency transformer to have the possibility of changing the frequency as needed. The on-board systems, therefore, operate in alternating current AC, as well as the electricity supplied by the national grid, the AC allows for simpler management as well as the possibility of transporting electricity over long distances more efficiently (Kozak, 2020). Thinking about a port and its definition of *a smart port*, the integration between systems operating different technologies means that DC current must also be taken into account.

Electricity generators that use renewable energy, such as solar panels, operate in direct current and require a transformer, while wind turbines and hydroelectric power plants, which in Italy represent the largest source of production from RES, often already include one within their schemes. Several devices as well as many electric vehicles use direct current for their operation, defining a complex and integrated system it is necessary to ensure that each internal operation can be properly powered ensuring the security of energy demand within the port. (AC-DC)

A circuit is essentially made of an electrical generator and an electrical consumer, who has a load to be fed, put together by an electrical connection. This theoretical structure declines rapidly when reality constraints are included. The structure of an electrical grid is much more complex, as first transformers are needed, which are static electrical machinery able to change, with high efficiency, the voltage and the current of the incoming electricity (Peddi, 2024). Matching the specific voltage and current required by the system's hardware is fundamental, every machine is designed to work with specific electrical characteristics. If there is a mismatch between hardware operative specifics and the electricity provided, machines may work unproperly representing a serious risk in terms of unpredictable functioning. Moreover, if there is a mismatch, permanent damage to the device can occur, followed by an electrical fire hazard (IEEE, Cold Ironing Power System design and electrical safety, 2012). Even if there are no major problems, the difference in compatibility in terms of current and voltage translates into a loss of efficiency with a consequent increase in the energy consumption required to do the same job. It is clear, in fact, the presence of different hardware with a specific purpose, their totality makes up the complete scheme of the CI service which can be divided into three different parts: systems of the national electricity grid, systems on the quay and systems on board. Due to the technical differences and the port's specific constraints, there are many different solutions to install a CI system.

III.1 Technology Required

Listing the usual required hardware is useful to have a theoretical benchmark to better understand the structure of specific case studies' systems structures.

For the port side (Sciutto, 2021) :

1. Medium voltage national grid connection cabin or transformer substation

2. Connected to the high-voltage grid;
3. Medium-voltage cable distribution within the port area;
4. Conversion substation 50 Hz / 60 Hz;
5. Distribution to ship connection points;
6. Ship connection system;
7. Ship connection and interface switchboard;
8. On-board MV/LV transformer;
9. Ship distribution network.

Starting from the national electricity grid, the first fundamental element is the primary substation that reduces the voltage of the electricity supplied. The substation has the fundamental purpose of passing electricity from high to medium voltage and then transmitting it to users. From the national electricity grid, the first fundamental element is the primary substation that reduces the voltage of the electricity supplied. Primary substations in Europe convert high-voltage electricity up to 220kV into a voltage between 1 and 35kV. The secondary substations, on the other hand, are responsible for further reducing electricity by switching electricity from medium to low voltage (<1kV). The secondary substation is inside or at least very close to port areas. The energy is thus distributed widely, in this case, a direct connection with the CI infrastructure is provided, which requires higher voltages than usual consumption points as an office, for example. The transformer near the docks has the task of regulating voltage and frequency to meet the needs of the docked ship. The dependent CI system can be categorized as low or high voltage depending on the specifications of the power supplied. The so-called low voltage systems are the first generation, the first installations date back to the early 2000s, the low voltage supply connection (LVSC) provides energy in a range from 400 to 680 V. The low-voltage wiring requires more cables, this is because Ohm's law establishes that to maintain the same power output, as the voltage decreases, it is necessary to increase the current, having the cables a limit regarding the current that can be transported, is necessary to use several of them to ensure that the service works. On the contrary, the cold ironing service intended for High Voltage Supply Connection (HVSC) operates between 6.6 and 11 kV, guaranteeing a much higher voltage, and allowing the installation of one or two cables. The most effective solution is the installation of HVSC systems accompanied by a transformer capable of modifying the voltage of the current supplied according to the vessel to be powered. The cables are physically housed by a CMS or CMSS (Cable Management System) that is used to move them (IEEE, 2014). These systems, comparable to small cranes, are able to lift and carry the cables up to the host socket on board the ship. The conformation of cables may not seem as fundamental an issue as energy production, but this becomes very relevant in a context such as the operation of a port where the time it takes for a ship to connect to the electricity supply if too long due to the multitude of connections to be made, it would be unacceptable.

With a view to building a common service to the fleet of commercial vessels, it was necessary to define standards for the configuration of systems and procedures. In the context of international ports, only the compliance of these systems in ports can guarantee their use in the long term.

III.2 Safety Standards

The construction of infrastructures for the provision of the service is a significant source of risk, although the processes and components are mostly standardized, the addition of new hardware in which high-voltage energy passes can generate dangers. First of all, there is the danger of electrocution, i.e. the possibility that a worker will be electrocuted by coming into direct contact with electricity. Secondly, the risk of fire is also not negligible, large electrical components tend to overheat during the passage of energy, especially if there is an overload, i.e. if the input current exceeds the capacity of the cable or transformer (Paul & Haddadian, 2005). Energy losses can also be a source of heat as the electricity released translates into heat emitted by the apparatus. The BESS (Battery Energy Storage System), for example, and the transformers provide a fan system for heat dissipation that can sometimes be insufficient, especially in summer with high temperatures. For this reason, the issue of prevention and training is of vital importance, from the substation of the national network to the ship it is necessary to map the possible sources of risk and the possibility of a problem occurring. It is, therefore, necessary to develop internal and effective protocols to manage dangerous situations, both on the ship side and on the quayside. The dangers generated by the consumption of fossil fuel by ships at the quay mainly concern fuel spills that could cause fires and explosions, while the use of batteries and electricity supply systems can also catch fire. CI in this sense can be seen as more dangerous, not so much because it is actually dangerous but because it is less technologically mature than the burning of fossil fuels; therefore, it requires the creation of ad hoc protocols and standards. Recently it has developed into the concept of resilience in the field of engineering, *"a resilient system is that system that maintains the desired performance even following a large fluctuation in the ability of components to operate."* (T. Vairo, 2024). This definition makes clear that, in order to move towards a safer future, it is necessary to design systems that can operate with a greater safety margin, i.e. that do not see an exponential increase in the possibility of a danger from the malfunction of a component. In this sense, ESPO believes that it is necessary to align the obligations of port authorities with the obligations of shipping companies in order to incentivize this service.

It is possible to identify three different standard categories, which have been issued by the following regulatory bodies: IEC (International Electrotechnical Commission), IEEE (Institute of Electrical and Electronics Engineers), and ISO (International Organization of Standards). These are common and at the same time specific according to the shipping category, for instance, tankers need specific safety standards due to their operational aim, at the same time cruise ships, which have the most important load compared with the other ships categories, will need different cables and sockets. The regulatory framework is highly standardized, ensuring the right functioning of the system, in the right context, the CI system will be a pivotal service to decarbonize ports.

The figure III.1 shows the standards defined in 2022, these are fundamental, as highlighted above, a second piece of information that can be drawn is the lack of standards in other fundamental phases that crown the cold ironing service and the energy produced within the port.

Figure III.1 Standard for maritime electrical connection

SSE Type		Interconnectivity	Interoperability	Data Communication	International/EU Regulatory
OPS (Onshore Power Supply)	High-Voltage Shore Connection (**HVSC**)	IEC 62613-1:2016 (General) IEC 62613-2:2016 (Connector geometry/ dimensions)	IEC/IEEE 80005-1 (HVSC) Mandatory in EU	IEC/IEEE 80005-2 (Data Communication)	IMO OPS Guidelines EU AFID
	Low-Voltage Shore Connection (**LVSC**)	IEC 60309-5	IEC/IEEE 80005-3 (under review/development)	IEC/IEEE 80005-2	IMO OPS Guidelines already refer
	LVSC – Inland Waterways (IW)	EN 15869-2:2019 (up 125A) EN 16840: 2017 (above 250A)		Possible application of IEC/IEEE 80005-2	CCNR CESNI – ES-TRIN2019
	Recreational Craft/ Marinas For charging eg. overnight, or OPS	IEC 60309-2	Not standardized	Not standardized	Not relevant international standard applicable to
SBC (Shore-side Battery Charging)	SBC-AC (AC charging)	IEC 60309-5/ IEC 62613-2 AC connection (As standard OPS connectivity)	IEC/IEEE 80005 series As OPS – ship-side charging.	Not standardized (possible development/ applicability for IEC/IEEE 80005-2 or ISO15118) for connections EV-station	No applicable international regulatory instrument applicable to SBC
	SBC-DC (DC Charging)	Not standardized EV's CCS-2 for fast charging of recreational craft; upcoming MCS CharIN	Not standardized		

(Reference: ESMA,2022)

The cost of implementing this technology can be divided into two different categories, the investments aimed at building the infrastructure and the investments necessary to manage the Cold Ironing network and service. IAPH (International Association of Ports and Harbour) in the World Port Sustainability Program has estimated for European ports the cost of the cold ironing system ranging from $300,000 to $4,000,000 per port depending on the type of installation and system needed (WPSP, 2024), while an OPEX of 12% per year is also estimated by researchers (Wang, 2021).

III.3 Barriers to the development of cold ironing system

Economic barriers to the implementation of the cold ironing service include the high cost of infrastructure and operations, the long return on investment for ship refurbishment, increased operating costs due to the cost of electricity, and frequency and voltage system management. In addition, the effectiveness of the total emission reduction is not applicable in all modes of ship operation since some types of ships such as, for example, oil tankers require the operation of the boiler on board to operate the pumping system, so as not to let the fuel cool excessively. In Italy, the legislation regarding incentives will guarantee a discount for ships using the service, as will be discussed in more detail in Chapter V, a specific measure is not yet envisaged, this constitutes uncertainty that represents the biggest obstacle for both public and private stakeholders. The regulatory framework is crucial for CI efficacy, in Italy, different public entities have spread competencies about territory, environment, and berth competence. National laws mismatch with the limited possibility for a single public entity to carry out a project. Coordination among public entities, including energy regulators, is necessary, but not always easy, which increases the efforts to complete an infrastructure and to make a service as CI operational.

Focusing instead on the technical aspects, the greatest difficulties arise from the standardization and structure of the plant and the management of the service with regard to the connection of the ship to the shore network. The use of cold ironing obviously guarantees some environmental benefits while on the other hand, if not explicitly designed to run on renewable energy, it cannot guarantee to have only positive implications for the environment. In general, the legislation proposed by Europe is not yet sufficient to give the right support for the widespread dissemination of the service, if the privilege to choose the method of implementation of the legislation by the member states represents freedom, on the other hand, it creates uncertainty that slows down the innovation process. Some international boards held mainly by the ESPO and the IMO work jointly with the different stakeholders to create unity and confrontation for the parties involved. Pursuing the objective of sustainable port development is only possible through integrated collaboration between the stakeholders of the supply chain (Le, 2024). In addition to the technical factors of energy supply and the environmental benefits of using CI, some psychological decision-making factors can also slow down the process of change. Shipowners often see the cold ironing service as an expense, because it is ancillary and new, they do not consider the cost of fuel as it has already happened previously (bunkering has already been done when the ship moors), while the electricity "bill" of the CI service arrives later and is therefore perceived as a cost, even if the amount is lower than the figurative consumption of fuel. The cash-out generated by the CI is less eligible than a higher expenditure on fuel consumption. This is part of the problems of path dependency and the acceptability of innovation.

III.4 Best Practices

Several ports worldwide have successfully implemented Cold Ironing, offering valuable reference models and best practices. The Port of Los Angeles, which is the pioneer of this technology, has significantly reduced emissions through its extensive use of CI. The port's success is attributed to robust stakeholder collaboration, comprehensive regulatory frameworks, and substantial infrastructure investment. Los Angeles integrates CI with other green initiatives, maintaining continuous stakeholder engagement and leveraging public-private partnerships for funding (Journal, 2009). In this sense, the US government has been much more effective than the EU Commission in ensuring the economic basics to make this service possible.

One of the most crucial aspects of successful Cold Ironing implementation is robust stakeholder collaboration. Engaging all relevant parties, including port authorities, shipping companies, utility providers, and regulatory bodies, ensures that all perspectives and requirements are considered. For example, in the Port of Gothenburg, continuous dialogue with environmental organizations and the local community has been instrumental in gaining public support and ensuring transparency (PortofScandinavia, 2023). Regular stakeholder meetings and collaborative planning sessions help align objectives and streamline the implementation process establishing comprehensive regulatory frameworks is vital for the effective deployment of Cold Ironing systems. These frameworks should address safety standards, operational protocols, and environmental regulations.

Significant investment in infrastructure is necessary for the successful installation of CI systems, such as the development of high-capacity electrical grids, installation of shore power connections at multiple berths, and upgrading existing port facilities. Investments should also cover the integration of renewable energy sources to further enhance environmental benefits. The inclusion of renewable energy is fundamental for the healthy evolution of the port. The main problems are the costs that arise from the transition. In the context of the port, it is not always clear who bears the costs. Implementing advanced technological solutions is another best practice for Cold Ironing installation. This includes the use of smart grids, real-time monitoring systems, and automated control systems to optimize energy use and ensure reliability. These technologies not only improve operational efficiency but also help in achieving sustainability goals. Integrating CI with broader energy and sustainability initiatives enhances the overall environmental impact. Ports should align CI projects with other green initiatives such as the use of renewable energy, energy efficiency measures, and carbon offset programs. The Port of Rotterdam, for instance, incorporates Cold Ironing into its broader strategy to become a carbon-neutral port by 2050, ensuring that all sustainability efforts are synergistic (RotterdamAnnualReport, 2021). This integrated approach maximizes environmental benefits and supports long-term sustainability goals. The visionary

Offering financial incentives and developing innovative funding mechanisms are essential for encouraging the adoption of Cold Ironing. Ports can provide reduced fees or subsidies for shipping companies that utilize shore power. The Port of Hamburg has implemented a fee reduction program for vessels that use Cold Ironing, making it financially attractive for shipping companies to switch to shore power (PortOfHamburg, 2021). Additionally, leveraging public-private partnerships can secure the necessary funding for large-scale infrastructure projects. Since the purpose of this research is to investigate the economic sustainability of the cold ironing service in the port of Genoa, different aspects will be analyzed, using first and foremost best practices already explored by other EU ports. Referring to systems that will then be used and monitored by experienced employees, it is necessary to provide effective training and capacity building for port staff and shipping crews are critical to the successful implementation and operation of CI systems. Comprehensive training programs should cover technical aspects, safety procedures, and operational protocols.

III.5 Stakeholders involved in the project

The large-scale implementation of CI is complex and requires the collaboration of different stakeholders. The Port Authorities (PAs) manage port infrastructure ensuring regulatory compliance and coordinating with other stakeholders to facilitate the installation and integration of CI systems. PAs work with other port users to effectively locate and integrate a CI system. In Europe, CI efforts have been initiated by PAs like Hamburg and Gothenburg, which have adopted stringent environmental practices leading to significant investment in the infrastructure to cut emissions. North American ports are the first comers, leading the way along the Pacific and Atlantic coastlines. Some states, including Massachusetts, New Jersey, and Virginia, have already implemented statewide programs as authorities migrate toward the Emission Control Area (ECA) (Zis, 2019).

Italian ports are also moving forward. Even though initiatives like Genoa, Venice, and Civitavecchia are currently in operation, some harmful regulatory fragments sometimes become an obstacle. The shipping companies Maersk and MSC are also at the forefront of the initiative and are making a concerted effort to reduce emissions. The position of ship owners with regard to the CI is uncertain; all agree on the environmental benefits, but they are unwilling to achieve them if they face an economic loss. In Northern Europe, which hosts the most advanced ports on this topic, network operators, and electricity companies in Sweden and in Germany are collaborating with ports to develop convenient cold iron structures. In northern Europe, ports have more freedom, they operate as independent companies, and this structure makes it easier for them to allocate strategic resources and create effective partnerships.

The aspect of legal and financial support from European and national organizations such as the European Environmental Bureau (EEB) and the Italian Legambiente (as example), is crucial. These organizations are very active in promoting cold ironing because of its social value. In every port, one of the most important stakeholders is represented by local communities that not only get cleaner air but also a reduction in noise levels. The most important aspect of implementation is defined by the degree to which the conditions for cold ironing are available. This comes from the local communities and the speed with which leaders or stakeholders are willing to implement specific projects.

III.6 System development

To implement a CI system, it's necessary to follow many critical phases. As first, the process begins with a feasibility study, assessing the technical and economic viability of the project for a specific port. According to EU directives, projects for new infrastructure, especially if financed with EU funds, require a social and environmental impact assessment (EU-Lex, 2014). Once the feasibility is confirmed, the design and planning phase commences, involving detailed engineering of the CI system, including electrical infrastructure and safety measures. This phase requires close collaboration between port authorities, shipping companies, and engineers to ensure the system meets all technical and regulatory requirements. Obtaining regulatory approval is the next crucial step, which involves securing necessary permits and ensuring compliance with relevant regulations to guarantee the system's safety, reliability, and environmental benefits. Regulatory bodies such as the IMO and local environmental agencies, in Italy PAs, and *Capitanerie di Porto*, play significant roles in this phase. Then there is the infrastructure development phase, involving the construction and installation of the required equipment and systems. This includes building power supply systems, installing connection points, and integrating monitoring and control systems. Usually, these processes are procured by external companies with specialized conductors and installations. Before the system becomes operational, it will be tested multiple times in different conditions, ensuring the correct functioning, according to the concept of operational resilience.

IV. The context of Ports of Genoa

The Ports of Genoa, which include terminals in Genoa, Prà, Savona, and Vado Ligure basins, represent a crucial logistics hub in the Mediterranean Sea. Liguria benefits from a strategic geographic location at the most northern point of the Mediterranean Sea, providing optimal access routes to continental Europe. Specifically with respect to the Rhine-Alpine link, for which the construction of the third pass is underway, which is a strategic infrastructure that will allow goods to reach the central European regions quickly, respecting the objectives of the TEN-T network. The physical and morphological structure of the area includes wide quays that extend along 22 kilometers of coastline (AdSP, 2021) integrating a dense network of both domestic and foreign connections. Vado Ligure has evolved significantly since the 1960s, featuring deep natural harbours and extensive hinterland connections. This port specializes in container and passenger traffic and holds a Mediterranean leadership position in fruit cargoes. The multipurpose platform in Vado Ligure, developed in partnership with the global shipping giant Maersk, underscores the strategic importance of the Ports of Genoa. The port of Savona is characterized by a mix of commercial, industrial, and tourism activities. It appears to be slightly less integrated with the city than the port of Genoa, which has a distinctive conformation. It includes areas dedicated to ship repair, terminal operations, and a cruise terminal that supports the local economy through tourism. The prospect of new infrastructure developments will improve the port's capabilities, integrating it closely with the logistics needs of northern Italy and the wider Mediterranean region.

