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Port as renewable energy hubs: Insights from the Italian case

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Abstract

The application of the concept of energy hub to ports is still scarce both in academic reviews and research analyses as well as in terms of empirical and practical cases. As a result, there is a lack of studies and practical analyses assessing technical solutions for the design of an innovative Port Renewable Energy Hub (PREH), grounding on a range of green strategies (GSs) to effectively manage energy consumption and production in the port. Finally, very limited prior studies provide detailed designs and technical solution when configuring the architecture of the PREH (i.e. PREH configuration).
The manuscript scrutinizes the most relevant opportunities and challenges which ports are expected to experience as PREHs for achieving environmental, economic and financial sustainability goals. A conceptual framework capable to assess available options/investments/interventions for transforming ports in renewable energy hubs is developed and tested on the Italian ports. For the aim of the study, the Moscow method is used to identify, test, and validate the most important components that constitute a successful PREH configuration by applying a stakeholders' perspective. The empirical results emerging from the analysis of the Italian case show that 36% of green strategies actually planned and

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implemented by Italian ports are related to energy efficiency interventions, 23% refer to the development of facilities/infrastructures for electric energy supply and 22% of the sample GSs focus on renewable energy sources. From the stakeholder perspective (e.g. PAs, public entity, trade association, university, private companies operating in the port domain), the most important inputs for PREH are solar and wind and the most important outputs are electricity, hydrogen, and heating.

Keywords: Port, energy hub, energy efficiency, renewable energy.

1. Introduction

Different forms of energy including electricity, heat, cooling, fuels are consumed for the completion of port related operations and activities, making ports potential complex Multi Energy Systems (MESs). Nonetheless, ports still tend to manage energy flows operating as traditional energy systems where the different energy types (i.e. electricity, heat, cooling, fuels) are considered, managed and scheduled separately or independently and are not optimal combined. This leads to significant energy inefficiency of port activities and higher costs, given the energy-intensive nature of these activities. According to Iris and Lam (2019), energy costs represent a significant overhead for ports, terminals and other actors operating within the port and reducing them could result in substantial cost savings and financial performance improvements. In this perspective, by operating as MESs, ports can improve their energy efficiency.

According to Mancarella (2014), MES where electricity, heat, cooling, fuels, transport, and other form of energy optimally interact with each other at various levels (for example, within a district, city or region) represents a major opportunity to increase technical, economic and environmental performance compared to "classical" energy systems where these energies are managed "separately" or "independently". In this vein, the optimal combination of these systems can lead to several technical, economic, and environmental advantages for ports, which could be possible through the integration and the interaction between different energy systems thank to the use of innovative technologies such as electric heat pump, combined heat, and power (CHP) production, renewable energy production etc. However, the successful performance of these systems could be guaranteed by an integrated framework that can ensure an optimal management of the various components (e.g., energy production, transmission, energy demand, energy storage) of the system namely an Energy Hub (EH).

According to Geidl et al. (2007) EH represents an entity where multiple energy carriers can be converted, conditioned, and stored. The main purpose of the introduction of the EH concept is to move toward MES, to capture the synergistic benefits stemming from different energy carriers, non-hierarchical structure, and integrated management of different energy infrastructures. These synergistic benefits can be obtained among various energy carriers by harnessing their specific virtues. Geidl et al. (2007) claim that some real structures can be considered as energy hubs including industrial plants (steelworks), large building complexes (shopping mall), rural and urban districts, small isolated systems (trains, ships, planes) and transport hubs (airports) etc. Following this logic, ports can also be considered as EH, since they represent a transport hub. In addition, ports are traditionally considered to be EH due to the different types of energy production, storage, and consumption that take place within the port, and their suitable location for the importation and exportation of different types of energy.

In addition, recently both scholars and practitioners have started to consider ports as ideal locations for implementing innovative energy generation systems which include centralized distribution, grounding on the economies of scale principle (Notteboom et al., 2022). This perception is also supported by Acciaro et al. (2014) that consider ports as energy hubs, i.e., a geographical concentration of high-energy demand and supply activities where energy-intensive industries, power generation, distribution and related activities and projects are located. The energy-intensive nature of port activities and stricter environmental regulations from policymakers, indeed, have increased the pressure on PMBs to find solutions to reduce pollution arising from their activities. The growing demand for energy in port areas has triggered towards higher energy costs, pollutants, and greenhouse gas emissions.

Therefore, PMBs are urged to improve their energy management strategies in order to balance, when possible, energy demand and supply within port areas. This need to better understand and constant monitor energy-related activities taking place within the port has become more apparent because of the growing relevance of energy trades and the high volatility that characterizes the energy market. In addition, the global energy crisis of the second decade of the 21st century amplified the volatility of energy prices to the extent that energy efficiency is not more an option for ports, but a sine qua non condition for their survival from the environmental, economic, and financial perspective.

In this Perspective, several scholars have recently stressed the necessity for PMBs to implement energy management strategies in the port domain (Vahabzad et al., 2021). But several concerns about the real feasibility of EH hub also emerged. According to Moghaddam et al. (2015) EHs are feasible due to the existence of distribution networks for energy such as natural gas and electricity in different areas, together with the increasing of renewable energy and technology developments such as combined heat and power systems, electric heat pump, absorption chiller, thermal energy storage and electrical energy storage jointly with smart control and measurement equipment, and integrated operation for energy management.

Nevertheless, the application of the concept of energy hub to ports is still scarce, studies addressing viable solutions for designing innovative PREH also considering the range of GSs for effective energy management are still scarce in port literature and no study provides a port energy hub configuration.

Given the above, the paper addresses ports as future renewable energy hubs in order to achieve environmental, economic and financial sustainability of the port development in the long-term. For this purpose, it first provides a conceptual framework capable to assess available options/investments/interventions for transforming ports in renewable energy hubs. Secondly, the current state of the art ("as is" scenario) within Italian ports is explored and the conceptual framework is then tested for identifying potential future evolutionary patterns toward renewable energy hub configurations grounded on implemented, ongoing, and under development GSs of PMBs. Third, the most important components that constitute a successful PREH configuration by applying a stakeholders' perspective to achieve environmental, financial and economic sustainability is provided.

The structure of the paper is as follows. The section 2 provides the conceptual framework and the theoretical foundation of the study consisting of literature review on the energy hub concept. In section 3, the methodology is presented. Section 4 provides the findings by presenting the as is situation of the Italian ports and the most important inputs and outputs of a PREH. The results are discussed in section 5 through the presentation of the PREH configuration. Finally, the section 6 presents the conclusions.