As introduced above, the port of Genoa has a particular geographic structure, and the limited space availability of the Liguria region greatly complicates the planning and installation of new infrastructure. The following figure (IV.1) makes explicit the national power grid connections in the territory between Savona and Genoa. The port finds itself operating in this context where small spaces impose a pronounced efficiency of the energy facilities.

Figure IV.1 Electricity grid between Genoa and Savona

Source: (AdSPMLO, 2022)

Concerning the new efforts that the AdSPMLO has already put in place, several investments underline that energy transition is a priority for the port. Below, the table shows the most relevant strategic investments.

The fundamental tool for planning port development is the Port Master Plan (PRP). It is a strategic document that determines how the port will be managed in the following years. Each port authority (PA) is required to produce a PRP to effectively define and communicate the management's intentions regarding the port's development. Currently, Ports of Genoa is developing a new master plan that will see the light of day in the second half of 2024. Each PA is required to produce a PRP to effectively define and communicate the management's intentions regarding the port's development. The development of the PRP involves many different consultations with stakeholders, including local and regional authorities, environmental organizations, industry representatives, and the public. The plan also has a considerable political resonance as it defines the strategic objectives that the port will pursue in the coming period.

Table IV.2 Electrical development project status

Project Location	Description of Investment	Status
Area Bacini e Riparazioni Navali (Genova)	Electrification of dry docks and ship repair areas; construction of the electrical distribution system, including a 50/60 Hz frequency converter	Completed
Porto di Prà	Electrification of the container terminal; installation of shore power connections and upgrades to the electrical infrastructure	Ongoing
Piattaforma Maersk (Vado Ligure)	Installation of a new high-voltage substation, electrification of the terminal, and ensuring redundancy in power supply	Ongoing
Terminal Crociere e Traghetti (Savona/Genova)	Study and extension of cold ironing capabilities to the cruise and ferry terminals, including infrastructural upgrades and shore power installations	Ongoing
Bacini di Carenaggio (Genova)	Installation of a high-capacity frequency converter to provide 60 Hz power to docked ships; implementation of innovative power distribution solutions	Completed
Submarine Cable (Riparazioni Navali)	Laying a submarine cable for power distribution to the ship repair area; integration with high-voltage safety systems and protections	Ongoing

Source: DEASP ADSPMLO[1]

The fundamental tool for planning port development is the Port Master Plan (PRP). It is a strategic document that determines how the port will be managed in the following years. Each port authority is required to produce a PRP to effectively define and communicate the management's intentions regarding the port's development. Currently, the AdSPMLO is developing a new master plan that will see the light of day in the second half of 2024. Each PA is required to produce a PRP to effectively define and communicate the management's intentions regarding the port's investments. The development of the PRP involves many different consultations with stakeholders, including local and regional authorities, environmental organizations, industry representatives, and the public. The plan also has a considerable political resonance as it defines the strategic objectives that the port will pursue in the coming period.

Looking at a comparison within Italy, the numbers for the Ligurian Ports take on a different value, ranking Genoa as Italy's most important port. In general, cold ironing in Italy is present but to a very small extent, and if it is true that Italian ports have experienced a less exponential evolution than foreign ones, it is also true that they have had more time as they have had longer longevity to develop adequate protocols. The ports of Genoa, in the position in which they are located, can effectively represent a national reference for new technologies regarding electrification and energy efficiency, which is one of the missions of AdSPMLO.

The most important work for the change of the port of Genoa concerns the new dam that will be completed by 2026. The new dam will allow the most modern large ships to enter the port and use port services. Specifically, more room for manoeuvre will be created that will allow World Class cruises and the most modern cargo ships of more than 400 meters to transit more safely (AdSPMLO, 2022). The AdSPMLO seeks to exploit the strategic and geographical role of the port of Genoa by strengthening the port. As will be addressed later in the analysis, the new dam project opens the door to a bright future for the port which will have the tools to become a green port in all respects, allowing the port of Genoa to reduce its emissions.

The first step in making advances in terms of decreasing emissions is to have a clear idea of the current situation. The DataCH Software is a clear example of the role that digitalization has in the energy transition. There is a huge link between digitalization and energy consumption, nowadays there are many digital solutions able to facilitate data acquisition. Smart meters are an example, the potentiality to have an interconnected system able to rely on real-time data is huge in terms of efficiency. All modern applications of the ports of the future concern the availability of data and the ability to store and manage it properly.

IV.1 The Dataset: DSFE

The DataCH Ship Footprint Evaluator (DSFE) software was used to conduct this analysis; the program is capable of real-time monitoring of emissions from ships calling at ports. The DSFE software was created in the first instance for monitoring waste disposal by ships. It is based on the platform created by the company DataCH, which uses the automatic identification system (AIS) to monitor the ship's position every 15 minutes combined with the IHS Markit ships database. To acquire data, the software receives data from the Maritime Information System (MIS) which is a platform created by DataCH that collects data from many Italian ports. DFSE collects and elaborates data storing it in different categories dividing it into different steps and acquiring these data:

- Departure coordinates
- Arrival coordinates
- Average speed (in knot)
- Type of operation (berthing, anchoring…)
- Type of operational phase (transit or manoeuvring)
- Estimated energy consumption for main engines ($Energy_{ime}$)
- Estimated energy consumption for auxiliary engines ($Energy_{iae}$)
- Estimated energy consumption for auxiliary boilers ($Energy_{iab}$)

Through the data received, the system is able to accurately estimate the emissions of ships, having inside also the data of engines and auxiliary systems, how much they consume and how much they emit in terms of CO_2, CH_4, $N2O$, HFC, NO_x, NMVOC (non-methane volatile organic compounds), PM (particulate matter), and SO_2. These data make it possible to estimate ship emissions considering their cargo and transit within port areas, from roadstead(/anchoring) to port exit. The methodology used was defined according to European guidelines, including IMO guidance incorporated into the formula developed by the University of Pisa. Marine Environmental Protection Committee (MEPC) guidelines to calculate the Energy Efficiency Design Index (EEDI) are also included in the methodology.

Mathematically, the following formula is executed:

For main engines:

$$Energy_{me} = (MRC_{me} \text{ x } Load_i) \text{ x } Activity_i$$

Where:

- MRC_{me}= maximum energy of main engines in Kw/h (source IHS Markit)
- $Load_i$ = (SpeedActual / SpeedMaximum)3
- SpeedActual = average speed in the step (e.g., 15-minute step)
- SpeedMaxim= maximum speed of the ship (source IHS Markit)
- $Activity_i$= time in hours = (example 15-minute step = 0.25 h)

While for auxiliary engines is:

$$Energy_{me} = (MRC_{ae} \text{ x } Load_i) \text{ x } Activity_i$$

Where:

- MRC_{ae}= maximum power output of auxiliary motors
- $Load_i$ = load factor in the various operating phases as reported in the study conducted by Entec UK Ltd for the European Commission
- $Activity_i$ = time in hours = (example 15 minutes = 0.25 h) The System can be defined as monitoring ship activity.

To calculate energy consumption, the following assumptions are considered to estimate loads. In the following operational phases engine types are matched scoring different capacity loads according to ships' activity. Table IV.2 expresses the load coefficients used in the DSFE methodology.

Table IV.3 DSFE Load Coefficients

Loads Estimation Coefficients	% load of MCR	% of the time all MEs operating	% of electric power from shaft generators	% load of MCR for AE operation
At sea	80	100	50	30
In port (+pumps for tankers)	20	100	0	60
In port	20	5	0	40
Manoeuvring	20	100	0	50

Reference: DSFE internal document

If data from IHS Markit are not available, DSFE estimates energy consumption using pre-defined table coefficients to measure loads. To measure ships' emissions, the IMO toolkit's emission factors are used to calculate the quantity produced for each different pollutant. IMO's tables refer to HFO with 2,7% sulfur content, considering also the inclusion in the evaluation of the ship's years of service and allowing those using the database to change the emission evaluation factors.[2] This analysis uses a database of one year, from the entry into the use of the software in March 2023, to one year later i.e., April 2024. This period represents the database used for the analysis.

The data show that 8.070 transits were recorded within the port of Genoa and 1.773 in the port of Savona during the period under consideration. Main engine consumption, auxiliary engine consumption, and boiler consumption are reported. Not all types of ships operate in the same way, for example, as visible in the table, Ro-Ro freighters do not use the boiler while 10% of the energy consumption of container ships is attributable precisely to the boiler system. The whole energy required in the twelve months amounts to a heavy total of 673.826 MW considering all the 8.070 calls. The sum of the energy consumption underlines that 85% of the total energy load is represented by the auxiliary engine. This data evidence the coherence between the energy consumption and the ship's activity, since

[2] Datach ship footprint evaluator technical sheet cod. Dsfe.001 (internal document)

berthed ships usually switch off their main engine to run the auxiliary one. The electricity generated onboard is created using auxiliary engines, also known as generators. The main load for a ship is the hotelling service, this is even more substantial for cruise ships. To satisfy this load at berth, while the main engine is switched off, auxiliary engines burn fuel, usually diesel, to maintain the ship operational.

The 7,8% is consumed by the main engine, most ships have a two-stroke marine oil engine usually able to power s containership up to 25 knots. Ships' engines are not as usual as the car ones, while the average power for cars is around 100 cv, a ship's engine may reach 100.000 cv. This power is needed to transfer motion to the drive shaft, which in turn turns the propeller, which rotates on average between 200 and 500 rpm. It is also important to underline that burning fuel, usually marine oil to run a ship, is not so efficient. Almost 51% of the fuel energy burned is dissipated as heat (Sellers, 2017). The majority of this thermal energy, approximately 26%, is lost in the exhaust gas. This can be translated into several losses and inefficiencies by ship energy management. Several ships utilize waste heat recovery (WHR) boilers to generate steam from the high-temperature exhaust gas and scavenged air. This steam can be integrated with a steam turbine to establish a Steam Rankine Cycle (SRC), which generates usable electricity. These systems are capable of converting thermal energy into electricity with a decent efficiency of around 20%. However, sources with lower temperatures, such as the engine jacket water ranging from 80°C to 95°C, are not sufficiently hot to efficiently operate an SRC. The boiler's energy consumption counted slightly less than the main engine's scoring a 7,4%. is a power plant installed in the ship that can produce large amounts of energy exploiting steam compression, it is necessary to warm fuel to increment its viscosity, to produce hot water, and it is fundamental to run pumps for tankers to charge and discharge the load.

Looking at the port aggregated data concerning the emission calculated as CO_2 Equivalent, berthed ships in the ports of Genoa and Prà, recorded for 483.948 CO_2 EqTon while Savona and Vado Ligure less than a tenth, 42.142 CO_2 EqTon. Ton equivalent is a way to estimate and give a standardized number to measure the impact of a source of energy consumption. The software processes data regarding electricity consumption and multiplies it by a standard emission factor due to electricity generation. As described in the introduction, regulators and international organization defined different measures to monitor and reduce ships emissions. It's fundamental to define precisely the method to calculate ship emissions to divide competence the responsibility.

The whole footprint of the Ports of Genoa is biased by the ship's pollution. The port authority is also responsible for around one-fourth of the total emissions, in 2016 contribution to the overall emissions of Ports of Genoa was 19% (AdspMLO Sustainability Report, 2021). A very big part of the pollutants emitted in port areas come from ships, for that it is important to enhance coordination and commitment to decarbonization. If the main ones responsible for pollution are ships, on the other hand, the bigger part of the negative externality is beard by ports. Nevertheless, ports play a crucial role in society, specifically the port authority is the subject in charge of linking citizens with port operations. This is one of the missions of the Ports of Genoa, given the geographical structure of the ports, interconnections, and community interests are priorities for the port authority. The materiality analysis conducted by the port authority's ESG committee emphasized that the interest of both the authority and stakeholders is the development of occupational safety, energy efficiency, and coordination among those involved in port operations, including port community relations and mitigation of port impacts.

V. Where to get electricity in the port of Genoa

V.1 How to produce electricity

Electricity within port areas can be produced through different technologies. In the port master plan (PRP), that the authority is developing, several pilot projects are included aimed at understanding which technologies represent the most viable solution. The AdSPMLO intends to align its energy-environmental strategies with international, European, and national priorities, as well as coordinate with regional and local initiatives already underway. In Liguria, the Regional Environmental Energy Plan (PEAR) defined the energy strategy for the period 2014-2020, with prospects up to 2030 and 2050 (RegioneLiguria, 2021). For what concerns the Port Authority, in 2019, the DEASP was drawn up, which included various initiatives for the improvement of energy efficiency and for the exploitation of CI and LNG. Subsequently, the DEASP was updated in 2022 to meet the needs of the new guidelines. Without indicating other development elements for the development of a self-production network or a smart grid such as that of the PSA terminal in Voltri. The PEAP states that it is necessary to support the demonstration and commercialization phase of decentralized technologies for the production of energy from renewable sources (PEAP pp.25). The advantages of decentralized energy production are emphasized, arguing that decentralization has many advantages, including better security in the supply from local energy sources, shorter transport distances, and a consequent reduced dispersion. In addition to better technical performance, it would also benefit society, increasing cohesion among local stakeholders and job creation. This solution fits perfectly into the mission of AdSPMLO.

The ways to produce electricity vary a lot, the main constraint is that the plants rely on the production capacity necessary to meet the required load. Specifically, given the context of the port of Genoa, the choices regarding the technology to produce electricity are limited. The biggest limitation is represented by the limited space of the port areas. The Genoa basin is an integral part of the city's historic center, which makes it impossible to exploit more space for large renewable energy plants such as wind and independent photovoltaic systems. In recent years, some projects have been presented that could have generated electricity in order to reduce the amount purchased from the national electricity grid, however, these projects were then rejected because they involved too high efforts for the AdSPMLO.

The DEASP document contains several projects aimed at the production of electricity, specifically the FER-1 and FER-2 projects of 2019 which provide for the installation of photovoltaic systems on the roofs of buildings located within the port areas of 8 MW and 3.6 MW respectively, the FER-1 refers to the port of Genoa, while the FER-2 includes Savona and Vado Ligure. The projects will be completed in 2025, the FER-1 will guarantee a production of 10GWh/year, while in the port of Vado Ligure, the FER-2 will guarantee a production of 5GWh/year. The total investment cost for the two plants is around 14 million euros (AdspMLO, DEASP , 2023). The planning was done by calculating 70% of the square meters available for the installation of the panels, some port areas' roofs do not have the requirements for the installation of systems so a theoretical reduction of space is applied for good measure. This aspect highlights the need for the port to decentralize the production of electricity, as the available spaces are already saturated.

The impossibility of exploiting the spaces leads to three possibilities, namely, working on the efficiency of existing structures in order to reduce energy consumption, expanding the available territory, or rebuilding existing works. The latter possibility specifically represents what is happening with the new dam of the port of Genoa. Studies were ordered in March 2022, following an environmental impact assessment, the Liguria region and the Ministry of Culture said they were in favor of the construction of a wind farm built on the new Genoa brakewater. The project was then rejected by the authority *Ministero della Transizione Ecologica* (AM, 2022).

Another attempt has been included in port planning, the FER-3 project concerning the experimentation of electricity production from wave motion. It is in fact a pilot project that involves the installation of a seawater channelling system that flows into a Kaplan turbine, which generates energy by rotating. The electricity is transported via submarine cables. The 1:5 scale prototype has already been tested and now a larger project is being developed that will extend for 600 meters of water breaker. The project, which has a cost of 15 million euros, would guarantee the potential production of 13 GWh/year, considering an estimated *load* of 94 GWh/year in total. This project will be included in the PRP that is expected by the end of 2024.

Although there is a lack of major projects aimed at self-handling, some pilot projects have been included in the DEASP that will be useful in order to understand and contextualize future port planning. The strong support of the National Recovery and Resilience Plan or *Piano Nazionale Di Ripresa E Resilienza* (NRRP) has allowed the port authority to go further than conventional methods by also being able to integrate new investments such as the production and supply of green hydrogen to refuel some hydrogen vehicles. The project involves the installation of a hydrogen production system by electrolysis powered by a photovoltaic system. In general, the 2017 National Energy Strategy indicates a 2030 target for the use of renewable sources for the transport sector equal to 21% of gross final energy consumption, to be achieved through the use of advanced biofuels and electricity. In this sense, no concrete projects have yet been promulgated with regard to biofuels (AdspMLO, 2022).

V.2 Technologies and Social Implications

The port context prefers projects that can be financed with NRRP investments, as a public body the AdspMLO must necessarily comply with the guidelines regarding the use of funds. Over the years, the European Union's vision has led to abandoning fossil fuels as much as possible in favor of the use of renewable energy. Wind energy, for example, might seem like a good solution given the high number of windy days in Liguria, wind turbines are usually installed offshore or adjacent to the port. This type of plant is very invasive, the blades adjacent to the port can exceed 100 meters in height and as many in width, considering the installation of several turbines and the space required between them, the result is a large investment in economic, social, and environmental terms. In this type of assessment, the visual and acoustic impact of the turbines must be taken into account. Genoa, as well as all of Italy, has a large slice of its economy that derives from tourism, most of the projects in fact, are rejected for their consequences on the territory. In this sense, solar panels and energy obtained from wave motion offer less impact and consequently are more easily accepted by the community (Sütterlin, 2017). The European Sea Ports Organization (ESPO), in compliance with the directives of the European Commission, has disseminated to all European port authorities the new guidelines regarding energy efficiency, for which all buildings on which solar panels are to be installed will be necessary (Internal communication ESPO, 2024). This legislation provides for some exceptions regarding the conservation of the territory, of the historical heritage of the cities, so some buildings will be exempt from the construction of their own photovoltaic system. In the case of the AdSPMLO, many of the buildings inside the port areas, including the headquarters of *Palazzo San Giorgio*, fall under this exception. It is emphasized that self-production at an acceptable percentage will only be achieved through the construction of large plants.

The transformation of the territory, even outside the port, takes time, an effort by the authorities and the community is needed to be able to effectively promote a project. An example is the ENEL power plant, located in the heart of the port of Genoa, which remained active until 2016 (IndustrialGenoa, 2022), burning coal to produce energy, it was only in 2021 that the underlying territory returned to the property of the AdSPMLO, which started the decommissioning works. A phenomenon that is an enemy of innovation in the area is NIMBY, or *not in my backyard*, this acronym expresses the community's dissent to accept, usually an infrastructure, close to their home or usual place. So there is not always a scientific contestation with respect to the project, but a rational if irrational negation. A practical example is the *FRSU Toscana* regasification terminal, after having stopped for weeks within the Genoa basin, numerous objections have been raised regarding its mobilization in front of Vado Ligure, in front of some of the most popular tourist destinations in the area. Every environmental danger has been overcome by the technicians who have defined these disputes only as an end in themselves, moved by an unjustified sense of opposition (Vairo, 2024).

As mentioned above, one of the biggest efforts that the AdSPMLO is carrying out is communication with citizens. The acceptability of projects depends largely on community involvement in decision-making processes and transparent communication about long-term benefits. In this sense, communication regarding the self-production of energy not only as economic savings but as an opportunity for sustainable development for the entire port area is necessary.

V.3 Smart Grid in the Port of Genoa

The example of the coal power plant in the port of Genoa perfectly fits the need to move to distributed generation (DG) or decentralized production (DP). The DG means a variety of technologies that generate electricity near where it will be used. It may serve a single structure or it may be a part of a smart grid (Nadeem, 2023). Smart grids and also virtual power plants (VPPs) are two ways to act on the transformation of traditional energy systems into more intelligent, flexible, and, sustainable models. In a port context, where energy demand is high and operations require a continuous and reliable energy flow, these technologies can provide innovative solutions for energy management and optimization. Moreover, a smart grid is a network that links different hardware, having the possibility to manage bidirectional flows of energy and data.

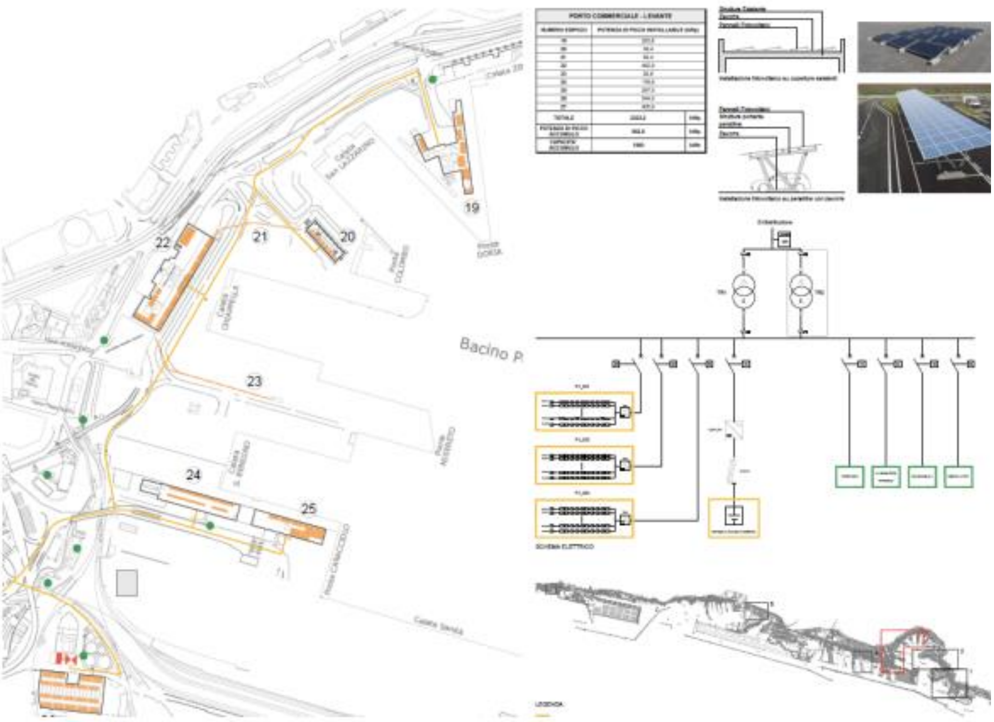
The possibility of connecting different elements allows for flexible production, which can be adapted at any time. The systems used in the DG are usually related to the production of electricity (PV, Wind turbines, or small-hydro), Thermal energy production (boilers, heat pumps), or Combined cycles systems (CHP & CCHP). The production of several types of energy is defined as polygeneration, for example, a CCHP plant, which is capable of producing heat, useful for providing hot water to buildings within the port. Generation is operated by an Energy Management System (EMS) that uses an optimization model to ensure grid efficiency.

A smart grid is a useful way to connect each power generator to a grid that can better manage it. As addressed in the previous paragraph, the production of electricity from solar panels is set to increase for installations on buildings in port areas, having the possibility of interconnecting the system would ensure greater efficiency and energy management. The only downsides to installing a smart grid are a slight increase in energy consumption and the cost of installing the system. It is a very complex ICT structure, it requires the installation of various smart meters capable of acquiring and monitoring, sending data to a System Control and Data Acquisition (SCADA) that manages information. The smart grid allows the port to become prosumer, meaning producers and consumers at the same time. The growing need to reduce emissions, improve efficiency, and ensure the resilience of energy operations that is fundamental for the port’s operations. The port of Savona has already integrated a smart grid into it. According to

AdSPMLO, the purpose of the network is to maximize the use of renewable energy and increase the energy independence of the port system from the public grid, ensuring energy security (AdspMLO, DEASP , 2023). The electric grid at the Port of Savona operates as a self-sufficient energy system (SSPC), independent of national transmission or distribution networks. The Port of Savona aims to maximize the self-consumption of renewable energy generated locally, particularly from solar panels.

For what concerns the creation of a smart grid in the Genoa basin, investments in solar panels amounting to 11.492.052,00 € are planned (AdspMLO, 2022). Figure V.1 shows the design of the grid.

Figure V.1 Smart Grid in Genoa



Source: DEASP 2022

Specifically, these hardware will be installed:

- Photovoltaic Systems: These will be installed over a surface of 215.336 m2 with a peak power capacity of 10.353 kW, producing 12.398 MWh annually.
- Energy Storage: Energy storage systems with significant capacity will be integrated, with a total cost of €2.826.423,60.

- Electric Charging Stations: 17 charging stations (both fast and regular) will be installed, with an estimated cost of €1.257.000,00.
- Electric Vehicles: Fossil fuel-powered vehicles will be replaced with electric ones, with an investment of €650.000,00 (AdspMLO, DEASP , 2023).

The network also includes the preparation for the use of electric vehicles, the current vehicles will be replaced with electric and hydrogen vehicles which will also be produced by electrolysis powered by solar energy. It is important to stress that the second and third items on the list are consumption loads and not production loads, echoing the definition of the smart grid given above, it is underlined that this includes both loads and consumption

Increasingly, decentralized production takes place through a virtual power plant (VPPs). A VPP is an aggregated system of energy assets remotely and automatically optimized by a software-based platform to dispatch services for distribution. The figure V.2 shows an example of the set of energy assets.

Figure V.2 Virtual Power Plant integration scheme

Source: Guidehouse Insights

VPPs are promising solutions to address decarbonization and energy efficiency goals in smart grids. They coordinate local energy resources such as energy generation, storage, and consumption, addressing issues related to the intermittent nature of renewables, lack of storage devices, and insufficient flexibility of local energy demand. The smart grid is the network infrastructure that optimizes energy distribution at a local or national level, while a VPP coordinates and manages decentralized energy resources to optimize production and provide energy on demand (Gao, 2024).

Both technologies can be complementary and fundamental in the port environment. The smart grid manages energy distribution, while the VPP aggregates and manages distributed sources to improve flexibility and efficiency (PeakPower, 2022). Both systems bypass the intermittency of renewable sources, ensuring better management of resources and energy generation. The involvement of stakeholders and the community is essential in order to incentivize the financial mechanisms for the use of these systems even outside the port (Goia, 2022). These systems work in the cloud exchanging large amounts of data in real time, so it is necessary to protect data and through IT security. Significant capital is needed to create, manage, and defend the digital infrastructure (Kumar, 2021).

V.4 BESS Integration

The introduction of a battery system can prove to be fundamental for the correct development of a port network, it allows the intermittency of renewables to be managed. Specifically, Battery Energy Storage Systems (BESS) are storage systems that allow electricity to be conserved for a limited amount of time (Lawder, 2014). A grid based only on renewable energy would be completely unreliable. Therefore, a system that can manage capital losses and capital gains of energy is necessary. The port, given its activity, needs a large continuous flow of energy and essential energy security. Criticalities: the critical issues behind the installation of a BESS are many, particularly its cost and correct maintenance. It is in fact a very advanced system that relies on machine learning to manage the electricity management flow. One of the main characteristics of these systems is modularity, in the same way as batteries are mounted in parallel or in series, the BESS system can also be modified according to the needs of the system (Li, 2023). Its operation also guarantees a safety margin in the event of a blackout. Lithium-ion batteries are the most common type of BESS due to their high energy density, efficiency, and long cycle life. Although flow, fuel cell, and compressed air batteries are also on the market.

Many ports have already integrated this type of system into their electricity grid, in particular, the port of Civitavecchia has adopted this system in its supply network for cold ironing. For this type of use, a BESS with a power of 8,73 MW and a theoretical capacity of 121 MWh (Caprara, 2022).

The choice of the capacity of the power of the system was made according to the data collected in the port of Civitavecchia: in fact, a maximum power demand of up to 14 MW and an energy consumption of 165 MWh were recorded. (Caprara, 2022). Using a capital investment cost based on the capacity of the BESS is 297,5 €/kWh, the total CAPEX for Civitavecchia's port installation was 30,6 million euros. The port of Genoa would require much larger investments given the amount of energy required.

V.5 Energy Communities

The European Union has recently revised its energy policy in order to promote the transition to clean energy and meet its and fulfill its commitments under the Paris Agreement to reduce greenhouse gas emissions. greenhouse gas emissions. In particular, implementing the Union's 2015 energy strategy, in 2019 the 'Clean Energy for all Europeans package' was launched, consisting of four regulations and many directives, namely:

- Directive 2019/944/EU of 5 June 2019, which is aimed at adopting common rules for the energy market and is therefore geared towards adapting the current regulatory framework;
- Directive 2018/2001/EU of 11 December 2018 which promotes the use of energy produced from renewable sources renewables and in particular refers to the 'promotion of the use of energy from renewable sources renewable energy sources' stipulating that Member States must collectively ensure that by 2030 the share of energy produced from renewable sources is 32% of the gross final energy consumption Union's gross final energy consumption and that the share of energy from renewable sources in the transport sector is 14% of final consumption.
- Directive 2018/2002/EU of 11 December 2018 aimed at improving efficiency in the supply and use of energy;

- Directive 2018/844/EU of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings (EPBD) and Directive 2012/27/EU on energy efficiency in buildings. Energy Performance of Buildings (EPBD) and Directive 2012/27/EU on energy efficiency;
- Regulation 2019/943/EU of 5 June 2019 defining the principles for having integrated and functioning national markets integrated and functioning national markets that guarantee fair access to all producers and consumers of electricity;
- Regulation 2019/942/EU of 5 June 2019 establishing the Agency for the Cooperation between National Energy Regulators (ACER);
- Regulation 2018/1999/EU of 11 December 2018 on the governance of the Energy Union, which defines procedures for achieving the climate and energy goals of the Agenda 2030 (GSE, 2024).

The RED II Directive and IEM introduce cooperative models for the management of energy produced from renewable sources. In particular, the RED directive introduces the concept of Renewable Energy Community (REC), The REC must be non-profit, as according to the reference legislation, it must achieve environmental, economic, and social benefits at the territorial level rather than financial profits. It is non-profit to provide a benefit to individual participants in the form of cost savings, proportional to their consumption capacity (Vallati, 2024). Renewable Energy Communities (RECs) were introduced in Italy through the *Milleproroghe* Decree 162/2019, implementing the European RED II Directive (2018/2001/EU). With Ministerial Decree 414/2023, €5.7 billion in incentives were allocated, of which €2,2 billion came from NRRP funds, to promote electricity produced by plants powered by renewable sources included in self-consumption configurations (BibLus, 2024). In addition, various incentives have been provided to finance energy transition and consequently auto production, the study of Mågui Lage compares the incentives provided by Italy and Portugal (Lage & Castro, 2024). In Italy, the main incentives are the 110% Superbonus, which covers 110% of the installation costs of photovoltaic systems, favoring smaller systems, and the Ecobonus, which offers a 50% deduction and the possibility of selling excess energy, ideal for larger systems. In Portugal, the Environmental Fund covers up to 85% of the costs of photovoltaic systems, with a limit of 2.500 euros. Users can benefit from a reduction in electricity tariffs, with a 50% discount for individual self-consumption and 100% for energy communities. Both systems worked well, but Italy's 110% Superbonus had a greater impact on incentivizing the installation of small plants, while in Portugal, energy communities were more profitable.

The establishment of RECs begins, like the projects included in port planning, with an analysis of context, feasibility, and impact. Once the technical design constraints have been identified, such as the positioning of the primary substations, it is vital to define the potential subjects who will be part of the community. A cost-benefit analysis is also carried out to quantify the savings that the participants will achieve.

RECs are entities that do not have financial purposes and this places limits on the legal form they can take. In fact, corporate forms with a predominantly profit motive, such as corporations, are excluded; On the other hand, associative forms, both recognized and unrecognized, consortia, consortium companies, cooperatives, and foundations are permitted, preferring a form that does the patrimonial separation between the assets of the company and the personal assets of the members, thus guaranteeing perfect patrimonial autonomy. The aim is to guarantee the legal autonomy of the community without conflicting with its constitutive objectives.

This is followed by the identification of the subjects involved and the roles in the RECs:

- Activator: a natural or legal person who is responsible for the configuration of the technical and administrative management of the REC. This is the point of reference for relations with the GSE.
- Owner: a person who enjoys full availability of the facility. It can be part of the RECs or a third party which, however, in this case, is subject to the rules of the RECs
- Producer: the person (both natural and legal person) who produces the energy and does not necessarily coincide with the Owner
- End customer: the consumer or consumers, who withdraw and use the energy produced

Once established, the area in which to install the production plant must be identified, which can be made available either by one (or more) participating members or by a third party, as it is not necessary for the plant to be owned by the community, but it must be located close to consumers. For each member of the community, the installation of a smart meter capable of detecting in real-time information on the production, withdrawal, transfer, and self-consumption of energy from the grid must also be taken care of. In this sense, data management is also a topic that needs to be considered (Toubeau, 2023).

The study (Tatti, 2023) identifies three different models regarding the development of RECs in Italy. The Bottom-Up model is promoted by citizens or Small-Medium Enterprises (SMEs), who invest independently to reduce energy costs. The Top-Down model sees the involvement of local administrations, with the aim of fighting energy poverty and promoting the use of renewable energy. Third, the Energy Operators model is led by energy companies that provide technical and financial support for the implementation and management of RECs.

RECs can access various incentives, but not necessarily all of them. The main incentives include the feed-in premium tariff for the renewable energy produced and shared, the partial reimbursement of grid charges for self-consumed energy, and the possibility of accessing public funding and tenders to cover the costs of plant construction (GSE, 2024). Specifically, the premium tariff, expressed in €/MWh, varies according to the power of the plant and the zonal price of electricity (Pcs), according to these formulas:

- Plants > 600 kW: Premium tariff (TIP) = 60 + max(0; 180 - Pcs), with a maximum limit of 100 €/MWh.
- Plants between 200 kW and 600 kW: TIP = 70 + max(0; 180 - Pcs), with a maximum limit of 110 €/MWh.
- Plants ≤ 200 kW: TIP = 80 + max(0; 180 - Pcs), with a maximum limit of 120 €/MWh (MASE, 2024).

In addition, for photovoltaic systems, the tariff can be adjusted according to the geographical region:

- Central Regions (Lazio, Marche, Tuscany, Umbria, Abruzzo): +4 €/MWh.

- Northern regions (Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardy, Piedmont, Trentino-Alto Adige, Valle d'Aosta, Veneto): +10 €/MWh (MASE, 2024).

In the context of RECs, the decree provides for capital grants of up to 40% of eligible costs for the development of renewable plants, often combined with storage systems.

V.6 Port Renewable Energy Communities (PRECs)

Port systems play a central role in promoting the economic and social development of a country: as strategic nodes for the international trade of people, goods, and commodities, they are real engines of economic growth, allowing the continuous exchange of goods and services all over the world. The multiplicity of activities that are carried out within port areas ranging from maritime transport to the handling of goods and maintenance and infrastructure management services requires a high energy requirement, which has significant environmental impacts. The issue of the environmental impact of the port sector has gained increasing importance, a trend accelerated by the recent geopolitical tensions between Russia and Ukraine, which has led to strong tensions in the energy markets particularly in the European one, highlighting how vulnerable the energy supply system of European countries was and, on the other hand, accelerating the transition towards renewable energy. In response to this, the European Commission has launched the REPowerEU plan (EuropeanCouncil, 2022), with the aim of becoming increasingly independent from Russian gas, oil, and coal imports through:

- Accelerating the reduction of dependence on fossil fuels
- Diversification of supplies
- Accelerating the development of renewable energy
- Improving the interconnection of Europe's electricity and gas networks
- Strengthening the European Union's contingency planning for security of supply
- Improving energy efficiency and promoting circularity

In this context, the Port System Authorities (AdSPs), which coordinates Italian ports, are among the main recipients of EU and Italian regulations for the implementation of the energy transition. An important recognition of their role comes from Decree-Law no. 50 of 17 May 2022 subsequently converted with amendments by Law no. 91 of 15 July 2022. According to Art. 9 paragraph 2 of the aforementioned Decree, "*in order to contribute to the sustainable growth of the country, to the decarbonization of the energy system and for the pursuit of national energy resilience, the Port System Authorities may establish one or more renewable energy communities, in line with the energy and environmental planning document referred to in Article 4-bis of the same Law No. 84 of 1994*".

By giving port authorities the opportunity to set up energy communities, the Law Decree contributes in an important way to giving substance to the transition to the use of renewable energy, supporting a real promotion of the spread of green energy in the areas of port competence by facilitating not only ports but also companies and the construction of infrastructures that are needed to achieve the EU's energy objectives.

Green Ports and the electrification of berths, which are part of the NRRP investments, require an active role of the Port System Authorities of the Western Ligurian Sea (AdSPMLO) in the promotion of renewable energy within the ports and in the economic sustainability for the companies involved in the energy transition. Italian Port Authorities, in general, can set up one or more PRECs in accordance with Legislative Decree n°199/2021, following the guidelines of the Energy and Environmental Planning Document (DEASP). Plants powered by renewable sources that are part of the PREC will be able to benefit from the incentives, even if they exceed the power of 1 MW (GSE, 2024).