2. Theoretical foundations

2.1. The energy hub concept: Literature review

The energy hub concept was firstly introduced by Patrick Favre-Perrod (2005) as an interface between participants and transmission system where energy is conditioned, transformed, and delivered to meet consumer needs. EH aims to meet multi-energy demands at an affordable price in the integrated energy systems, by considering for individual energy systems, the physical and operational constraints (Li et al., 2018). For Han et al. (2023) in addition to meet several types of demand at the same time, EH also have the objective to increase the flexibility of the system. Mohammadi et al. (2017) instead defined energy hub as a place where production, conversion, storage, and consumption of different energy carriers take place. This definition is in line with the conception of EH considered in this paper.

Several research contributions on EH emerged in the literature and different typologies of EH has been identified. Specifically, the EH is studied following different perspectives, and for the aim of this paper a classification based on different criteria is provided. These criteria include the type of inputs used (e.g., electricity grid, natural gas network, renewable energy source or hybrid), the use of smart technologies, tools, and software for increasing the EH efficiency, flexibility and stability, the use of energy storage and conversion systems, the combination of several energy systems, the combination of traditional and renewable inputs.

Based on these criteria, seven typologies of EH has been identified including: traditional energy hub, hybrid energy hub, energy hub based on energy converters and energy storages, smart energy hub, dynamic energy hub, multi energy hub, renewable energy hub.

2.1.1. Traditional energy hub

These energy hubs use national electricity, gas and heating networks as inputs for meeting the energy need of the system. Energy converters and storages are useful to increase the flexibility of the energy system and allow the multi energy demand satisfaction. However, issues related to the uncertainty of electricity demand and related price due to the fluctuation, as well as the energy planning and optimisation problem brings some limitations to this typology. In addition, these EHs scarcely contribute to the pollution reduction issues as the national energy networks do not always use renewable energy sources to produce energy. In this vein, several contributions in the literature propose different solutions to these limits. In a regional context, Wang et al. (2022) propose a unified modelling and linearization method for energy hub station to obtain an optimal dispatching of energy.

Yang et al. (2022), propose a three-stage multi-energy sharing strategy for a gas-electricity integrated energy system, with the aim to solve the multi-energy imbalance problem among energy hubs based on the peer-to-peer (P2P) trading mode. While Li et al. (2018) provide a decentral framework for the optimal dispatch of integrated power distribution and natural gas system in networked energy hubs.

According to Wu et al. (2022) to increase the energy efficiency of the energy supply in an energy hub, the adoption of a joint planning of an integrated energy system employing a group of cooling, heat and power can be an effective approach. In this vein, Wang et al. (2021) provided a day-ahead cooperative trading mechanism in a multi-energy community that depends on an energy hub to couple electricity, natural gas, and heat for all prosumers.

Traditional energy hubs are widely discussed in the literature, but some authors argue that adding renewable energy sources to traditional EH inputs could bring more benefits to the energy system as a whole.

2.1.2. Hybrid energy hub

The hybrid nature of this type of EH is due to the combination of renewable energy resources and the national electricity, gas and heating networks. It partially addresses some of the challenges associated with traditional EH. Using renewable energy resources contributes to the reduction of pollution and provides a myriad of possibilities for energy planning. But this EH type brings some issues related to the uncertainty of renewable energy production, forecasting errors and cost-effectiveness…etc. Some authors in the literature address the problem related to the optimisation and cost reduction benefits of hybrid EHs. Qiao et al. (2022) propose an innovative and extended EH to analyse the coupling characteristics of multi-energy flow and provide a configuration optimization method of integrated energy system based on EH. While Han et al. (2023) investigate the presence of an electric vehicle parking in an EH considering the components such as CCHP, a photovoltaic unit in the presence of demand response programs, and its effects on optimizing power consumption to reduce cost. They use the demand response programs to reduce the operating costs of the energy hub. The uncertainty problem related to energy demand and resources during the energy planning phase also represents a serious issue. It seems difficult to evaluate the availability of energy resources and the energy demand during the energy planning phase. This uncertainty phenomenon can lead to several problem resulting in biasing the whole energy planning. To extensively consider the impact of uncertainties of variable energy resources and load demands during the energy scheduling planning, Cheng et al. (2021) suggest a multi-time scale coordinated optimization (MTSCO) method of the EH with multi-energy flows and multi-type energy storage systems (MESSs). While Ma et al.(2022) instead considered the integrated demand response of energy loads and the uncertainty of renewable energy output, for conducting a decentralized robust optimal dispatch study on user-level integrated electricity-gas-heat systems (IEGHSs) composed of EHs and some users.

For Rahmani et al. (2019), an operation strategy based on a multi-objective information gap decision theory approach represents a viable solution for modelling the uncertainty sources of multi-carrier energy systems which includes the uncertainties of demand forecasts, wind power forecasts, and solar power forecasts. In addition to the uncertainty of energy demand and energy resources, Dolatabadi et al. (2018) also consider the uncertainty of energy price in their study by addressing the scheduling problem for energy hub system that include wind turbine, combined heat and power units, auxiliary boilers, and energy storage devices through hybrid stochastic/information gap decision theory approach.

To guarantee the flexibility, cost reduction and energy efficiency of a EH, the right energy storage and conversion systems need to be identified as the right combination can lead to a successful EH. Accordingly, some authors in the literature have studied specific energy conversion and storage systems as energy hubs, given their paramount importance.

2.1.3. Energy hub based on energy converters and energy storage.

EH can be considered as a multiple-input and multiple-output energy conversion system, where energy is converted, stored, and consumed (Zhao et al., 2020). According to Samanta et al. (2023) the combination of several converters such as Solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC), in a unique EH can lead to generation of several different outputs. In this vein, they developed a conceptual framework for an advance integrated multigeneration energy hub by combining SOFC, MCFC, proton exchange membrane (PEM) electrolyser and methanol production unit.

Regarding the energy storage system, according to Zhou and Hu (2022), compressed air energy storages (CAESs) represent for the future a new cleaner energy hub when addressing integrated energy systems. They developed a flexible multi-source dynamic electricity-heat pricing mechanism (MDEH) to help with the economic scheduling, by conducting an in-depth analysis of the potential of CAES to provide spinning reserves to improve the reliability of integrated energy systems accessed with highly proportioned renewable energy generation.

Li et al. (2021) instead propose a hybrid optimization strategy for micro-energy grid dispatch based on the non-supplementary fired compressed air energy storage (NSF-CAES). This enables flexible dispatch for cooling, heating, and electricity. Bai et al. (2021) investigate the external characteristics of advanced adiabatic compressed air energy storage (AA-CAES) and exploits its ability to analyse the daily self-dispatch of the energy hub in presence of uncertainties of load and ambient temperature.

2.1.4. Smart energy hub

As an interface between participants and transmission system, the EH processes a large flow of information. The appropriate processing of this information is therefore a key success factor for EH. Improving the processing and management of this flow of information requires the integration of information technologies. In this vein, together with multi-carrier energy systems, these information technologies introduce the smart energy hub (SEH) concept. This type of energy hub can use natural gas network, electricity grid or renewable energy sources as inputs, and its specificity is based on the introduction of technologies, tools, software for better managing the information flow in the EH. Additionally, to achieve the highest level of performance and optimal operation of the SEH, the introduction of stochastic modelling of intermittent renewable energy resources and fluctuating demands is required. Ding et al. (2022) analyse an internet of things (IoT) based EH control structure and then, review the corresponding state estimation, communication, and control methods for managing large EH data sets. Qamar and Nadeem Malik (2022) investigated a comprehensive model for a SEH which includes the stochastic nature of electrical, heating, and cooling demands in the presence of renewable energy resources, batteries, and thermal storages.

However, energy, cost and environmental efficiency appears to be a great challenge faced by this type of EH. To address this challenge, Dwijendra et al. (2022) propose two-layer energy management necessary to achieve the energy saving. The first layer consists of optimising the energy demand and then, apply the optimized energy demand in the second layer to reduce cost related to energy generation. Chamandoust et al. (2020), present a multi-objective optimal scheduling of smart energy hub system (SEHS) in the day ahead with the aim to reduce the operation costs and emission polluting related to energy production side, reduce the loss of energy supply probability (LESP) in demand side, and perform the optimal shifting of electrical and thermal loads in the day ahead.

Regarding the pollution issue faced by EH, George-Williams et al. (2022) propose a SEH which encompasses Vehicle-to-Grid (V2G) charging, photovoltaic energy generation, and hydrogen storage aimed at reducing the negative impact of electric vehicles (EV) on the electricity grid.

2.1.5. Dynamic energy hub

In integrated energy system, the uncertainty related to efficiency of energy devices that operate under tough and changing working conditions threatens the operation of the system. Dynamic EHs are considered to be a potential solution for such issues since they are designed to consider the changing working conditions of an energy system and introduce technologies, tools, software to increase the efficiency of EH devices and reduce the related cost and pollution.

In this perspective, Xu et al. (2023) proposed a low-carbon economic dispatch method for the integrated energy system that consider the uncertainty of energy. They design a dynamic energy hub (DEH) by integrating an efficiency correction technique into the traditional energy hub. To correct energy efficiency affected by the load level, temperature, and pressure, they used a deep neural network (DNN) method with excellent accuracy in nonlinear mapping. Finally, based on the DEH, and in order to minimize operational costs, they formulated a low-carbon economic dispatch model.

The same authors, Xu et al. (2022) developed a DEH model for adapting the EH to variable energy conversion efficiencies. Then, they formulated a multi-objective economic-environmental dispatch (EED) for the IES, considering the framework of the DEH model, to set up a trade-off between operational cost and emitted pollutants.

Nozari et al. (2022) instead developed a dynamic energy storage hub (DESH) concept that include an interconnected short and long-term electricity storage facilities. Then, they stressed the synergistic benefits that derived from the connection of thermal and electrical storage units through the DESH scheme.

2.1.6. Multi energy hub

EH faces an uncertainty phenomenon related to energy demand, renewable energy resources, energy price…etc. To address these uncertainty factors that characterise EH, several scholars consider the multi-EHs to be a viable the solution as they have more advantages related to the flexibility and stability of the system than the single-EH (He et al., 2023). In this regard, Farshidian et al. (2021) propose a model for planning multi-hub in an energy system considering the competition between the hubs.

By considering a system of interconnected EHs as a key multi-carrier energy system model, Liu et al. (2020) propose a standardised modelling and optimisation method for the direct calculation of the operational state of the model due to of its highly dimensional nonlinear characteristics. Arsoon et al. (2022) analysed a peer-to-peer (P2P) energy swapping framework for enhancing the resilience of networked energy hubs (NEHs) against extreme weather events.

Other authors address different challenges such as energy efficiency, cost and congestion reduction faced by network of energy hub. For instance, Wu et al (2023) address a distributed energy trading scheme with non-discriminatory pricing for a cluster of networked energy hubs. They considered EH as self-interested agent and proposed a hybrid AC/DC microgrid-embedded EH model to optimize the operating costs under corresponding local energy balance constraints.

Hu et al. (2021) investigate the complementarity of multiple energy resources in EHs to solve possible distribution network congestions. They considered EH with components such as combined cooling, heating and power units and heat pumps and integrated them with renewable energy resources. Single EH are used to model the intrinsic coupling relationship among various energy carriers, to form a flexible and complement operation of electricity, natural gas, cooling and heat. Then, they apply an optimal operation strategy of multiple energy hubs to enable gas-to-electricity to provide local energy supply for EH during electricity peak periods and consume renewable energy generation by the complementarity of electricity, heat and cooling.

2.1.7. Renewable energy hub

A growing number of studies in the literature recently introduced the concept of renewable energy hub (REH). According to Van Binh and Phap (2022), REH can be considered as a geographical area that presents the conditions for the exploitation of renewable energy sources (wind and solar) on both a large and concentrated scale. They claim that REH can bring important economic efficiency per unit of land use and supply the power to the utility grid. Therefore, REH can positively impact the sustainable growth of a considered area (e.g., city, municipality, port…etc.). In this regard, they developed a set of 30 criteria to identify, monitor, and evaluate the development process of a sustainable REH.

Wan et al. (2023) and Kountouris et al.(2023) instead introduce the concept of power to X (P2X) energy. The former analyse the extent to which P2X energy hub can trade in an optimal way in the electricity market and its capability to satisfy local energy demand under the assumption of a long-term strong climate scenario in year 2050. They also quantify the key conditions for profitable operations of a P2X energy hub. The latter instead investigate the optimal operation of an energy hub by leveraging the flexibility of P2X, including hydrogen, methanol, and ammonia synthesizers through the analysis of potential revenue streams such as the day-ahead and ancillary services markets.