To promote the creation of port RECs in the ports of Genoa and Savona-Vado Ligure, the AdSPMLO has defined the planning in three main phases (AdspMLO, DEASP , 2023):

I. Preliminary study: Analysis of the regulatory, technical, and administrative conditions to facilitate the establishment of PRECs. This phase carried out with the support of IRE SpA[3], is scheduled to be completed in 2023.
II. Stakeholder involvement: Sharing of the knowledge acquired with port operators through technical meetings, webinars, and information campaigns. This activity will be carried out in the first quarter of 2024.
III. Support for the start-up of PRECs: Once knowledge on the subject has been consolidated, the Port Authority will support the start-up of PRECs in ports, adapting the operating methods based on the specific characteristics of the electricity grids of the ports of Genoa and Savona.

The areas available for the installation of renewable plants will be mapped and economic and technical feasibility studies will be carried out for pilot configurations. The authority expects that the integration of PRECs will help achieve the FER-1 and FER-2 targets described in the previous chapter.

As regards the cost/benefit analysis of the PRECs, the authority must prescribe that the costs to be incurred include technical and regulatory expenses, support for information campaigns, notary and design costs, initial investments, plant maintenance, monitoring devices, and administrative costs of the GSE[4]. While the concrete benefits have not yet been quantified.

V.7 The cost of energy produced and its implications on the CI service

The cost of self-produced energy is a crucial element for the competitiveness of PRECs, especially in a context where economic efficiency is closely linked to energy sustainability. The auto production of energy through renewable sources makes it possible to significantly reduce energy costs for the AdSPMLO, reducing system charges (*Oneri*

[3] IRE S.p.A. is a public company in Liguria, Italy, focused on infrastructure development, energy recovery, and urban renewal. It was formed in 2014 by merging three regional agencies to enhance expertise in energy and public works management.
[4] GSE (Gestore dei Servizi Energetici) is an Italian government-owned company that is the guarantor and promoter of the country's sustainable development.

Generali di Sistema) which represent about 50% of the cost of energy purchased from the grid.

In Italy, ARERA is responsible for defining electricity tariffs, specifically, the price is added to the system charges. These are divided into two components, namely A_{sos} e A_{rim} (ARERA, Formazione del prezzo dell'energia, 2023). The A_{sos} component covers the costs related to supporting renewable energy and high-efficiency cogeneration, and financing incentives for the production of energy from renewable sources such as solar, wind, and hydropower. This is the most significant item of system charges, as it is linked to the objectives of energy transition and emission reduction. The A_{rim} component, on the other hand, includes a number of different costs, including compensation for disadvantaged areas, costs for securing nuclear plants, and incentives for energy efficiency.

Due to government incentives and the recovery of network charges, at the moment, PRECs can not only meet their own energy needs but also sell excess energy, thus creating new revenue opportunities. However, in Italy, Port Authorities are exempt from participating in profit-making activities, so as is still the case in the port of Savona, excess energy can neither be stored through a BESS nor an energy carrier and sold to the national network. This aspect underlines how great regulatory efforts are still needed to make the service effective. Theoretically, the cold ironing service could benefit greatly from the self-production of energy. Avoiding management charges on the price of energy could have a key impact in being able to ensure the cost-effectiveness of using the CI compared to fuel consumption within the port. The regulatory push that allows the use of systems even above the limit of 1 MW, is fundamental as the port is a highly energy-intensive structure. However, there is no standardization in the reforms, each port must move autonomously by evaluating the feasibility of the project without being able to rely on a consolidated regulatory structure. Like all activities with high barriers to entry, the CAPEX and OPEX of cold ironing are not adequately covered by a system that allows the AdSPMLO to generate revenues since, at present, it is the AdSPMLO as regulatory entities that are inhibited from carrying out economic activities with the consequent outsourcing of the energy supply activity to ships (Griffi, 2023).

V.8 Renewables in the port areas

Within port areas, it is not always possible to benefit from large spaces that can be used for the installation of infrastructure for energy production. In a context in which the energy transition and the reduction of CO_2 emissions are fundamental, it is necessary to invest in sustainable technologies that support the development of the port. As for the methodologies used for energy production, the most used technology is photovoltaics. Solar panels offer a simple and mature technology that is easily applicable and does not require complex installations or a high degree of maintenance. The benefits of PVs are related to how they produce energy, i.e. how sunlight is converted into electricity through the photovoltaic effect. This process occurs when photons from light hit solar cells, made of semiconductor materials such as silicon, they release electrons, generating electricity. The discovery of the photovoltaic effect dates back to the first half of the eighteenth century, while industrial development took place in the aerospace sector starting from the sixties. In recent decades, the use of this technology and the development of new materials has made it possible to standardize the use of solar panels, providing a mature and reliable technology.

A measure of comparison for the cost of solar panel installations is represented by the Levelized Cost of Energy (LCOE).

Comparing different LCOEs → is the average net present cost of electricity generation for a generator over its lifetime. This measure includes the total lifetime cost/Total lifetime energy production.

$$LCOE = \frac{Total\ lifetime\ cost}{Total\ lifetime\ energy\ production} = \frac{\sum_{t=1}^{n} \frac{I + FO\&M_t + VO\&M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

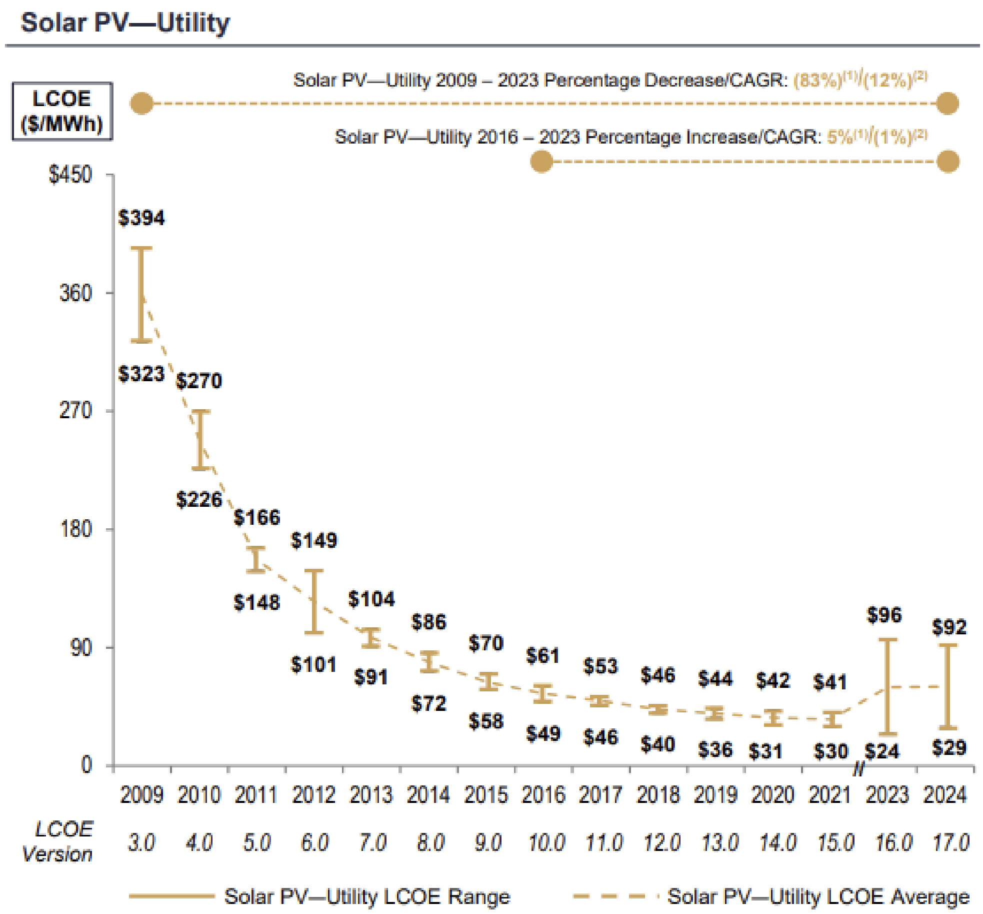
Where:

- I: Investment costs
- FO&Mt: Fixed operation and maintenance costs in the year t
- VO&Mt: Variable operation and maintenance costs excluding fuel costs in the year t
- Ft: Fuel costs in the year t

- Et: Energy production in the year t
- r: Discount rate
- n: Expected asset lifetime

The meaning of this indicator is to give back the possibility to compare different technologies. The monetary value that comes out of the formula can be considered a proxy for the unitary cost of electricity generation using that specific technology expressed in €/MWh. Obviously, the different technologies have different costs and issues to deal with, LCOE does not include in its calculation external barriers like regulation, the efficiency of the power plant, or specific technology variables like the GHI for the PV technology. The data provided by Lazard about 2022 stands that "*selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances*".

Figure V.3 Solar PV LCOE 2009-2024



Source: Lazard 2024

The level of LCOE for solar technology has decreased significantly over the past fifteen years (figure V.3), making panel installation less expensive. This aspect is fundamental for the strategic investment decision, although it is not the only decisive aspect.

To date, there are different types of photovoltaic solar panels, the operation is always linked to the photovoltaic effect while the materials and their efficiency change.

The key factor that defines the difference between the various panels is their efficiency, which also has an impact on the cost. It is generally calculated as follows:

$$\eta_g = \frac{E_{el}}{A \ x \ RAD} \ x \ 100$$

- E_{el}: electricity production [kWh/day, kWh/year]
- RAD: solar radiation [kWh/(m^2day), kWh/(m^2year)]
- A: overall array area of PV plant [m^2]

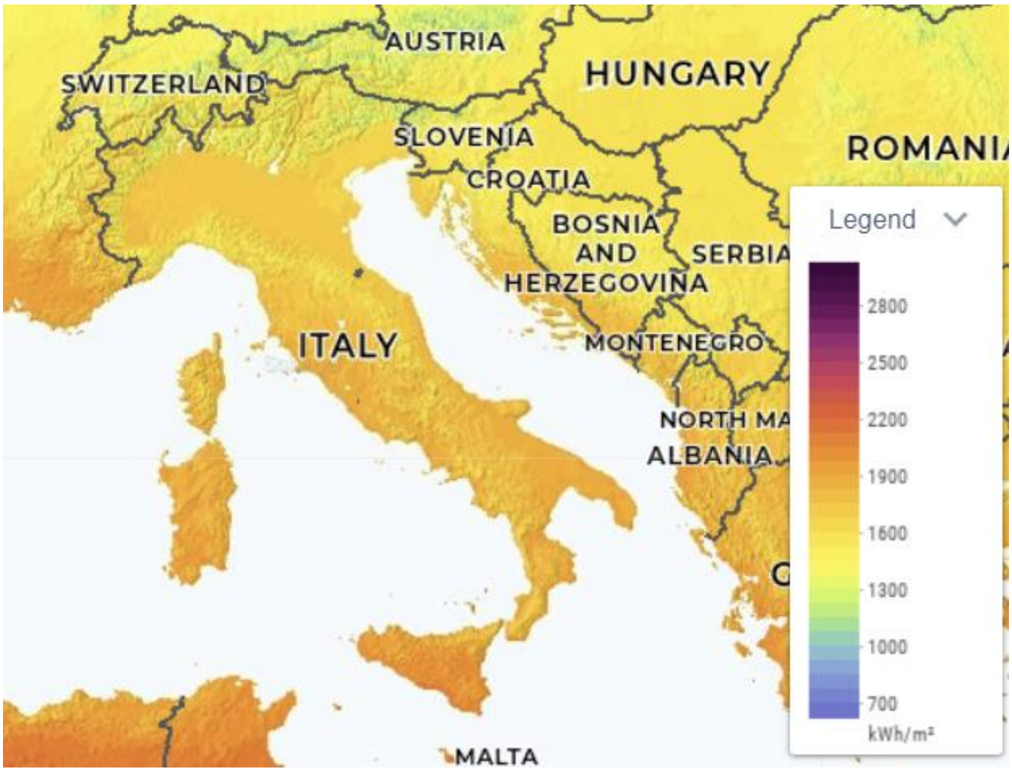
The formula emphasizes how higher efficiency indicates better conversion of solar energy into electricity.

The main types of PVs include monocrystalline, which has an efficiency of about 18%-22%, ideal for limited spaces, and polycrystalline, less efficient 15%-18%, therefore cheaper. Thin-film panels are flexible and suitable for particular surfaces, although they are less efficient, 10%-12% (Dambhare, 2021). Bifacials capture light from both sides, exceeding 22% efficiency, while CPV concentrator panels reach 35%-45%, but require a solar tracking system that allows the modules to vary their azimuth[5] and tilt angle. The new frontiers of studies on photovoltaic cells are bringing to light new types of photovoltaic cells that are currently incompatible with large installations.

[5] The photovoltaic (PV) azimuth is the direction towards which the PV panels face.

Specifically, a fundamental factor that influences the production capacity of the panels is solar radiation. The following figure shows how the irradiation factor varies according to the geographical location of the photovoltaic system.

Figure V.4 Solar Charts Average 2020-2024



Source: Global Solar Atlas 2024

The solar chart (figure V.4) shows how irradiation in Italy is different according to geographical areas. Southern Italy is characterized by an annual irradiation of more than 2,200kWh/m2, while the north has a value of almost half, equal to an average of around 1450kWh/m2. Factors such as the cleanliness of the panels and climate change can also affect the irradiation of the modules.

V.9 Renewable Energy Investments by AdSPMLO

Since 2019, AdSPMLO has invested large amounts of capital to increase its self-production of energy by integrating targeted projects to achieve this goal.

The DEASP encompasses the planning of port areas and defines the FER-1 and FER-2 projects for the self-production of electricity in the ports of Genoa and Savona. Specifically:

1. FER-1 installation of photovoltaic systems on roofs of buildings located within the boundaries state-owned port of Genoa
2. FER-2 installation of photovoltaic systems on roofs of buildings located within state-owned boundaries port of Savona/Vado Ligure

The FER-1 project concerns the installation of photovoltaic panels on the roofs of buildings within the port areas of the port of Genoa. The buildings on which it is possible to carry out installations were considered, applying a percentage of 70% to the total usable area, identifying a usable square footage of 123,880 m2. In the presentation of the project contained within the DEASP, the AdSPMLO calculated the production of the panels using a lower-than-average irradiation index, for prudence a figure of 1,200kWh/kWp was used. The maximum power is 8 MW, which corresponds to an estimated annual production of 10 GWh.

The FER-2 is similar to the previous one but is concentrated in the port of Savona/Vado Ligure. Following the same calculation methodology as FER-1, a space of 54.720 m2 was identified that could be used for the installation of PVs. The installable power is 3.6 MW and, including the same thrifty irradiation factor of 1.200 kWh/kWp, the plant produces a total of 5 GWh per year (AdspMLO, DEASP , 2023).

For both projects, monocrystalline modules with an efficiency of 20%, and thin-film modules, with a lower efficiency of 15.5%, were installed. This choice is justified by the type of installations that are made within the port areas, the first type of panels has a weight of about 12 kg/m2 while the thin-film modules are about 2,2 kg/m2, which makes them more flexible in terms of installation.

Focus FER-3 Project

In addition to the production of electricity from the use of solar panels, the AdSPMLO has planned an investment of €15,000,000 for the experimentation of energy generation from wave motion. This project is part of the innovative initiatives within the PNNR, contributing to the sustainable development of the port. This project was presented in 2021 by the Council of Ministers, with a view to the technological advancement of the port. The principle of energy generation takes place by moving a column of air or water inside a recess that allows it to pass. Installations of this type are referred to as Oscillating Water Column (OWC) for air systems, or Oscillating Water Column Motor (OWCM) for water systems. The correct functioning of the system is based on twenty years of wave motion observations that show a wave greater than 1 meter on average for 182 days a year. In addition, wave motion, compared to solar technology, offers higher energy density and better predictability.

This type of sea power plant lends itself to ad hoc installations, which are often large, very expensive installations involving several parties and a large amount of space. The cost-effectiveness of this OWCM system is achieved with targeted optimization models aimed at lowering the operating costs and consequently the LCOE of projects (Rosati, 2022).

The AdSPMLO project concerns the construction of an OWCM system that directly utilises a water column instead of air. The water is channelled through hydraulic pumps to a Kaplan turbine suitable for handling low head but high flow water flows.

An OWCM experiment was carried out in 2010 at the dam in front of the Fiera del Mare, and an installation of a 1:5 prototype led to encouraging results. In fact, the data proved to be very consistent with the forecasting mathematical models, indicating a correct evaluation of the design. The AdSPMLO has proposed a modular installation, a first module consisting of 100 pumps directed towards a Kaplan turbine will generate 3 MW equivalent to 13 GWh per year. Subsequently, the extension of this project is planned, first of all by another 8 modules equivalent to 24 MW on the airport pier dam, and finally a large-scale installation of a total of 9 modules, equal to 36 MW which will also include the VTE breakwater part reaching a total amount of 158 GWh per year. In economic terms, this major expansion translates into a request for funds of around €150,000,000 in the period between 2021 and 2026.

In May 2022, the project for the new breakwater was approved, which will see the FER-3 project enlarged further. The proposed extensions of the new breakwater are expected to increase the size of the plant, estimating a production capacity of 239 GWh, and a related cost of €260 million for the installation and €19 million for the annual maintenance. The power plant has a modular structure, one module houses five floats that move up and down and pump water within the system to a vertical Kaplan turbine that converts kinetic and potential energy into electricity through rotation. Each module costs EUR 1,5 million. If the project is completed it will cover all 7,2 KM of the new Genoa dam.

According to the project, the benefits of completing the OWCM are many different. Starting with the possibility of supplying electricity to ships without having to rely on the national power grid. The other impacts of the project concern the possibility of desalinating the surplus energy, to be used for agricultural or public utility purposes, the physical impact of the structure, which will allow for water recycling within the port areas, and an increase in the structural strength of the dam (OWCM, 2024).

Within the high OPEX, several expenses are included for the optimization of the system, sensors are foreseen that are able to continuously communicate the health status of the components and their operation. the project aims to be efficient and reliable in order to guarantee a huge amount of energy generated by the sea.