Keeping an energy market perspective, Akbari et al. (2023), analyse the energy management of electrical and thermal networks considering renewable energy hubs as the regulator of flexibility of these networks based on flexible pricing services. They claim that incorporating renewable resources, storage generators, and responsive loads into a REH leads to around 32.9% of economic improvement.

Several authors also introduced the concept of hydrogen based-energy hub. Qiu et al. (2022) argue that the development of hydrogen-enriched compressed natural gas (HCNG) can lead to a fully utilisation of the existing natural gas infrastructure, therefore, considerably reducing the economic and technical pressure on the development of pure hydrogen. Zare Oskouei et al. (2022) proposed a framework that rely on the distinctive opportunities that can derive from hydrogen-based facilities to increase the flexibility and adequacy of energy distribution networks by also considering the high penetration of renewable energy sources (RESs).

2.2. Port Renewable Energy Hub (PREH): conceptual framework

According to Acciaro et al. (2014) ports represent a place where high-energy demand and supply activities are concentrated and, energy-intensive industries, power generation, distribution and related activities and projects take place. These high energy demand and supply activities are responsible for significant harmful emissions in the port, and energy efficiency, economic and financial sustainability of port activities remain a major challenge for port energy hubs. These challenges can be addressed by considering ports as an ideal location for the implementation of innovative energy generation systems which include centralized distribution, grounding on the economies of scale principle (Notteboom et al., 2022).

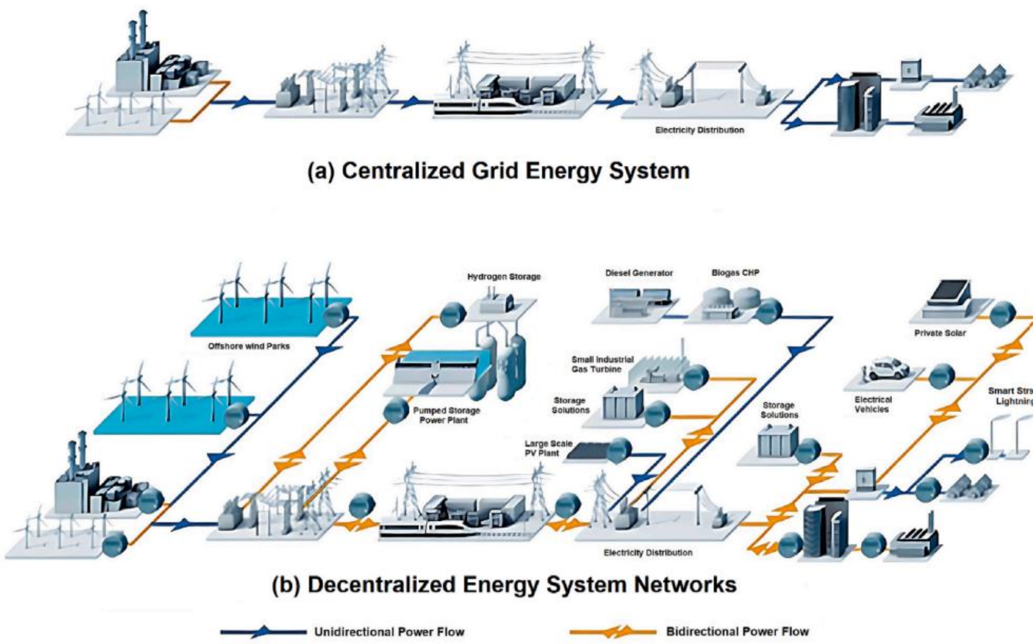
Traditionally, even if ports do not belong to the energy sector, they have equipment, tools, instruments, know-how and experience to carry out operations related to energy activities due to the high energy demand arising from the port activities. Over time ports are trying to better manage their energy system in order to increase the energy efficiency.

The consumption of different forms of energy demand for carrying out port's activities including electricity, heating, cooling, fuel and so on gives ports the status of multi-carrier energy system. To be more efficient, it is essential to introduce the energy hub concept in the port, as this is an appropriate model for integrating the different energy infrastructures, and many benefits can be generated by the synergy of the different energy carriers. However, this should not be narrowed down to the integration of traditional energy resources by considering only current infrastructures such as the electricity grid and natural gas networks, but renewable energy sources and the related technologies should be considered since they can lead to several benefits for ports such as energy efficiency, energy cost reduction, flexibility, emission reduction.

The PREH model requires moving towards the use of sustainable and clean sources including renewables, especially in the form of Distributed Energy Resources (DER). DER are systems for power generation that can be realized close to the consumption location and lead to reduction of energy costs, reduction of the losses related to the transmission and distribution and greater energy efficiency (Akorede & Pouresmaeil, 2010).

These systems can use different technologies including fuel cells, waste heat recovery equipment, micro gas turbines, and renewable technologies such as photovoltaic, wind turbines…etc. The PREC aims to move from the traditional one-way energy system, whereby power flows from a centralized energy system to ports, to a decentralized energy system in which ports can produce their own energy locally and even trade (Figure 1).

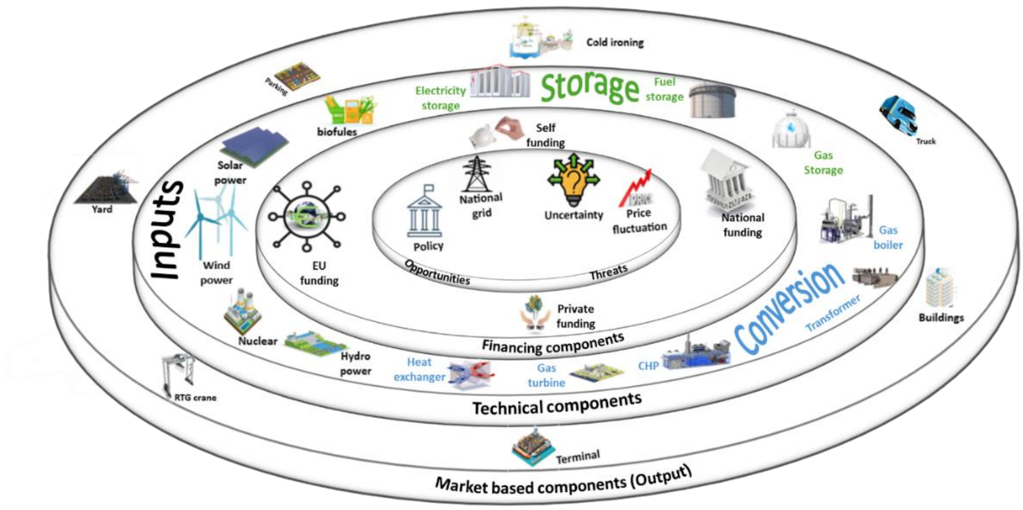
Figure n.1: Centralized grid energy system Vs decentralized energy system.