Therefore, self-production within the port of Genoa/Prà is calculated as follows:

Table V.1 Autoproduction Capacity in the Port of Genoa

	1° phase	2° phase	3° phase	New Project
FER-1	10	10	10	10
FER-3	13	118	158	239
Total GWh	**23**	**128**	**168**	**249**

Source: Our Elaboration

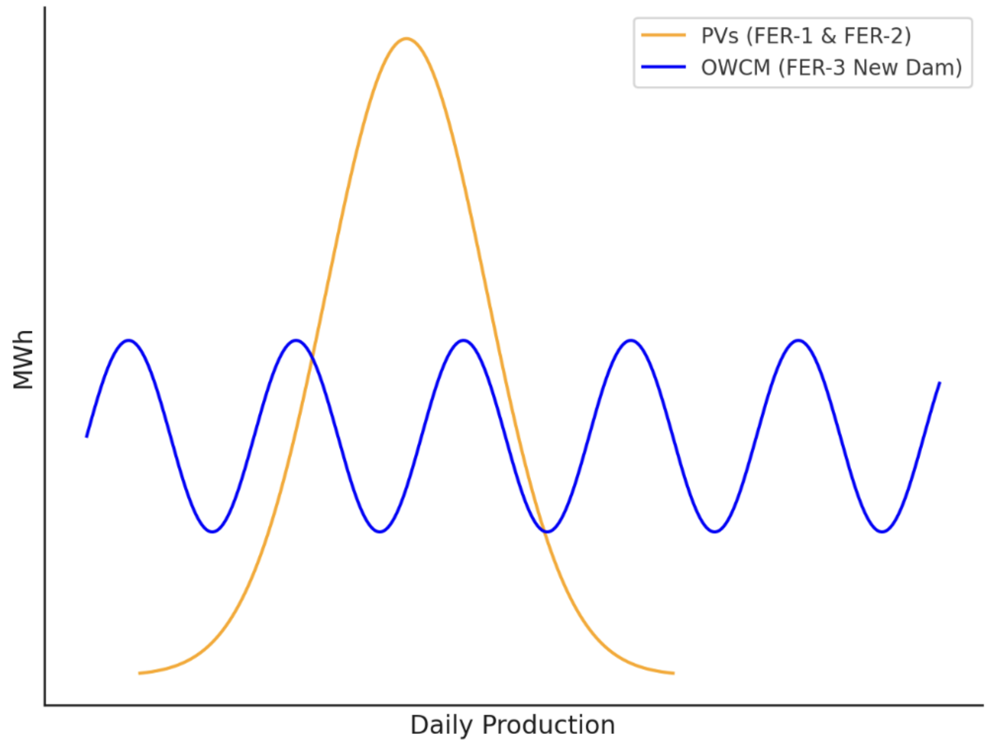
The table V.1 shows the various levels of -generation in the Port of Genoa, considering the FER-1 and FER-3 projects and its stages of development. As much as stages II, and III and the new breakwater project can offer a great deal of energy, it is worth noting that at present, the AdSPMLO is working to finish stage I, which concerns the first installations of the FER-3 modules. The new dam will be completed by 2026, although this official estimate has already been delayed from what was planned. Therefore, this is a theoretical assessment of the potential of the Port of Genoa.

V.10 Shaping a new energy mix

The estimates of the plant's production are voluntarily conservative, especially with regard to the turbine activation threshold which takes place from 50 centimetres of wave upwards. In the DEASP the estimate concerns 1 meter of wave, present on average 182 days a year in the port of Genoa while the estimate taking into consideration 50 centimetres changes considerably since the undertow is almost always present. Therefore, production could be much higher than conservatively estimated. This would result in a further surplus for the port that would have to be stored to fully exploit the benefits of the FER-3 project. In addition to BESS systems that are undoubtedly useful for managing the electricity supply, the most promising storage method is the one deriving from the production of hydrogen by electrolysis. The so-called "green hydrogen" would be generated, which turns out to be zero emissions. A large amount of water, preferably desalinated, and an equally large amount of electricity are required for electrolysis. Perfect circumstances are present in the context of the new Genoa breakwater. Moreover, the production of hydrogen in large quantities would have great strategic value for the city of Genoa in view of the objectives of the TEN-T network defined by the European Commission.

This process is currently economically inconvenient as the electricity needed as input is not compensated by the current price of hydrogen. The focal point of this technology would be to be able to store energy in the form of a physical carrier. The hydrogen produced would be stored in the form of liquid hydrogen, which presents many technical difficulties including storage temperature and explosiveness but on the other hand, hydrogen maintains its potential energy inside. The use of a carrier would make it possible to store and transport energy for long periods which could definitively bridge the intermittency of the availability of renewable energy, ensuring energy security from renewable sources. The figure V.5 represents the comparison between the two production curves of solar panels and wave energy. The panels peak during the early afternoon and then decay in the hours of darkness, while the OWCM is linked to wave motion which in itself has a less volatile and more constant trend. It is clear that it is not possible to rely only on the production of energy from renewable sources without having a storage system capable of mitigating the intermittency of production.

Figure V.5 Comparison between Solar PV and Wave OWC daily production curve



Source: Our Elaboration

The transition to such a centralized type of production within the port defines a substantial push toward circularity. Currently, the fuel transport chains (HFO, MGO, LPG) involve several operators who occupy a portion of the supply chain that starts from the extraction of the raw material to the procurement of the finished product within the port. Each of these operators has profited from its work, so the final price of the product increases significantly by having to contain the value absorbed by the participants in the supply chain. The final price for electricity or refueling with a carrier is paid by the end customers, which in this case can be categorized as the AdSPMLO for electricity for services and carriers for vehicles used in port areas, and for the shipowners of the ships that supply them with fuel. It is therefore a very long supply chain that involves the involvement of different actors.

The operation of the FER-3 project and the production of hydrogen would drastically shorten the supply chain, representing enormous savings for the port and for shipowners. This change would have a big impact on stakeholders who are unlikely to accept the port's change in energy mix. It is estimated that the change could take place with a great individualistic push by the port with a view to radically changing the future of energy supply. The elements of social and political acceptability are central to a public body that does not have the independence of a private enterprise. In Europe, there are examples of ports that have been able to act more autonomously and have pursued these objectives, such as the port of Rotterdam or the port of Oslo. It is emphasized again that in order to achieve a real energy transition, it is necessary to work on several fronts.

VI. Potential Impact on Port's Areas

In this chapter, the economic aspects regarding the self-production of energy in the port of Genoa will be analyzed, with specific regard to the economic, energy, and environmental aspects.

VI.1 Energy saving

The auto production of energy in the port would allow AdSPMLO to reduce the amount of electricity to be purchased from the national grid. In terms of ecological transition, there is no doubt that increasing the efficiency of existing structures would reduce energy consumption by a large percentage. Although, in Italy, a large percentage of buildings are old and energy-inefficient. Around 65% of buildings are more than fourty years old and were built before energy regulations were introduced (Manganelli, 2019). The most widely used technologies for the efficiency of maritime buildings in Italy, concern, specifically, the use of water source heat pumps to exploit marine energy, the recovery of heat from chiller condensers, the replacement of glass facades with photovoltaic glass to produce electricity, and the installation of photovoltaic canopies to generate solar energy without compromising the roof structure. An example is the Port of Naples where the proposed measures have led to significant energy savings, with reductions ranging from 24% to 41% in primary energy consumption and a reduction in CO_2 emissions from 16 to 34 tons per year (Barone, 2021). Even though existing buildings represent a great opportunity for reducing global energy consumption. However, technical difficulties and high costs often limit their large-scale deployment (Belussi, 2019).

Another destination for auto produced electricity would be to use it for CI service. The energy consumption of the AdSPMLO stands at 1,716,885 MWh (AdspMLO, DEASP , 2023) of which 80,6% is due to maritime traffic, and the remaining 19,4% deriving from port operations which include energy for buildings, lighting of port areas, cargo handling, logistics and others. Therefore, most of the energy consumed by the port is due to the energy demand of the ships at the berth

It is necessary to underline that auto production, coming from renewable sources, must necessarily be compensated with storage systems capable of smoothing out the intermittency of renewable energy as explained in the previous paragraph. Ideally, this level of self-sufficiency could be produced by the AdSPMLO at around 23 GWh per year considering FER-1 and the first stage of the FER-3 project.

According to the data collected by the DFSE system for the year April 2023-2024, the consumption of auxiliary engines of the ships stationed within the port of Genoa stands at around 570 GW. Therefore, to date, it would be possible to guarantee a supply of about 5% of the energy required by ships at the quay.

Before considering electricity auto production for the cold ironing system, the analysis focuses on the role of energy communities in the port context.

VI.2 Evaluation of economic benefits of PRECs

The AdsPMLO will be able to produce at least 23 GWh of electricity per year from renewable sources (considering FER-1 and S1 FER-3), it could create a port energy community with significant economic and environmental benefits. ARERA classified in 2022 the port areas as *Sistema di Distribuzione Chiuso* (SDC) which are networks managed by energy distributors with connection obligations limited to users and third parties that can be connected. In ports, electricity distribution takes place through concessions issued by the Port Authority, maintaining the classification of the networks as public. Port and airport networks are considered existing SDCs regardless of the date of granting or transmission of the documentation to ARERA. In addition, the regulator offers the possibility for users to request ARERA to examine the tariffs applied by the operators.

Self-consumption of this energy would drastically reduce dependence on the national grid, allowing the AdSPMLO to benefit from government incentives provided for renewable energy production. Specifically, if the energy is not sold on the grid but rather self-consumed, the C_{acv} (*Compenso per l'Autoconsumo Collettivo Valorizzato*) in a renewable energy community is quantifiable on the basis of the amount of energy shared within the community itself. The contribution is recognized by the GSE and is mainly linked to the economic benefits deriving from the self-consumption of the energy produced. The exact amount of the contribution depends on various factors, including the amount of energy that is actually self-consumed by PRECs members and the conditions set out in the applicable technical rules, such as the avoided cost of purchasing energy from the grid and environmental benefits.

For the Genoa Port Authority, the C_{acv} could be a useful tool to enhance self-produced and self-consumed electricity within port energy communities. This mechanism makes it possible to calculate the compensation based on the electricity self-consumed within the port, considering several factors:

- CUA_{fa}: This is the variable unit component of the transmission tariff (TRASE) for medium-low voltage users, which for 2023 is set at €8,48/MWh.
- EACV: Indicates the self-consumed electricity in kWh.
- CUA_{fb}: This component concerns distribution for medium-low voltage users (BTAU), with a value of €0,60/MWh in 2023.
- EACVC: Part of the self-consumed energy that comes from plants located within the port or the port energy community (ARERA, 2024).

Finally, the calculation also considers the savings due to the losses avoided (1.2% for plants connected to the MV network and 2.6% for the LV network, multiplied by the hourly zonal price (P_{cs}). This mechanism could allow the Port Energy Community of the AdSPMLO to optimize the economic benefits related to self-consumption, contributing to the reduction of emissions and the improvement of energy efficiency.

By performing the calculation and using the following data:

- Self-consumed electricity 23 GW/year (the pessimistic scenario)
- Medium voltage network (1.2% losses avoided)
- Mean hourly zonal price 2023-2024 106,14€/MWh[6]
- CUA_{fa} 8,48€/MWh

It is possible to identify an estimated C_{acv} for a port energy community in the port of Genoa of 224,34 € for 2023. This figure represents an income for the AdSPMLO which would earn money generated by the amount of self-consumed energy. The increase in the

[6] Our calculation using GSE historical data 2023-2024

percentage of self-consumption and self-production with the arrival of new investments could lead to an even more considerable increase.

It is also necessary to estimate a notional charge of 23 GWh not purchased from the grid, which corresponds to a much greater saving than the C_{acv}. In 2023, the average price for industrial clients in Genoa was 195,1 €/MWh (GME, 2024) corresponding to 4.487.300 €. Adding this saving to the C_{acv}, it is possible to find the real impact of the PREC of the AdSPMLO, which would have generated a gain of 4.711.635 € in 2023.

Specifically, the AdSPMLO has planned a total expenditure including the FER-1, FER-2, and FER-3 projects of 30.000.000 €. The savings are significant due to the technical life span of these three systems which is 15 years. The AdSPMLO has estimated a total saving of 5.600.000€ generated by energy not purchased from the grid (AdspMLO, DEASP , 2023).

Cost-benefit analysis (CBA) is carried out to compare the economic sustainability of different energy efficiency strategies in order to identify the most advantageous solutions in terms of energy efficiency (Garcia, 2016). A CBA was also evaluated for all three projects, specifically different scenarios were considered in which different cost levels were estimated. In fact, the expected benefit remains the same while the cost changes, which could increase during the work. Specifically,

- The FER-1 project has a benefit/cost ratio ranging from 2.12 to 0.91, becoming negative only in the fifth scenario with the most pessimistic cost hypothesis.
- In all the scenarios considered, the FER-2 project has a Benefit/Cost ratio greater than 1, indicating the ability of the intervention to generate net benefits even in the presence of worse conditions than those envisaged by the project. This varies from 2.29 to 1.16 in the three scenarios considered, where a doubling of investment costs was assumed as each scenario increased.
- The FER-3 is the most constant in the 4 hypothetical scenarios, the benefit/cost ratio fluctuates between 1.57 and 1.15. Being an experimental project, it is good to be cautious about evaluating the benefits from a conservative perspective (AdspMLO, DEASP , 2023).

Hence, all three projects are positively evaluated by the analysis also with a view to an exponential increase in external costs, ensuring a positive output for the AdSPMLO.

As regards the parties involved in the creation of these plants, also with a view to the creation of the PREC, the AdSPMLO indicates that cooperation with the concessionaires will be fundamental, ENEL specifically for connection to the grid, the GSE, the municipalities of Genoa and Savona, and the Customs Agency, and the Customs Agency, and the company in charge of developing the prototype for the production of energy from wave motion of the FER-3 project is also included. With particular reference to FER-2, the installation of photovoltaic panels in the port of Savona, it should be noted that from an administrative point of view, it must be taken into consideration that at present the system of purchase, transformation, and distribution of electricity within the port of Savona is the responsibility of the company S.V. Port Service according to the configuration of Simple Production and Consumption System (SSPC) (S.V.PortService, 2023), as defined by ARERA's TISSPC[7] regulation. In this context, even in the case of the implementation of energy self-production systems, there will be, from an administrative point of view, a single producer.

At the moment, in fact, the configuration of the Savona network is SSCP, while the creation of a PREC is configured with the SDC structure, which is recognized as having the C_{acv} as described above. Current legislation (ARERA, 2024) limits configuration as SSCP up to 20 kW. Introducing a new power plant as PREC will shift the SSCP to an SDC configuration.

VI.3 CI investments by the AdSPMLO

The electricity auto production in the port of Genoa and in the port of Savona could instead be channeled into the cold ironing service. A very large theoretical self-production of energy could significantly lower the overall cost of the service, encouraging its use by shipowners. Assuming the maximum production level of the three FERs projects included in the DEASP, the AdSPMLO could count on a production of 23 GWh/year respectively divided into FER-1 and S1 FER-3 at the first stage in the port of Genoa for a total amount

[7] The TISSPC is the (Testo Integrato dei Sistemi Semplici di Produzione e Consumo), by ARERA, defines all the measure about SSPC systems.

of 23 GWh/year while the FER-2 of the port of Savona will guarantee 10 GWh/year. With regard to ships in berth, it is worth noting that only a percentage are enabled to refuel by cold ironing, many studies agree on a percentage around 10%. In the port of Genoa, in the year between April 2023 and April 2024, electrical consumption for the auxiliary engines and boiler (if installed) of ships required 620 GW of energy. The figure is inclusive of each type of ship, specifically, container ships appear to weigh most heavily on the total energy balance, while the singularly most energy-consuming ships are cruise ships. Cruise ships usually have the predisposition for the use of cold ironing as they are newly manufactured, while for the other types, there is an estimated around 10 percent of the total. A special case is tug-boats that have already been provided with cold ironing within the port (Glavinović, 2023).

The DEASP contains two investments regarding cold ironing, respectively NAT-1 and NAT-3. The first was launched in 2019 at a cost of €9.000.000, while the second is from 2022, with a cost of around €30.000.000.

The first CI experiment by the AdSPMLO is the NAT-1, built in the port of Prà serving LO-LO ships. The motivations that brought the PA to start electrification from Prà's terminal are mainly four:

- Average low power needed for utilities of these ship's connections;
- Increasingly high consistency of ships able to use;
- Relatively long berth time, 24 to 36 hours;
- Absence of passengers at Prà terminal.

The NAT-1 project aimed to feed two berths simultaneously with a nominal power of 7,5 MWA each. Nowadays container ships run on 6., kW of electricity with a frequency of 60Hz, the plant is designed to run also at 50 Hz. The absorption for a single ship is 5 MW (7.5MWA). The NAT-1 is specifically designed for container ships, moreover, those have different characteristics compared with cruises or RO-RO vessels. Also, benefits have been considered in a CBA, that are not consistent due to the inactivity of the service. Today the service is not operational due to the impossibility of the AdSPMLO to sell electricity to the shipping companies, therefore the systems in the Prà terminal are functional but not used due to a lack of regulation. As discussed in the previous paragraph, the legislation is now making progress in defining the regulation regarding the port's ability to self-produce, self-consume, and sell energy. The difficulty, especially for ARERA, is to build fair and just legislation to ensure the best management of resources. Electrification projects, however, are very convenient in the long term, given the expected benefits and the creation of value deriving from the reduction of pollution, in Europe there are about 80% of the ports in the world able to guarantee the CI service, ranking Europe as the greenest continent in this respect. In this wake of development, other NRRP funds were used for the creation of the project NAT-3 del 2022. This second project involves the electrification of the quays in both the port of Genoa and the port of Savona, specifically two berths for cruises and four berths for ferries at 11kW, 60 Hz, for a total of 20MW. To make the plant operational, it was also necessary to plan the construction of an underwater connection on the seabed of the port of Genoa and two 20MW converters. In the port of Savona, two berths for cruise ships will be electrified, also at 11kW, 60 Hz for a total power of 10MW. The project is nearing completion and is expected to be operational by 2025 (DEASP , 2023).