Source: Nadeem et al. (2023)

The objective of this section is to provide a conceptual framework for the development of a renewable port energy hub configuration in term of inputs and output (Figure 2). The conceptual framework consists of four layers including the market-based components, the technical components (Energy hub configuration), the financial aspect and the opportunities and the threats that can positively or negatively impact the successful implementation of the port renewable energy hub concept.

Figure n.2: The conceptual framework for developing a port renewable energy hub configuration.



Source: Our elaboration

Specifically, the idea behind the development of the conceptual framework is based on energy production from renewable energy sources and the uptake of alternative fuels, combined with energy efficiency interventions, including energy conservation, and supported by operational strategies and energy management system tools and technologies, all governed by green policies and measures to decarbonise port industries and related activities, to ensure their environmental, financial and economic sustainability.

2.2.1. The market-based components (output)

The first layer encompasses the market-based components which consist of the port energy demand including electricity, heating, cooling and alternative fuel. This energy demand stems from different user profiles present within the port including port's buildings, common area, for cold ironing, yard and quay vehicles, port equipment and containers terminals and other areas (e.g., parking, road, yards). Electricity and alternative fuel such as liquefied natural gas (LNG) and hydrogen are used in the port to enable a technological shift for yard vehicles and equipment in order to reduce the port emissions. For instance, there are cranes, RTG, RMG, automated guided vehicle running on electricity from solar power and yard trucks, fuelled by LNG and hydrogen.

Since energy consumptions in port areas can experience high variations due to peak energy demand, suddenly changes of energy demand, handling volumes variations, continuous modification of ship calling patterns, variation of seasons, and fluctuations in the port stay times (both seaside and land side), it is fundamental for port to meet the energy demand in the best way possible. The technical components of the present framework can help to optimally meet the port's energy demand.

2.2.2. *Technical components*

The second layer consists of the technical components which consider the elements necessary for meeting the port energy demand: inputs, conversion system and storage system. The technical components in this paper represent green strategies that ports implement for producing and fostering the consumption of renewable energy. The input is converted into output, which can be used directly or stored before final use. The energy hub configuration depends on the energy need of each port, the energy production and consumption patterns. The inputs considered are essentially renewable energy sources. The choice of these inputs is based on valuable criteria such as the production cost, the emission rate, the energy efficiency, the availability (e.g., sunlight for PV may be available in some areas and may not be available in others), the level of energy security and flexibility provided, the share and the fluctuation of energy production, the technology readiness level, the installation effort, the utility and the reliability. The same criteria can also be used to prioritize outputs. When it comes to the conversion and storage systems, after the identification of the optimal input-output mix, each port deductively chooses the best solutions to couple the different energy loads considering criteria as cost, availability, flexibility, technology readiness level, installation effort, capacity.

2.2.3. *Financing components*

The third layer concerns finance which is a key support for the implementation of green strategies in ports. Indeed, green strategies are well-known to be capital-intensive and are characterised by a long payback period. For these reasons, ports have to find the best financing schemes to cover at least for a certain period the high CapEx[1], OpEx[2] and maintenance costs resulting from the implementation of green strategies. A wide range of funding can be considered such as international funding (e.g., from the European Commission), funding from national, regional and local governments, private funding (terminals, energy companies, banks) and self-financing.

[1] CapEx: Capital Expenditure
[2] OpEx: Operational Expenditure

2.2.4. Opportunities and threats

Opportunities represent all the elements that may strongly contribute to the success of PREH and can include the use of the energy national system as a backup to compensate for any anomaly, the compliance with policies and measures to decarbonise port activities, the use of tools, techniques, software, technologies such as demand response programs (e.g., incentive-based and price-based program), energy conservation, strategic load growth and flexible load shaping.

The threats instead regard all the difficulties that can hinder the success of port renewable energy hub such as the uncertainty of energy demand, the uncertainty of renewable energy production, the fluctuation of energy price, the limited capacity of energy storage system, the regulatory vacuum, the lack of energy trading criteria from peer to peer in EH.

3. Methodology

The paper provides a conceptual framework for achieving environmental, financial, and economic sustainability in the port by exploiting the EH concept. The framework is applied to the Italian ports by using a multiple case study with the aim of assessing the GSs developed within the Italian port and understanding the principal funding schemes that financed them. All the sixteen Port Authorities that compose the Italian port system are considered into the analysis. Data gathering is performed through desk research on Ports Authority websites, Port Environmental Energy Plan (PEEP), Strategic Planning Documents (e.g., Three-Years Operational Plan) as well as academic papers and industrial reports.

Following the systematic analysis and review of all the relevant documents gathered from desk research, a database consisting of 278 GSs (i.e., statistical units) has been developed.

The GSs are categorised according to the taxonomy developed by Satta et al. (2024). The only categories considered are those related to energy production and supply, energy efficiency and policies that foster the use of renewable energy. As a result, we identified the following 5 comprehensive and consistent categories (Table 1).

Table n.1: Green strategy categories

Green strategies	Description
Energy efficiency	Strategies for enhancing the energy efficiency of maritime logistics activities in the port. These strategies encompass the substitution of lighting systems and other technical and technological solutions to decrease energy consumption, related GHGs, and harmful emissions.
Renewable energy production	Development and installation of renewable energy production systems in the port domain. These strategies incorporate the installation of solar panels, wind turbine and wave energy technologies to produce energy.
Policies and measures	Policy frameworks and incentive schemes to drive the adoption of eco-friendly practices and behaviours. These initiatives include green energy procurement, establishment of technical committees specializing in environmental monitoring and promotion within the maritime cluster, and network collaboration agreements facilitating the port's transition to the green initiative.
Bunkering and storage facilities for alternative fuels	Bunkering and storage facilities construction for providing alternative fuels in the port domain, including liquefied natural gas, hydrogen, ammonia, biofuels, etc.
Facilities and infrastructure for electric energy supply	Construction of facilities and infrastructure for electric energy supply in the port domain. These strategies comprise the dock electrification (i.e., cold ironing) and electric vehicles charging facilities.