Even with the high CAPEX of about € 40.000.000 of the NAT-1 and NAT-3 projects, the expected benefits for the two projects are always greater than the costs, even if they increase from a pessimistic perspective. Both projects are in charge of the NIDEC ASI S.p.a. which is a company based in Genoa specializing in energy infrastructures. The industrial communication is around the green segment of ecological transition about the final aim

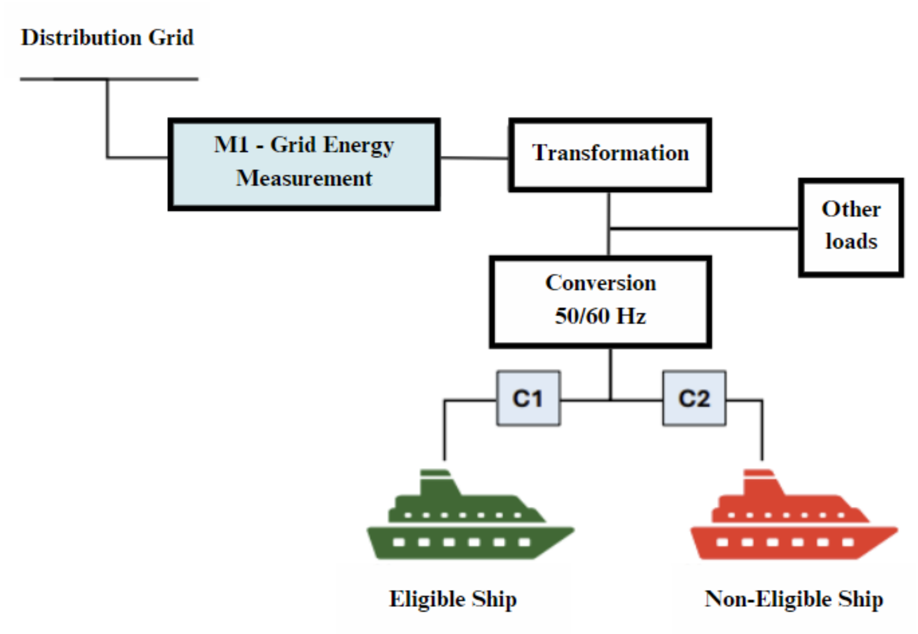
VI.4 New Regulation about CI

The role of the AdSPs with regard to ARERA's consultation document 211/2024/R/EEL, suggests the introduction of a discount measure, for a proportionate period, on the components of general system charges, applicable to the points of withdrawal of electricity also feed the infrastructure. ARERA stresses that “*it is essential that grid operators pass on the benefits of applying the measures to end users, i.e., owners, who are guaranteed fair and non-discriminatory access and supply conditions*” (ARERA, 211/2024/R/EEL, 2024). European Union, formally approved for Italy to apply a reduced tax rate for electricity supplied to ships berthed in ports (EUR-Lex, 2021), specifically from January 2022 to December 31, 2027. The AdSP is in charge of choosing an operator for the CI's infrastructure, according to the regulations proposed by ARERA, the infrastructure operator must also be the holder of the electricity supply contract and thus the owner of the point of delivery (POD). The shipowner who owns the vessel that docks at the dock and uses the service is configured as an end user, a customer of the CI operator, and is in fact the ultimate beneficiary of the facilities. The AdSP must verify the actual transfer of benefit to the end user. To identify the beneficiaries of CI infrastructure rebates, the use of the *Cassa per I Servizi Energetici e Ambientali* (CSEA) through an accreditation and self-certification procedure is deemed consonant. Regarding the application of the discount on general System Charges, ARERA prefers an ex-post approach, in which the CI network operator pays the full energy tariff and then receives a periodic reimbursement from the CSEA. This method of settlement would ensure that some situations that may arise are obviated. The port by its nature may require the use of energy even outside the CI service, e.g. lighting or refueling electric vehicles, coming out for that amount of energy consumed outside the discount. The same is true if ships in port do not qualify for the rebate. These situations can only be resolved by the CI operator being able to accurately and timely measure the energy flows delivered by the CI infrastructure to ships, using smart meters. The expense related to general system charges is assessed by applying a tariff based on three elements:

- Sum of a fixed fee (€/year)
- A fee proportional to the peak power drawn monthly at the POD (€/kW/year)
- An energy share (€/kWh)

1. In the first scenario, the port supplies all the energy dedicated to the service of the CI through the national grid. The structure of the network will follow the diagram in the figure VI.1.

VI.1 Cold Ironing diagram, energy drained by the national grid



Source: ARERA 2024

Specifically:

- The C1 meter detects the volume of energy supplied to the ships eligible for the facility (E_{C1});
- the M1 meter detects both the total energy withdrawalE_{prel} () and the monthly peak power (P_{imp}) at the POD;
- by applying the values of the A_{sos} and A_{rim} components and the data of E_{prel} and P_{imp}, the amount due for the OGS (SpesaOGS) can be calculated;

The amount of the repayment could then be assessed in proportion to the ratio between the energies:

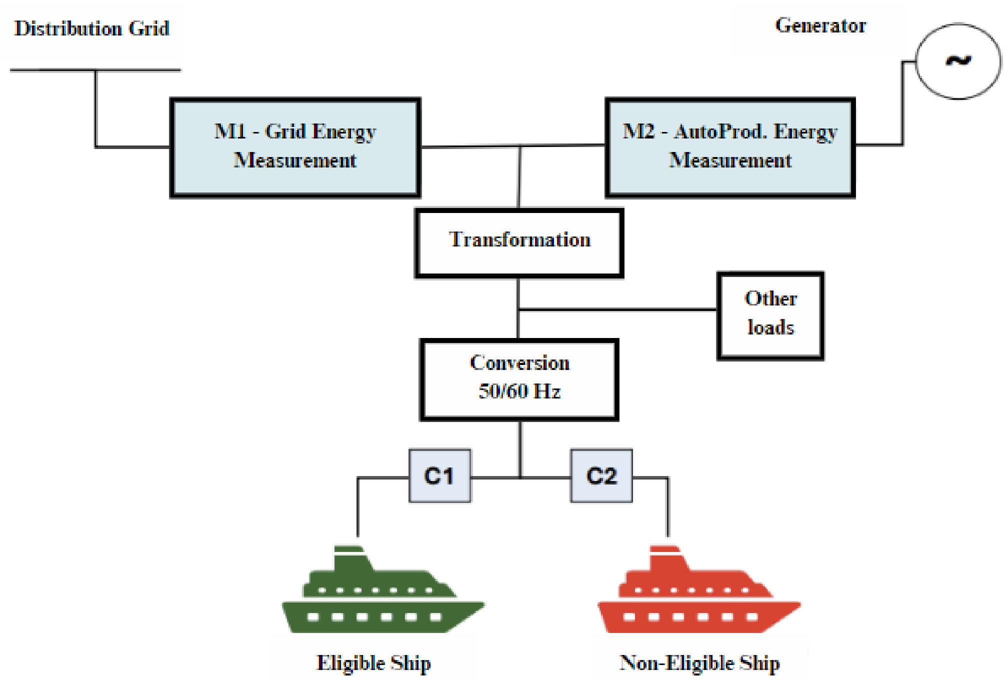
$$Reimbursment = ExpenseOGS\ x \frac{E_{c1}}{E_{prel}}$$

Specifically, the component A_{sos} concerns system charges intended to support renewable energy and cogeneration, while the A_{rim} groups other general system charges. This formula makes it possible to directly calculate the amount of reimbursement that will be given to the infrastructure manager and which will then have to be paid to the owner of the eligible vessel.

In its classic configuration, the CI system provides that all the energy necessary for the satisfaction of ships moored at the quay is charged to the national grid.

2. On the other hand, assuming that the port is able to self-produce energy, for example through the FER-1 and FER-3 projects, the service scheme would provide for a new component, i.e. electricity generation. The figure VI.2 shows the diagram[8]:

Figure VI.2 Cold Ironing diagram, including auto-generation



Source: ARERA 2024

[8] This scheme it is a simplification of the technical scheme and doesn't include ancillary elements like BESS or transformer.

- the C1 meter detects the volume of energy supplied to the ships eligible for the facility (EC1);
- the M2 meter detects the volume of energy produced by the generation plant (E_{prod});
- the M1 meter detects the volume of energy possibly withdrawn from the grid (E_{prel}) and the peak power (P_{imp}), if the energy and power produced locally are not sufficient to meet the needs;
- the values of the A_{sos} and A_{rim} components and the data of E_{prel} and Pimp, allow the calculation of the amount due for the OGS (ExpenseOGS).

The amount of the reimbursement cannot in this case be assessed by applying the same formula already illustrated for the simple case, because there would be a risk of generating distortions of various kinds; It is therefore proposed to adopt the following alternative formula:

$$Reimbursment = ExpenseOGS \ x \frac{E_{c1}}{E_{prel+}E_{prod}}$$

The variables that impact the reimbursement are therefore 4. To maximize reimbursement, it is advantageous to have high values of OGS expense and energy required, with low withdrawals from the grid or self-production. This is because since the reimbursement is paid on the basis of the energy supplied to the ships eligible for the facilitation, the increase in E_{c1} corresponds to an increase in the total reimbursement. By the same logic, a higher expense for system charges (ExpenseOGS) corresponds to a higher value of the reimbursement. Conversely, the total energy withdrawn and self-production reduce the amount of the dependent variable.

Therefore, working by maximizing the energy produced is in contrast to maximizing the reimbursement that is recognized for the energy of the national grid used for ships eligible for tariff facilitation.

VI.5 Electricity Pricing

In the second scenario, in which the port assumes, at least in part, the amount of electricity to be produced, it is necessary to understand how this reflects on the convenience for shipowners in using the service. Specifically, the convenience for the shipowner occurs when it is cheaper for the ship to use the CI service than to burn fuel while at berth. It is therefore necessary to take into account the price of fuel and the price of electricity serving the CI. With regard to the price of energy produced in port, a structure such as the following is suggested:

$$P_e = CAPEX + OPEX + ExpenceOGS + Markup$$

Specifically:

- P_e = Price for CI service €/kWh
- ExpenseOGS= Discounted OGS, reduced Asos and Arim €/kWh
- Infrastructure depreciation = Annual infrastructure depreciation cost €/kWh
- Markup = Remuneration for the service

The markup would theoretically not be directly payable to the AdSPMLO but rather could be considered as a contribution to the development of renewable energy within the port as if it represented an A_{sos} component but directed to the port that actually arranges the power plants for the production of clean energy.

Port of Savona/Vado Ligure

Assuming a CAPEX equal to the projects for the creation of the cold ironing infrastructure in the Port of Savona/Vado of €10.940.000 (NAT-3, and 50% of the FER-2 project), an OPEX equal to €115,000, a self-production level of 5 GWh and a useful life of 20 years, it is possible to estimate the cost of self-produced energy. To include both the cost of energy production and the installation of the cold ironing system in the formation of the price of auto-produced energy, a share of 50% of the CAPEX of the FER-2 project and 100% of the CAPEX of the NAT-3 projects is considered. The CAPEX share is therefore calculated as follows:

- CAPEX

Table VI.1 CAPEX contribution share for Savona/Vado Ligure

SAVONA	%	Share of CAPEX		CAPEX
FER-2	50% share	2.150.000	NAT-3	8.790.000
Final CAPEX	**10.940.000**			

Source: Our Elaboration

- OPEX

Table VI.2 OPEX contribution share for Savona/Vado Ligure

SAVONA	%	Share of OPEX		OPEX
FER-2	50% share	25.000	NAT-3	90.000
Final OPEX	**115.000**			

Source: Our Elaboration

Following the same methodology for the port of Savona and Vado Ligure these computation comes out:

Yearly Capital Expenditure (CAPEX) depreciation in 20 years:

$$\frac{10.940.000\ €}{20\ years} = 547.000€/year$$

CAPEX cost per kWh:

$$\frac{547.000\ €}{5.000.000\ kWh} = 0{,}1094\ €/kWh$$

Operation and Maintenance (OPEX) cost per kWh:

$$\frac{115.000\ €}{5.000.000\ kWh} = 0{,}023\ €/kWh$$

Expense for OGS (Asos and Arim) – Assumed as 0,003 €/kWh

Assuming a Markup of 5%

Applying the previous formula:

$$P_e = CAPEX + OPEX + ExpenceOGS + Markup$$

Hence,

$$P_e = 0{,}1094€/kWh + 0{,}023€/kWh + 0{,}003€/kWh + 5\%$$

$$P_e = 0{,}1422\ €/kWh$$

The esteemed price for auto-produced electricity in the port of Savona/Vado Ligure is 0,1422 €/kWh.

Port of Genoa

Assuming a CAPEX equal to the projects for the creation of the cold ironing infrastructure in the Port of Genoa of € 45.190.000 (NAT-1, NAT-3, and 50% of the FER-1 and FER-3 stage1 projects), an OPEX equal to €400,000, a self-production level of 23 GWh and a useful life of 20 years, it is possible to estimate the cost of self-produced energy.

To include both the cost of energy production and the installations of the cold ironing system in the formation of the price of self-generated energy, a share of 50% of the CAPEX of FER projects and 100% of the CAPEX of NAT-1 and NAT-3 projects is considered. The CAPEX share is therefore calculated as follows:

Table VI.3 CAPEX contribution share for Genoa/Prà

	%	Share of CAPEX		CAPEX
FER-1	50% share	4.800.000	NAT-1	10.000.000
FER-3	50% share	7.500.000	NAT-3	22.890.000
Subtotals		12.300.000	+	32.890.000
Final CAPEX	**45.190.000**			

Source: Our Elaboration

OPEX is calculated in the same way, following the data provided by DEASP.

Hence,

Table VI.4 OPEX contribution share for Genoa/Prà

	%	Share of OPEX		OPEX
FER-1	50% share	50.000	NAT-1	700.000
FER-3	50% share	50.000	NAT-3	180.000
Subtotals		100.000	+	880.000
Final OPEX	**980.000**			

Source: Our Elaboration

Yearly Capital Expenditure (CAPEX) depreciation in 20 years:

$$\frac{45.190.000\ €}{20\ years} = 2.259.500€/year$$

CAPEX cost per kWh:

$$\frac{2.259.500\ €}{23.000.000\ kWh} = 0{,}0982\ €/kWh$$

Operation and Maintenance (OPEX) cost per kWh:

$$\frac{980.000\ €}{23.000.000\ kWh} = 0.0426\ €/kWh$$

Expense for OGS (Asos and Arim) – Assumed as 0.003 €/kWh

Assuming a Markup of 5%

Applying the previous formula:

$$P_e = CAPEX + OPEX + ExpenceOGS + Markup$$

Hence,

$$P_e = 0{,}0982€/kWh + 0{,}0426€/kWh + 0{,}003€/kWh + 5\%$$

$$P_e = 0{,}1501\ €/kWh$$

The esteemed price for auto produced electricity in the port of Genoa is 0,1501 €/kWh.

Comparing the cost of electricity auto produced in the port of Genoa and the port of Savona underlines some differences in the cost structure:

- CAPEX per kWh: the installation cost for the port of Savona is 0,1094 €/kWh (table VI.1) which is slightly higher compared to Genoa 0,0982 €/kWh (table VI.3). Nevertheless, the total CAPEX for Genoa is four times Savona's; the amount of auto produced energy is significantly lower, increasing the kWh unit cost.
- OPEX per kWh: considering the Operation & Maintenance costs, Savona presents a significantly lower cost that is 0,023 €/kWh (table VI.2) compared to Genoa's which is almost two times more, 0,0426 €/kWh (table VI.4). This evaluation underlines that even if the capital investment per unit is higher, the O&M costs are more efficient in the westernmost harbor.
- Total cost per kWh: including the cost for CAPEX, OPEX, OGS Expenses, and a markup of 5%, the estimated price for auto-produced energy is similar for the two ports, even with their different cost structure. However, the electricity auto produced in the port of Savona is slightly less expensive.

Scenario analysis in the Port of Genoa

This first assessment was made following the first stage scenario of the FER-3 project regarding wave electricity production (table VI.5). Given the AdSPMLO investment project, it is also necessary to consider a forecast of the costs and capacity of the plants once fully developed.

The following table expresses useful data about the four scenarios:

Table VI.5 Different Auto Production Levels in the Port of Genoa

FER-3	Capacity	CAPEX	OPEX	GWh/year
Stage I	3 MW	15.000.000	100.000	23
Stage II	27 MW	115.000.000	500.000	128
Stage III	36 MW	150.000.000	800.000	168
New Breakwater	54 MW	260.000.000	19.000.000	239

Source: Our Elaboration

In order to understand the real potential of the auto-production impact over the unitary cost of electricity produced, also Stage II and Stage III calculations have been computed.

FER-3 Stage II

Table VI.6 CAPEX contribution share for FER-3 Stage II

	%	Share of CAPEX		CAPEX
FER-1	50% share	4.800.000	NAT-1	10.000.000
FER-3	50% share	50.00.000	NAT-3	22.890.000
Subtotals		54.800.000	+	32.890.000
Final CAPEX	**87.690.000**			

Source: Our Elaboration

Hence,

Table VI.7 OPEX contribution share for FER-3 Stage II

	%	Share of OPEX		OPEX
FER-1	50% share	50.000	NAT-1	700.000
FER-3	50% share	250.000	NAT-3	180.000
Subtotals		250.000	+	880.000
Final OPEX	**1.130.000**			

Source: Our Elaboration

Yearly Capital Expenditure (CAPEX) depreciation in 20 years:

$$\frac{87.690.000\ €}{20\ years} = 4.384.500€/year$$

CAPEX cost per kWh:

$$\frac{4.384.500\ €}{128.000.000\ kWh} = 0{,}0343\ €/kWh$$

Operation and Maintenance (OPEX) cost per kWh:

$$\frac{1.130.000\ €}{128.000.000\ kWh} = 0.0088\ €/kWh$$

Expense for OGS (Asos and Arim) – Assumed as 0.003 €/kWh

Assuming a Markup of 5%

Applying the previous formula:

$$P_e = CAPEX + OPEX + ExpenceOGS + Markup$$

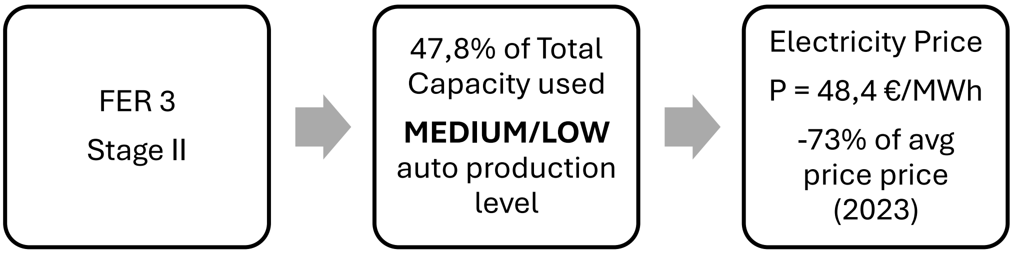
Hence,

$$P_e = 0{,}0343\ €/kWh + 0{,}0088\ €/kWh + 0{,}003€/kWh + 5\%$$

$$P_{e\ S2} = 0{,}0484\ €/kWh$$

In this scenario, the cost of energy including a 5% markup is 0.0484 €/kWh, significantly lower than in the previous one.