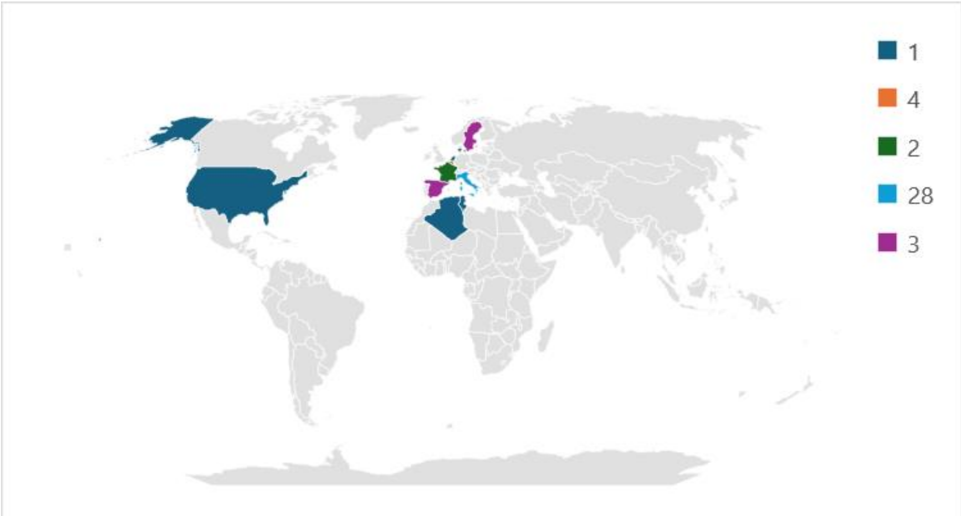
Source: Satta et al. (2024)

Then, the Moscow method is applied through a structured questionnaire to identify, test and validate the most important components that constitute a successful PREH configuration by applying a stakeholders' perspective to achieve environmental, financial and economic sustainability. The choice of the components is based on different criteria such as cost, emissions, energy efficiency, availability, security, and other criteria.

The questionnaire was administered to experts of maritime logistics and port industry with proven experience asking them to use a 7-point Likert scale to evaluate the most important components that constitute a successful PREH configuration and validate the theories developed in the conceptual framework related to the drivers of port renewable energy hub, the funding schemes, opportunities and threats. The international experts include PAs, public entity, trade association, university, private companies (Terminal operator, shipping company, carriers, forwarders, shipping agencies).

The questionnaire was distributed using Microsoft Form online and sent to the experts. The survey was open for responses from November 9, 2023, to March 15, 2024, and 45 experts responded to the questionnaire. The composition of the final panel showed dimensional consistency, heterogeneity, and experience of respondents. Notably, more than 35% of the participants had over ten years of experience in the maritime port industry, with 16% having more than 20 years of experience. The responses were obtained from experts residing in 10 different countries across the globe (Figure 3). Most of the respondents were in Europe, specifically in Italy (28), Belgium (4), Sweden (3), Spain (3) and France (2).

Figure n.3: Country of employment of the respondents.

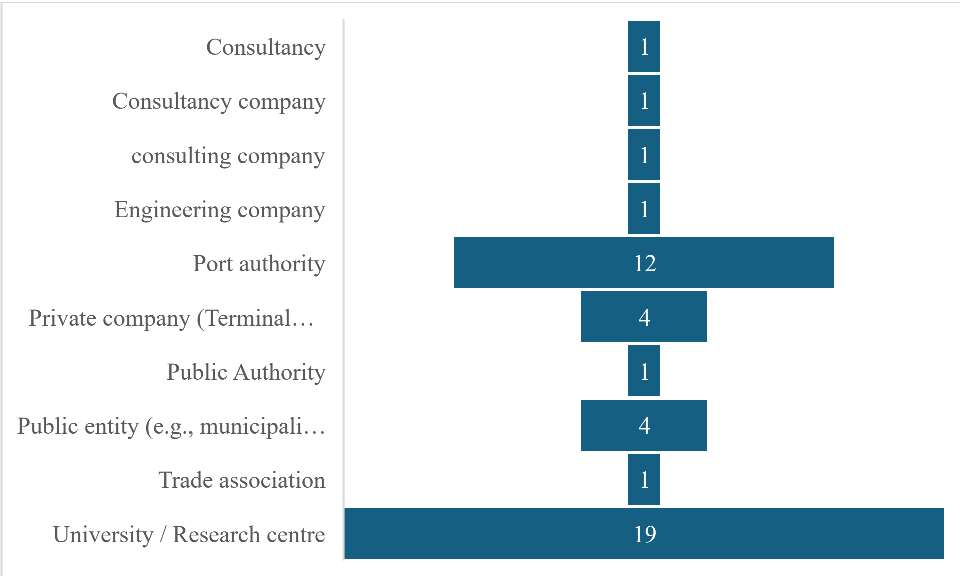


Source: Our elaboration

Furthermore, among the respondents, 42% are affiliated with universities or research centres, while 27% are associated with port authorities (Figure 4). 9% of the panel respondents work in private companies (including shipping companies, transport and logistics firms, terminal operators, and financial operators) and in public entities including municipalities, regions, transport-related ministries, national or international regulatory agencies, and other organisations involved in the maritime port industry. 78% of the respondents have already worked or collaborated with ports including top performer European ports such as port of Rotterdam, Antwerp, Marseille, Barcellona, Genoa, Malmo.

60% of the panel respondents stated that the ports they worked or collaborated with have a public energy policy, and 48% said that there is a specific department or office for energy issues. But only 41% of respondents affirmed that these ports introduced an energy management system.

Figure n.4: Type of companies of respondents.



Source: Our elaboration

About the Moscow Method

The MoSCoW method is a prioritization technique used in different business including business analysis, project management, management, as well as software development. It represents a stakeholder-based perspective used for reaching a common understanding with stakeholders on the perceived importance they assign on the delivery of each requirement. The term MoSCoW represents an acronym referring to the first letter of each of the four prioritisation categories. For this paper it is outlined as follows:

"**Mo**" stands for "Must Have", i.e. the components that are absolutely necessary for a successful port renewable energy hub. The absence of such components can lead to unpleasant consequences. The components with the average score between 5.5 and 7 are included in this category.

"**S**" stands for "Should have". These are those components whose presence has a significant impact on the success of a port renewable energy hub, but whose absence does not hinder the functionality of the energy hub. The components with the average score between 4.5 and 5.4 are included in this category.

"**Co**" stands for "Could have". The addition of these components can significantly increase the value of a port renewable energy hub, but their absence does not have a significant impact. To distinguish between "should haves" and "could haves", one must analyse the impact of their absence on the success of the port renewable energy hub. Those with the greatest impact can be classified as should-have, while the others can be added to could-have. The components with the average score between 3.5 and 4.4 are included in this category.