Figure VI.3 Stage II Recap



Reference: Our elaboration

Tables VI.5 and VI.6 led to the evaluation of Stage II of the FER-3 project. In this scenario, the auto produced electricity price is equal to 48,4€/MWh which is much lower than the average electricity price for industrial clients in 2023(Figure VI.1).

FER-3 Stage III

Table VI.8 CAPEX contribution share for FER-3 Stage III

	%	Share of CAPEX		CAPEX
FER-1	50% share	4.800.000	NAT-1	10.000.000
FER-3	50% share	75.000.000	NAT-3	22.890.000
Subtotals		79.800.000	+	32.890.000
Final CAPEX	**112.690.000**			

Source: Our Elaboration

Hence,

Table VI.9 OPEX contribution share for FER-3 Stage III

	%	Share of OPEX		OPEX
FER-1	50% share	50.000	NAT-1	700.000
FER-3	50% share	400.000	NAT-3	180.000
Subtotals		450.000	+	880.000
Final OPEX	**1.330.000**			

Source: Our Elaboration

Yearly Capital Expenditure (CAPEX) depreciation in 20 years:

$$\frac{112.690.000\ €}{20\ years} = 5.634.500€/year$$

CAPEX cost per kWh:

$$\frac{5.634.500\ €}{168.000.000\ kWh} = 0{,}0335\ €/kWh$$

Operation and Maintenance (OPEX) cost per kWh:

$$\frac{1.330.000\ €}{168.000.000\ kWh} = 0.0079\ €/kWh$$

Expense for OGS (Asos and Arim) – Assumed as 0.003 €/kWh

Assuming a Markup of 5%

Applying the previous formula:

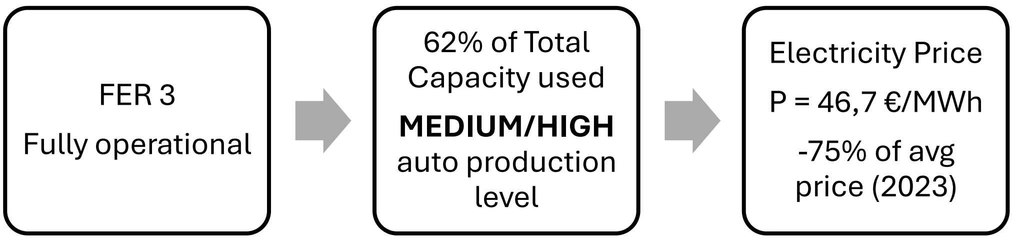
$$P_e = CAPEX + OPEX + ExpenceOGS + Markup$$

Hence,

$$P_e = 0{,}0335\ €/kWh + 0{,}0079\ €/kWh + 0{,}003€/kWh + 5\%$$

$$P_{e\ S3} = 0{,}0467\ €/kWh$$

Figure VI.4 FER-3 Fully operational recap



Reference: Our elaboration

This last phase of the FER-3 project is able to lower the electricity price through a medium high level of production reaching 46,7 €/MWh which is consistently less than the average price in 2023 (table VI.4).

New Breakwater Project

Table VI.10 CAPEX contribution share for FER-3 New Project - OWCM

	%	Share of CAPEX		CAPEX
FER-1	50% share	4.800.000	NAT-1	10.000.000
FER-3	50% share	133.000.000	NAT-3	22.890.000
Subtotals		137.800.000	+	32.890.000
Final CAPEX	**170.690.000**			

Source: Our Elaboration

Hence,

Table VI.11 OPEX contribution share for FER-3 New Project - OWCM

	%	Share of OPEX		OPEX
FER-1	50% share	50.000	NAT-1	700.000
FER-3	50% share	9.500.000	NAT-3	180.000
Subtotals		9.550.000	+	880.000
Final OPEX	**10.430.000**			

Source: Our Elaboration

Yearly Capital Expenditure (CAPEX) depreciation in 20 years:

$$\frac{170.690.000\ €}{20\ years} = 8.534.500€/year$$

CAPEX cost per kWh:

$$\frac{8.534.500\ €}{239.000.000\ kWh} = 0{,}0357\ €/kWh$$

Operation and Maintenance (OPEX) cost per kWh:

$$\frac{10.430.000\ €}{239.000.000\ kWh} = 0{,}0436\ €/kWh$$

Expense for OGS (Asos and Arim) – Assumed as 0.003 €/kWh

Assuming a Markup of 5%

Applying the previous formula:

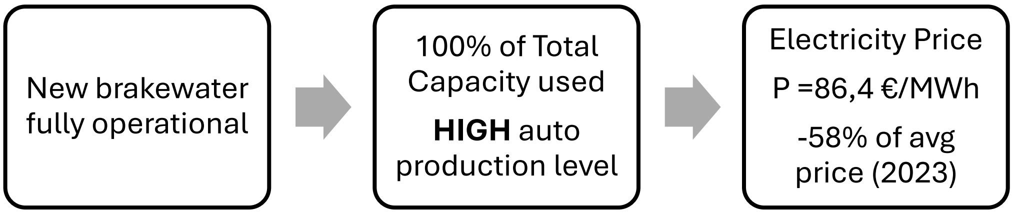
$$P_e = CAPEX + OPEX + ExpenceOGS + Markup$$

Hence,

$$P_e = 0{,}0357\ €/kWh + 0{,}0436\ €/kWh + 0{,}003 €/kWh + 5\%$$

$$P_{e\ NewProject} = 0{,}0864\ €/kWh$$

Figure VI.5 New Breakwater Impact



Reference: Our elaboration

Resuming the calculations made for the theoretical price for the sale of self-generated energy within the port of Genoa:

- Stage I: The estimated price per kWh is 0,1501 €/kWh equal to 150,10€/MWh
- Stage II: The estimated price per kWh is 0,0484 €/kWh equal to 48,40 €/MWh
- Stage III: The estimated price per kWh is 0,0467 €/kWh equal to 46,70 €/MWh
- New Breakwater Project: The estimated price per kWh is 0,0864 €/kWh equal to 86,40€/MWh

The table VI.12 represents how the final electricity price has been calculated.

Table VI.12 Pricing for Auto-Produced Electricity in the Port of Genoa

FER calculated as 50% competence								
	$CAPEX_{s1}$	$CAPEX_{s2}$	$CAPEX_{s3}$	$CAPEX_{NP}$	$OPEX_{s1}$	$OPEX_{s2}$	$OPEX_{s3}$	$OPEX_{NP}$
FER-1	4.800.000				50.000			
FER-3	7.500.000	50.000.000	75.000.000	133.000.000	50.000	250.000	400.000	9.500.000
NAT projects Calculated as 100% competence								
	$CAPEX_{s1}$	$CAPEX_{s2}$	$CAPEX_{s3}$	$CAPEX_{NP}$	$OPEX_{s1}$	$OPEX_{s2}$	$OPEX_{s3}$	$OPEX_{NP}$
NAT-1	10.000.000				700.000			
NAT-3	22.890.000				180.000			
OGSExp	0,003€/kWh							
Markup	5% of the cost							
Scenario	Stage I		Stage II		Stage III		New Project	
Final price	0,1501 €/kWh		0,0484 €/kWh		0,0467 €/kWh		0,0864 €/kWh	

Source: Our Elaboration

Introducing a higher share of self-production has a very positive effect on price. When the capacity of port owned power plant increases, fixed costs like CAPEX and part of the OPEX are amortized over the increasing amount of energy produced.

This cost structure creates an economy of scale that can reduce the cost per kWh produced due to the increasing amount of electricity generated; the effect can be seen especially in Stage II and Stage III scenarios, where an increase in CAPEX and OPEX corresponds to a large production capacity. As table VI.12 shows, the cost per kWh ratio is reduced making the plant more economically efficient with prices equal to 48,40 €/MWh and 46,70 €/MWh, respectively.

The new project based on the dam under construction has a larger production capacity of 239 GWh but has a higher price than previous stages at 86,40 €/MWh. The price which turns out to be almost double the Stage III esteem increases due to higher costs. The OPEX increases significantly generating a negative impact on the final price of auto-produced energy.

This phenomenon is also helped by the type of plant, as the electricity generated by the wave is part of the renewable sources. The OWCM system exploits wave motion, which in itself is free. Therefore, as with solar panels or wind turbines, the marginal cost of producing an extra kWh is almost zero. For this reason, the affordability of the new project related to the construction of the new dam will depend mainly on the ability of the AdSPMLO and the Stakeholders to manage the annual costs associated with the use of the facility.

In order to understand how this value can be useful for shipowners, it is considered necessary to compare the price of electricity with the price of marine fuel. Given that, it is fundamental to analyse how ships commonly generate electricity onboard.

The marine fuel most commonly used by ships calling at Genoa is MGO (marine gas oil), which is lighter than heavy fuels such as HFO. When ships do not use cold ironing, as in most cases, they keep their auxiliary engines running using their function as generators, converting the energy of the fuel combustion into electricity.

During 2023, the €/mt price of MGO in Europe averaged €801.66. To make an accurate calculation of the cost of electricity produced on board, it is necessary to assume a value for the efficiency of the generator, in this case, 45%. This leads to a final value of approximately 0,15€/kWh. This value drops considerably as the quality of the fuel deteriorates, i.e. as its sulphur content increases. If the price for VLSHFO is taken into account, the marginal cost for producing one kWh decreases by about 30% (Ship&Bunker, 2024).

Analyzing only the cost aspect between self-generation and on-board generation, it is clear that the former allows considerable savings with respect to fuel consumption. However, ARERA has defined an average price for industrial users of 19,51 cents/kWh for 2023 equal to 0,1951€/kWh, which raises the cost of energy for a ship that is also supplied from the national grid enormously. The advantage for the shipowner is the introduction, at least in part, of the use of a share of self-generated energy within the port, paid at a more competitive price when compared to the price of fuel or electricity from the national grid.

VI.6 Where to direct energy

The auto produced energy in the Port of Genoa should be managed to maximize benefits both for society and port stakeholders, specifically private companies operating in the port areas. In the analysis carried out, a very important part of the energy comes from the dam which represents the infrastructure of the port. For this reason, the energy produced should be used to support public services and community projects, enhancing port sustainability. On the other hand, the energy produced by the FER-1 project that exploits solar panels should be used to help reduce the cost of energy bills to those who installed PVs on its rooftop. This approach would be aligned with the concept of sustainable growth being valuable both for port stakeholders and for the support of sustainable energy management, moreover to promote Port Energy Communities (PRECs).

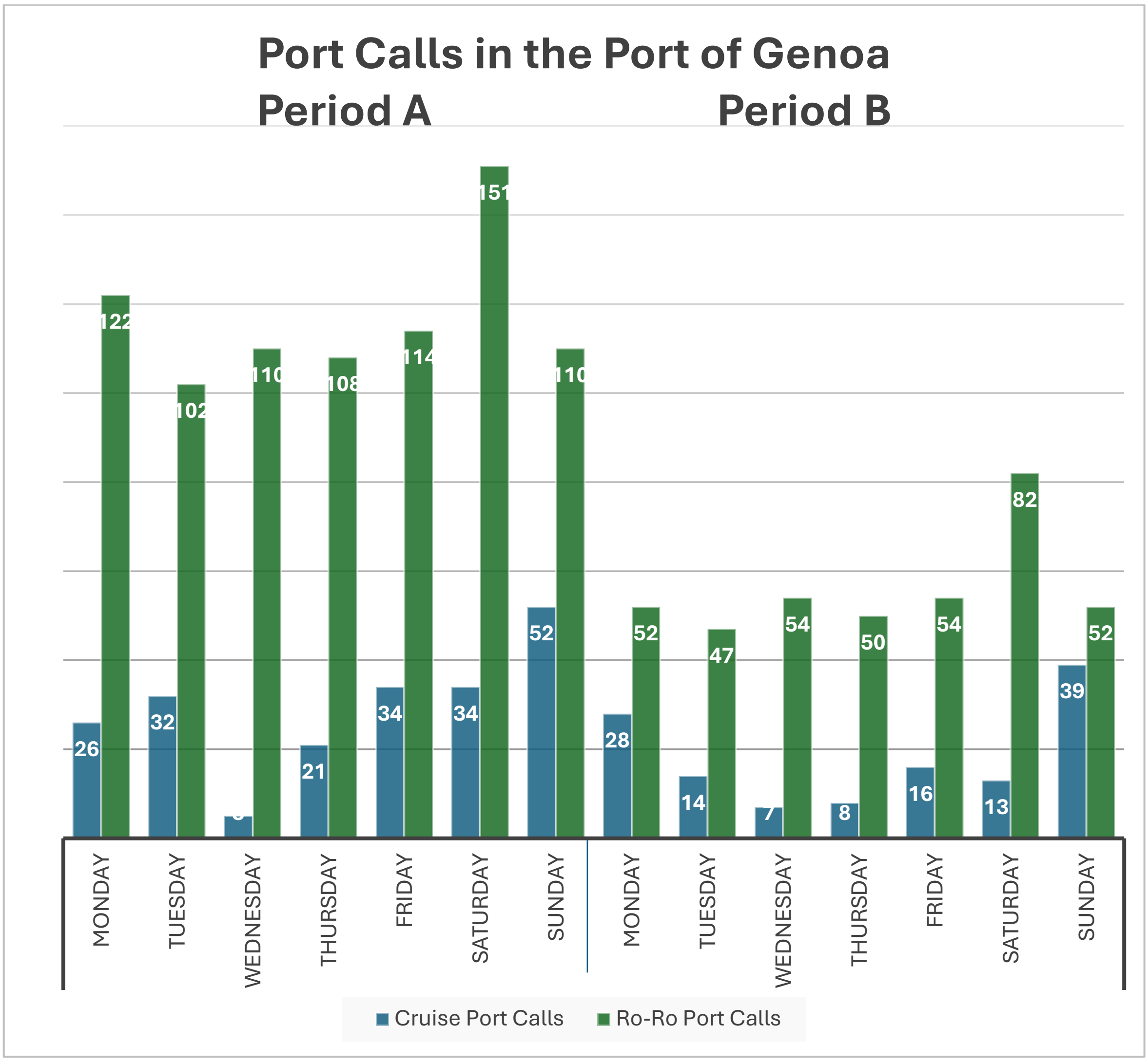
For what concerns the energy produced by the FER-3 New Project, it should be used mainly to reduce the impact of berthed ships by the CI service.

Analyzing port call data, two periods have been identified:

- Period A = from 1st April 2023 to 30th September 2023
- Period B= from 1st October 2023 to 31st March 2024

The first period is considered as “summer” while the second period is “winter.” There are fewer port calls during winter due to fewer tourists traveling than in summer. Specifically, the evaluation was conducted by aggregating daily data within the two periods by dividing them by days of the week to identify the stationing trend of cruise ships and ferries, the following results in Table VI.6 were obtained:

Figure VI.6 Average Weekly Port Calls Trend in the Port of Genoa/Prà



Source: Our Elaboration based on the DSFE database

In the port of Genoa, in Period A, the distribution of cruise calls is more uniform during the week while on the weekend there are distribution peaks. For RO-RO ships, Saturday is the busiest day with 151 Calls. Period B is characterized by much lower traffic decrementing cruise and Ro-Ro calls, nevertheless, Ro-Ro traffic is still equally distributed underling the consistency of the presence of this type of vessel in Genoa's port areas during the year. The same methodology has been applied to the Savona's dataset.

The port of Savona presents lower traffic in terms of port calls but for what concerns the Ro-Ro vessels during the whole year, those are more equally distributed than Genoa's data. In Period A, Savona registered more calls for cruise ships during the weekend compared to Genoa, having Saturday as the only day of the distribution of the two ports in which cruise calls are more than Ro-Ro ones. During Period B, Ro-Ro total calls are slightly reduced, while on Tuesday to Thursday, cruise calls almost disappear.

In general, Genoa has more calls than Savona, which has lower numbers but a more regular distribution of calls. For both ports, cruise ship traffic is concentrated at weekends, especially on Saturdays. Ro-Ro also increases their presence at weekends, presenting however a more regular distribution during the week.

Considering the development projects of the port areas, the port of Genoa certainly has a bigger push in terms of self-handling possibilities as presented above. In order to verify how the self-production from the FER-3 project could be used for the CI service, it was necessary to combine data concerning energy production and port calls within the port of Genoa.

VII. Reflection on CI Service, the NAT-3 Evaluation

VII.1 Port of Genoa

To investigate properly the availability of energy in the Ports of Genoa, the previous analysis has been linked with the port calls data obtained by the DSFE software presented in Chapter IV.

In order to compare energy production and cargo given by ships at the berth, some assumptions need to be made:

Assumptions:

- The port of Genoa has been considered for the future possibility of producing a large amount of energy, specifically the new Genoa dam project. The OWCM will produce 54,41 MWh. According to AdSPMLO calculations (239 GWh/182 days/24h). While the FER-1 production is 1,13 MWh combined with an average of 1,5 MWh for the S1 FER-3.
- The inconsistency of renewables is mitigated by their structure in that wave motion is more stable than solar technology, and the port's ability to mitigate volatility with the use of BESS storage systems is also assumed.
- Electrified berths in the Port of Genoa (NAT-3): 4 Ro-Ro, 2 Cruises
- Energy consumption for ships (both cruises and Ro-Ro) remains constant for each call, regardless of the day of the week or time of year.
- All the ships are able to exploit CI technology
- There are no significant energy losses during the production, distribution, or eventual storage of the energy produced, or during the consumption of berthed ships.

Using the ship transit data tracked via AIS it was possible to isolate the transit data of RO-Ro and Ro-Ro Pax ferries and cruise ships. The software calculates the consumption of each ship transiting the port areas and categorizes the various stages of its operations by monitoring its movement via AIS. To estimate when self-handling can affect the cost-effectiveness of the CI system, it was first necessary to aggregate the data for the two types of ships, ferries, and cruises. The following table VII.1 presents the data on the theoretical energy consumption by the auxiliary engines of ships at the quayside. Historical data from the beginning of 2023 to April 2024 were taken into account for ships that have moored in the 6 berths that will offer the electrification.

Table VII.1 Average Port Calls Mooring Consumption in the Port of Genoa/Prà

	MW when moored	The sum of mooring hours	Average mooring hours	Hourly consumption (MWh)
Passenger	56.648,36	6.057		
Passenger AIS	32,43	2.199		
CRUISE	**56.680,79**	**8.256**	**16**	**6,87**
Ro-Ro Passenger	941,98	49.176		
Ro-Ro Cargo	69.947,37	922		
RO-RO	**70.889,34**	**50.099**	**31**	**1,41**

Source: Our Elaboration based on the DSFE database

The DSFE software dataset made it possible to aggregate data on the energy consumption of the ships' auxiliary engines. Specifically, the NAT-2 project involves the electrification of docks used by cruise ships and Ro-Ro ferries. The data of the two types were formed by aggregating data from the passenger and passenger (AIS) categories for cruises, and Ro-Ro passenger and Ro-Ro Cargo for ferries.