"**W**" stands for "won't have". These elements have no importance for the success of a port renewable energy hub but may be useful for the future. The components with the average score between 1 and 3.4 are included in this category.

4. Results

4.1. Drivers of port as renewable energy hub

Before presenting the results of the paper, it is important to present the drivers of ports as energy hub deriving from the stakeholder perspective. As such, we asked port experts to choose drivers using a 7-point Likert scale. It emerged that the traditional energy hub nature of ports is guided by the following drivers ranked from most important to least important:

- Energy production/supply. For guaranteeing energy efficiency, environmental, economic and social sustainability several ports are increasingly producing part of their energy need, using renewable energy source.
- Availability of space for the installation of energy hub components (energy production, conversion and storage systems)
- Multi energy demand. Various form of energy is consumed for carrying out energy intensive maritime logistic and port activities.
- Volume of energy transiting within the port. Huge amount of energy transit within the ports through import and export activities. So, port have a good familiarity with energy management activities.
- Port location. As logistic node ports have preferential position, space for performing energy intensive maritime logistic activities.
- Port Size (sqm)

4.2. The port energy hub main components

The inputs and the selection criteria

Figure 5 presents the most important inputs and Figure 7 presents the selection criteria of the inputs resulting from the average scores given by the port experts. Following the Moscow (Figure 6), solar and wind with the average score of 5.89 and 5.80 are the "Must Have" inputs. They represent the most important inputs that have to be included in the PREH configuration. It is not possible to plan a PREH configuration without including solar and wind. Then, hydrogen (5.47), LNG (5.20), biogas (5.00), ammonia (4.87), hydropower (4.69), wave energy (4.58) represent the "Should have" inputs. They are important for the port renewable energy hub configuration and using them should bring important benefits to the energy system. And the "Could have" inputs of PREH are made up of waste (4.40), biomass (4.40), geothermal (3.87) and nuclear (3.67). The port renewable energy hub can also function without them, since if they are left out the impact will be negligible.

Figure n.5: Port renewable energy hub inputs

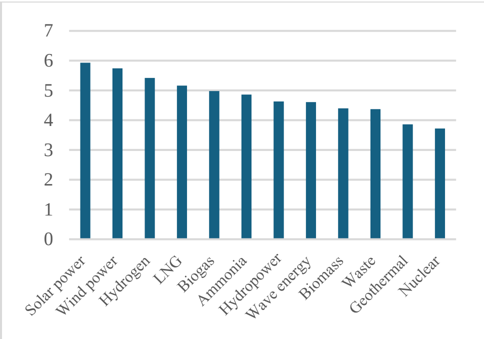
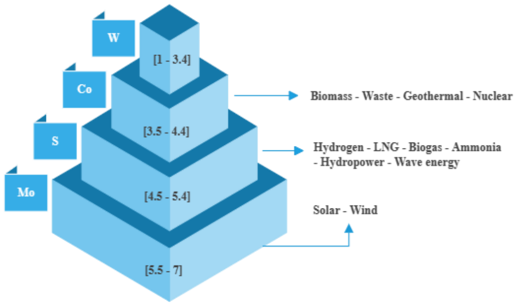


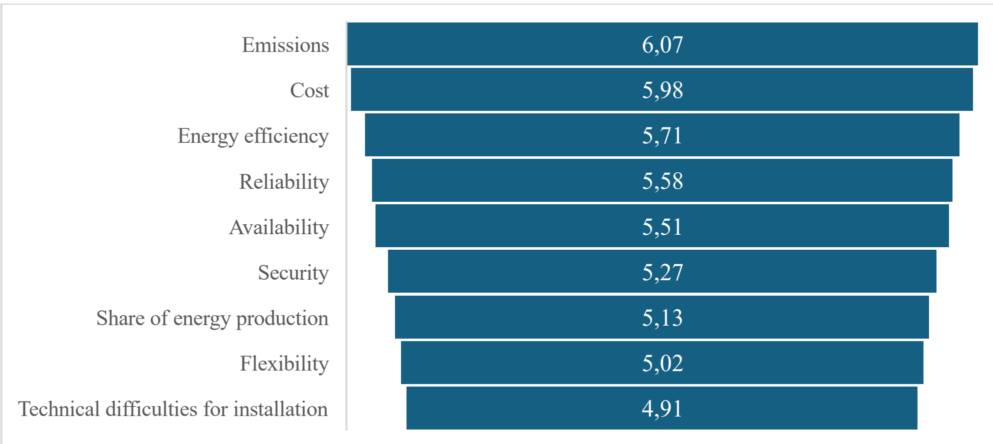
Figure n.6: Moscow classification of PREH inputs.



Source: Our elaboration

The implementation of these inputs is based on several selection criteria (Figure 7). The most relevant are the capability of emission reduction and the cost. Then, they are followed by the reliability, the availability, the security and the share of energy production. And finally, it is also important to consider the flexibility and the technical difficulties for installation the input technologies.

Figure n.7: Inputs selection criteria.



Source: Our elaboration

The Outputs and the selection criteria

The outputs and selection criteria are shown in Figures 8 and 10. Following the Moscow method (Figure 9) they are classified according to the average scores given by the port experts.

Unsurprisingly, the "Must Have" output is electricity with the average score of 6.56. This can be justified by the electrification strategies that ports are increasingly adopting through cold ironing, hybridization and electrification of port equipment (e.g. RTG, yard truck, quay crane). Then the "Should have" outputs include hydrogen (5.51), heating (5.20), water (5.07), Cooling (5,04) and LNG (5.00). Finally, the "Could have" outputs are natural gas (4.49) and compressed air (3.89).