The same aggregation was made for the hours ships were berthed, identifying an average stop for cruise ships of 16 hours and an average stop for ferries of 31 hours. The calculation of the average hourly consumption for the two categories is the result of dividing the energy consumption by the total berthing hours. The average hourly consumption in €/MWh makes it possible to calculate the average expenditure per port call as follows:

Energy consumption per berth:

- 4 Ro-Ro berths each consumes 1,4 MWh:

$$4 \, x \, 1{,}4MWh = 5{,}6 \; MWh$$

- 2 Cruise berths each consumes 6,9 MWh

$$2 \, x \, 6{,}9MWh = 13{,}8 \; MWh$$

Hence, the final hour consumption considering all berth working at the same time is given by:

$$5{,}6 \; MWh + 13{,}8 \; MWh = 19{,}4 \; MWh$$

The 2022 AdSPMLO NAT-3 project concerns the electrification of docks through the installation of CI technology. The possibility for quays to power berthed ships with electricity offers significant environmental benefits. The project follows the previous NAT-1, allocated in 2019 for the electrification of two berths in the port of Prà. This second investment, which is larger than the NAT-1, as described above, involves an investment of about € 30.000.000 and aims to electrify 8 berths between the Port of Genoa and the Port of Savona.

In addition, the docks in question, specifically 4 berths for ferries and 2 for cruise ships for the Port of Genoa, are particularly integrated with the urban context of the city. *Inside the cruise and ferry terminal of Genoa maritime station (Ponte dei Mille, Ponte Andrea Doria with reference to cruise traffic, Calata Chiappella, Ponte Caracciolo and Ponte Colombo with reference to ferry traffic;* table VII.2 summarizes the landings involved:

Table VII.2 Involved Berths in the Port of Genoa

	CRUISES	**RO-RO**
Number of berths	Ponte dei Mille	Calata Chiappella
	Ponte Andrea Doria	Ponte Caracciolo
	-	Ponte Colombo
	2	**4**

Source: DEASP 2022

After evaluating the possibility of self-producing energy in the port, assuming that the capacity of the FER-1 and FER-3 project using the FER-3 stage 1, the port of Genoa will benefit from a self-production of about 23 GWh/year.

As highlighted in Chapter VI, it is possible to investigate the possibility of using self-produced energy to support the CI service, assuming that the regulatory framework defined by ARERA and GSE comes in support of the port authorities, it is assumed that the AdSPMLO can sell the auto produced electricity to ships at rest, at a cost price adjusted for a mark-up as assessed in paragraph V.5. In this case, ships using the CI are eligible end-users for energy absorption at a reduced price.

Since the total consumption is equal to 19.4 MWh representing energy demanded for the 6 berths considered by the NAT-3 project in the Genoa basin. To introduce the impact of auto produced electricity within the port, it is necessary to consider the capacity of the self-production facilities. As outlined above, the planned investments for the port of Genoa are the FER-1 and FER-3 projects, capable of producing about 23 GW from renewable sources such as photovoltaics and wave motion. The current amount of self-generation that could be allocated to ships is the theoretical result of evaluating the projects contained in the DEASP. To date, no energy is auto-produced for use outside the port buildings. Therefore, the hourly capacity of FER-1 and S1 FER-3 is taken as the starting value for the calculation of auto-production.

In order to equally distribute the 2,63 MWh self-generated according to the relative energy needs for each type of berth, the following procedures were carried out:

$$\frac{5,6}{19,4} x\ 2,63\ MWh = 0,7594\ MWh$$

To distribute this energy among the four ferries, each will receive:

$$\frac{0,7594}{4} = 0,1899\ MWh$$

The auto produced energy for a single Ro-Ro ship is equal to 0,1899 MWh.

For what concern cruise ships, auto produced energy available is:

$$\frac{13,8}{19,4} x\ 2,63\ MWh = 1,8706\ MWh$$

Hence, the share of auto produced electricity available for a single cruise ship is:

$$\frac{1,8709}{2} = 0,9353\ MWh$$

To sum up, each ferry receives 0.1899 MWh and each cruise receives 0.9353 MWh.

In order to calculate the average expenditure per stay, it is necessary to introduce the economic component of the price. Specifically, the average price for 2023 in MWh and the theoretical price of auto produced electricity are presented in the table VI.12.

Specifically, the national grid price has been considered an electricity price of 195,1€/MWh while the esteem for the internal auto produced electricity is:

Table VII.3 Resume of Prices Obtain in the Chapter V Calculations

Port of Genoa Scenario 1 – Stage I	150,1 €/MWh
Port of Genoa Scenario 2 – Stage II	48,4 €/MWh
Port of Genoa Scenario 3 – Stage III	46,7 €/MWh
Port of Genoa Scenario 4 - New Breakwater Project	86,40 €/MWh
Port of Savona	142,2 €/MWh

Source: Our Elaboration

The two scenarios that are most likely are Scenario 1 and Scenario 4, as the former is a benchmark of the current situation, while the latter represents what was approved by the Council of Ministers in 2022 and will be completed with the construction of the new breakwater.

Energy expenditure draining energy from national grid:

$$RoRo\ Vassels = 1.4\ x\ 31\ x\ 195,1 = 8.467,34\ €$$

$$Cruise\ Ships = 6,9\ x\ 16\ x\ 195,1 = 21.539,04\ €$$

Including the share of auto produced energy the following results:

Scenario 1 - Actual

Energy expenditure including Genoa's port auto-produced energy:

Ro-Ro Vessels:

$$Energy\ RoRo\ National\ Grid = 1{,}2101\ x\ 31\ x\ 195{,}1 = 7.318{,}80\ €$$

$$Energy\ RoRo\ autoproduction\ share\ S1 = 0{,}1899\ x\ 31\ x\ 150{,}1 = 883{,}62\ €$$

Hence, the total average expense is:

$$Total\ average\ expense\ RoRo\ S1 = 7.318{,}80 + 883{,}62 = 8.200{,}42\ €$$

Cruise Ships:

$$Energy\ Cruise\ National\ Grid = 5{,}4647\ x\ 16\ x\ 195{,}1 = 17.058{,}60\ €$$

$$Energy\ Cruise\ autoproduction\ share\ S1 = 0{,}09353\ x\ 16\ x\ 150{,}1 = 224{,}62\ €$$

Hence, the total average expense is:

$$Total\ average\ expense\ Cruise\ Ships = 17.058{,}60\ +\ 224{,}62 = 17.283{,}22\ €$$

Results using actual production

The switch to the use of CI resulted in a cost reduction of 3,15% equal to 266,92 € for Ro-Ro ships and 19,76% equal to 4.255,82 € for cruise ships compared to the cost of energy from the national grid, showing greater savings for cruise ships.

Comparing the other self-production scenarios does not seem to be particularly meaningful, since the development of stage II and stage III of the FER-3 project would guarantee the following levels of energy availability for ships, sufficient to fully cover their needs, even if the energy would not be used only for CI service.

Scenario 4 – New Dam Project

In scenario 4, in which the FER-3 project is expected to be fully operational, the amount of energy available to be supplied to ships increases exponentially. It turns out to be enough to support the consumption of all the occupied berths at the same time.

Hence, by the ship side, the cold ironing service cost will be the following:

$$RoRo\ Vassels = 1.4\ x\ 31\ x\ 86{,}40 = 3.749{,}76\ €$$

$$Cruise\ Ships = 6{,}9\ x\ 16\ x\ 86{,}40 = 9.538{,}56\ €$$

The total cost for berth fell by 55.72%.

These values can certainly represent a turning point for the port of Genoa, which would become the first Italian port to make the CI service economically sustainable, generating benefits for both shipowners and the community and the port itself, considering the strategic value of this goal and the 5% markup. In addition, covering the consumption of idle ships would employ only 43,34 % of its production capacity, the remaining part, corresponding to full capacity at 739 MWh per day would be available at the theoretical price of 86,40 €/MWh. Creating a significant advantage to really achieve the goal of becoming a green port.

VII.2 Port of Savona/Vado Ligure

The NAT-3 project includes two berths to be electrified in the port of Savona. Specifically, the following cruise ship berths will be electrified:

- Calata della Valle
- Banchina Don Genta

One-third of the 30.000.000 € investment is dedicated to offering the CI service in the port of Savona which counts 384 port calls from cruise ships in the last year according to the DSFE software. With respect to the port of Genoa, the AdSPMLO, in agreement with the public authorities of the city of Savona, decided to focus on cruise ships as the first users of the CI service. This choice is mainly based on the largest consumption, in fact, as data show, reducing the impact of cruise ships is the biggest challenge for Mediterranean ports.

The data collected by the DSFE software framework the situation in the port of Savona for what concerns cruise ships:

Table VII.4 Average Port Calls Mooring Consumption in the Port of Savona/Vado Ligure

FER-2	**MW when moored**	**Sum of mooring hours**	**Average mooring hours**	**Hourly consumption (MWh)**
CRUISE	**25.651.083,7**	**5.874**	**29,7**	**4,34**

Source: Our Evaluation

Data highlights an average hour consumption of 4,34 MWh per hour (table VII.4), which is slightly less than Genoa's port data. This difference may be explained by the cruise ships size that berth in the two ports.

Considering the hour consumption, is possible to compute a theoretical CI economic benefit following the evaluation already presented in Genoa's dataset. Starting with the auto-production in the Port of Savona, supplied by the FER-2 project that is able to produce 3,6 MWh. The price for auto-produced energy in the port of Savona is 0,1422 €/kW while the average price from the national grid is still 195,1 €/MWh.

Given all the information needed to calculate the average cost of the energy required per berth, it is possible to compute the cost of draining electricity from the national grid

$$Cruise\ Ships = 4{,}34\ x\ 29{,}7\ x\ 195{,}1 = 25.148{,}00\ €$$

Dividing the energy consumption per single cruise ship at the quayside, and including a share equal to half of the self-production generated by the FER-2 project equal to 1.8 MWh:

$$Cruise\ Ships = 2{,}54\ x\ 29{,}7\ x\ 195{,}1 = 14.717{,}96\ €$$

$$Cruise\ Ships = 1{,}8\ x\ 142{,}2\ x\ 29{,}7 = 7.602{,}02\ €$$

Total expense including the auto-production share is equal to 22.319,98 €, equal to an expense reduction of 11,25%.

Considering the limited possibility of producing energy through the FER-2 project alone, the results obtained are encouraging and pave the way for future implementations.

In the current state of the limited possibilities of the Port of Savona to auto produce energy, it can only marginally contribute to the lowering of the cost of the CI service, while it could have a more effective impact in lowering the costs of electricity for concessionaires in the port.

Conclusions

Port infrastructures are categorized as major energy users, with energy consumption originating partly from the ships stationed in the port and the other part coming from port activities. At the macro level, the EU aims to limit pollution without limiting the economic growth of the member states, to increase internal traffic as envisaged by the TEN-T network, ports acquire an even more central role. To date, Italian ports pursue sustainable development through balanced economic, environmental, and social growth. On this premise, the purpose of this analysis is to offer a different contribution, focusing on how a clean energy supply could impact the port and its stakeholders. Given that ports operate in very specific contexts, affected in a peculiar way by the regulatory, geographical, and social situations, it is necessary to focus on a specific case study, trying to draw out highlights that could provide replicable elements in other Italian ports.

In the context of evolution, the Ports of Genoa (formally AdSPMLO) are experiencing a period of important development that can radically transform the way the port and its stakeholders use energy. The important port planning (by the port regulatory plan - PRP) in the ports of Genoa provides an ideal case study to deepen the opportunities that an Italian port can seize to pursue sustainable development. In this sense, port planning turns out to be a powerful strategic tool to push the port towards new objectives that must necessarily be aligned with the regulatory vision, also for the fundamental role of the Ports of Genoa as a gateway to northern Europe from the Mediterranean Sea.

Starting from the ship side, the best technology to limit emissions in port areas appears to be cold ironing (CI), highlighting the maturity of these systems that have been used for about twenty years. For this reason, the focus of the analysis is based on how to make the service convenient by specifically analyzing how the port supplies energy. Currently, the Ports of Genoa is carrying out different projects for the installation of systems to auto-produce energy in the ports of Genoa and Prà and the ports of Savona and Vado Ligure.

The possibility of auto-producing electricity shifts the focus of the analysis to the impact that a substantial change in energy supply will entail. Evidence underlines how new installations must be assisted by accumulation and storage systems with a view to energy security, which is even more fundamental in a highly energy-intensive context such as the port area. Among the Ports of Genoa's planned investments, the most onerous and definitely at an embryonic stage, involves the installation on Genoa's new breakwater of modules capable of converting the kinetic and potential energy of seawater into electrical energy (‘FER-3’).

The production curve of photovoltaic and oscillating water column (OWCM) systems is analyzed, highlighting how these are by their nature unstable. It is necessary to use electricity storage systems, first of all, BESS systems, secondly, looking to the future, it can be assumed that further investments will be made to be able to produce and store hydrogen.

Considering the area of operation of the Ports of Genoa it is necessary to underline how the specific analysis for each of the four basins is complex, auto-production projects, especially those in the embryonic phase, include homogeneous evaluations that clash with the desire to carry out an analysis focused on each basin.

The investments developed for the FER-1, FER-2, and FER-3 projects are currently aimed at electricity production to reduce the port's carbon footprint and mitigate utility costs. The analysis deepens also how the issue of auto production of energy is addressed within port planning, describing the role and impact that Renewable Energy Communities (RECs) and Port Renewable Energy Communities (PRECs) may have concerning the current situation. In particular, the legislation allows port authorities to form a REC even when 1 MW of power is exceeded. This advancement offers new perspectives for the use of PRECs that can contribute to the decentralization of the port's energy supply model, ensuring through smart grids, a constant flow of data useful for increasing overall efficiency and mitigating costs from the national grid. PRECs and RECs are the main instruments to promote distributed generation and the capillarization of smart grids. This can be translated into having a much larger availability of data, which is fundamental to perceiving high-efficiency levels.

Since these investments are particularly long and costly, it was useful for the analysis to focus on the different levels of investment completion in order to understand how the convenience of self-producing energy in port areas changes. Specifically, in the Genoa and Prà area, which currently receives most of the investments in the energy sector.

Within the ports of Genoa and Prà, four levels of self-generation provide four different prices for the electricity that the port could theoretically sell to stakeholders. The analysis evaluates the cost price of energy, considering the CAPEX and OPEX of the projects, part of the charges, and a markup of 5%. A *low level* of insufficient auto production of around 3 MW (Stage I) would make it possible to sell energy at the theoretical price of 150,1 €/MWh, not far from the average price in 2023. The *intermediate* development levels of the FER-3 project, equal to 27 MW and 36 MW, would ensure a price of 48,4 €/MWh (Stage II) and 46,7 €/MWh (Stage III). The advent of the new breakwater of the port of Genoa, and its completion, will guarantee a *high* production of 54 MW with the consequent price of 86.6 €/MWh. The ports of Savona and Vado Ligure is part of the scarce auto production given the impact of the FER-2 project alone, the calculation returns a value of 142,2 €/ MWh. In this case, the level of self-production is limited compared to investments in the Genoa and Prà basins.

The increase in capacity is therefore not directly related to a reduction in price, the intermediate tiers are cheaper than the higher capacity levels. The new project of the new breakwater is very expensive compared to previous scenarios, influencing the theoretical price of the electricity produced by the port. However, a price of 86,6 €/MWh would be affordable compared to recent years and in line with the average prices of historical 10-year years. Furthermore, since these are renewable sources, once the initial investment has been exceeded, there are limited operating costs as the marginal cost of producing an extra unit of energy (e.g. 1 kW) is close to zero.

Auto-production not only has an economic benefit but also a strong influence on the carbon footprint of the port. The energy supplied by the national grid has a certain carbon emission intensity within it, in Italy, the IEA estimates a value between 250 and 300 g CO_2/kWh produced, this value represents the amount of carbon emitted to produce one kilowatt. On the contrary, auto-produced energy has an emission intensity close to zero, the literature aligns itself with a value between 20 and 80 g CO_2/kWh for photovoltaics, between 10 and 30 g CO_2/kWh for wind power, while OWCM technology should be placed halfway between the two. This implies that, on average, the Ports of Genoa could produce electricity at a tenth of the emission intensity of the national grid. So it would be possible to reduce emissions from electricity supply by 90%.

As regards the use of the energy produced, the new draft of ARERA's regulatory proposals regarding Cold Ironing technology is used. The legislation is in line with the current context and suggests a valid starting point for developing an analysis regarding the impact of a portion of discounted system charges.

The analysis carried out on the historical data of the last year April 2023 to April 2024, collected by the DSFE system, made it possible to estimate on average the port calls made to the docks that will be equipped with CI, allowing a precise assessment of the average stop, the type of ship and its relative consumption during stationing. In the model, the auto-produced energy is destined for berthed ships, guaranteeing a share of electricity at a cost price of Ports of Genoa compared to the purchase of the total quantity from the national grid. The analysis concludes that the expense for shipowners would decrease by 55% in the port of Genoa/Prà and by 11% in the port of Savona/Vado Ligure, making the CI service cheaper than HFO and MGO fuel consumption. In this case, the savings in terms of environmental impact are very high, considering the consumption of fossil fuels and their entire supply chain.

The amount of equivalent tons of CO2 deriving from the consumption of auxiliary engines is 335.987 for the ports of Genoa and Prà and 30.346 for the ports of Savona and Vado Ligure. The data reported by the DSFE in the period 2023-2024 are consistent with the 2016 data regarding CO2 equivalent reported in the Sustainability report. Eliminating the tons of CO2 produced by the ships' auxiliary engines during the stopover would guarantee the Ports of Genoa to reduce the amount of direct emissions by 80%. It is necessary that the benchmark data date back to 2016, a more recent analysis would produce more precise results. A sensitivity analysis would be a valuable tool to identify thresholds useful for understanding how some fundamental variables such as the number of port calls, energy prices, and energy use can produce different results.

The analysis as a whole assesses how the Ports of Genoa are oriented towards sustainable development, with possible planning expansions towards a stakeholder-driven model, including port concessionaires, shipowners, the environment, and society as a whole. In this sense, the possibility of auto-producing a large amount of energy is a real game-changer for the development of the Ports of Genoa. Further analyses could deepen this same model applied to other Italian ports, producing useful evidence for port authorities regarding investment planning and state bodies for the definition of legislation.

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