Figure n.8: Port renewable energy hub outputs

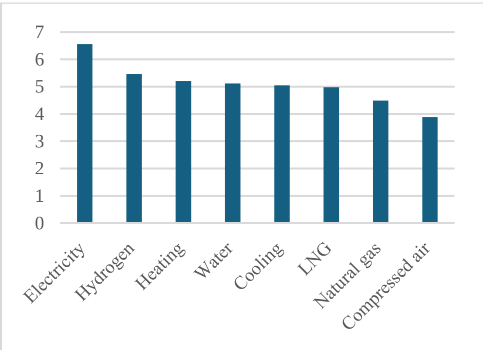
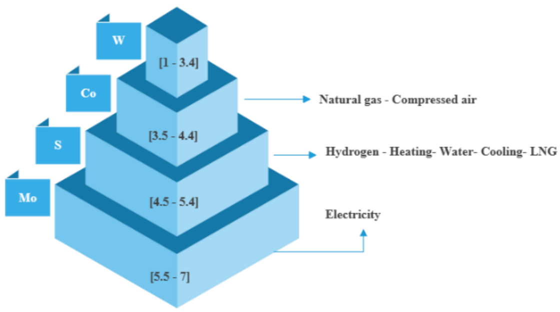


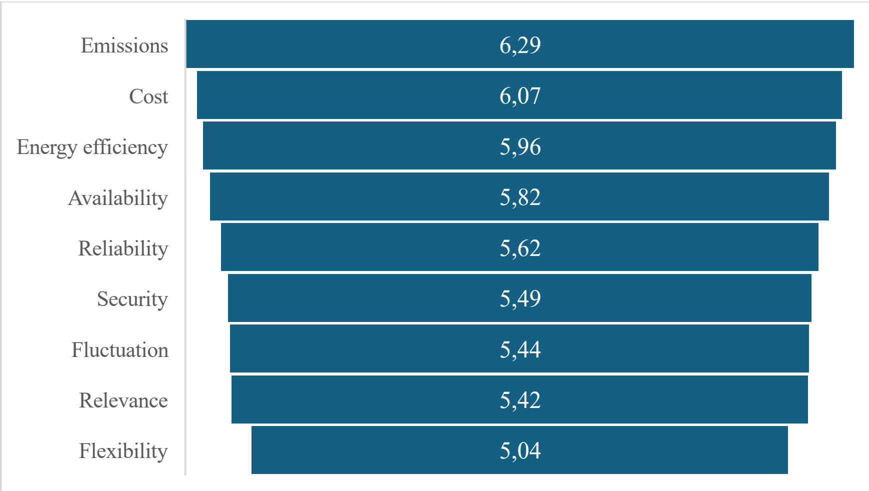
Figure n.9: Moscow classification of PREH outputs.



Source: Our elaboration

For selecting these outputs, as for inputs, the most important output criteria are emissions (6.29) and cost (6.07). Then energy efficiency (5.96), availability (5.82), reliability (5.62) and security (5.49) follow. And fluctuation i.e., sudden change in energy demand and production (5.44), relevance (i.e., is the importance of an energy type for the performance of port activities (5.42) and flexibility (5.04) complete the list.

Figure n.10: Output selection criteria.

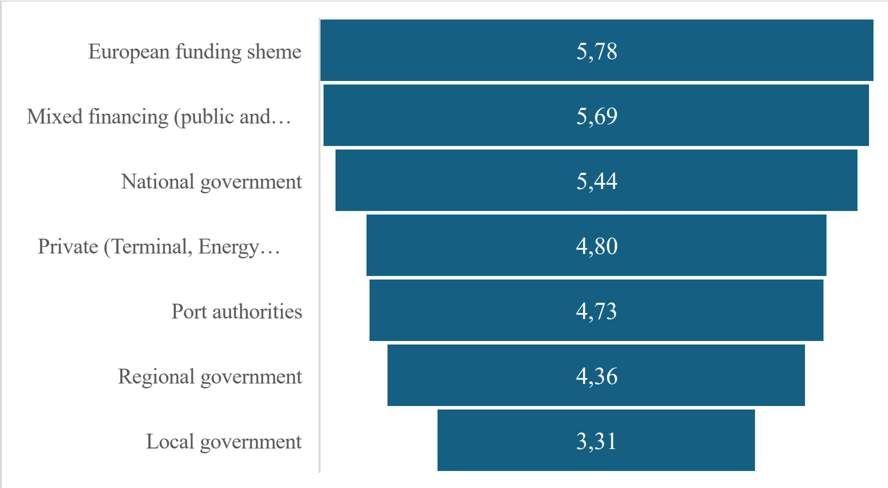


Source: Our elaboration

Funding, opportunities and threats

Figure 11 provides the different types of funding for financing the GSs according to the experts. It emerged that for financing the implementation of the GSs, ports must first rely on European fundings (5.78). Then, the mixed financing (5.69) scheme consisting of both public and private finance should be prioritized. Successively, funding from national government (5.44), private companies (4.80) such as terminal operators and energy companies and port authorities (4.73) could be taken into consideration. To finish regional government (4.36) and local government (3.31) can also finance the implementation of GSs.

Figure n. 11: Type of funding schemes for GSs.



Source: Our elaboration

To reach a successful port renewable energy hub, ports can take advantage of several opportunities. First, they might increase green policies and measures that foster the implementation of GSs in the port domain. Then, they might also introduce storage and conversion systems in the technical configuration. In addition, they should use the national energy networks i.e., electricity, gas, heating networks as a backup to face any anomalies that can occur in the national energy networks. Finally, it is also important to use tools, software and technologies for energy optimization and the introduction of demand side management in the port energy management can bring substantial benefits.

However, the port renewable energy hub is vulnerable to several threats of which the most critical are the fluctuation of energy price, the uncertainty of renewable energy production and the non-acceptance of the local community. Then, the uncertainty of energy demand, the limited capacity of energy storage system and the lack of qualified workers represents other threats to be considered.

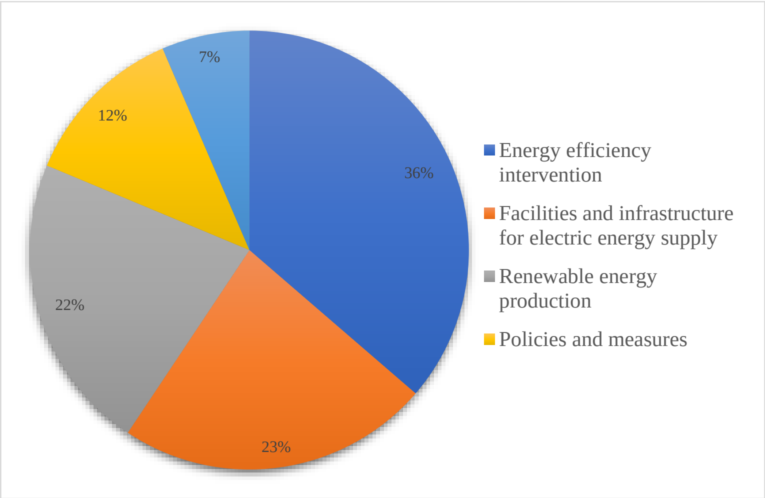
Application of the conceptual framework to the Italian case

The empirical results emerging from the analysis of the as is situation of the Italian port system emphases the growing number of interventions for reducing the energy consumption and decarbonising port areas. In this vein, 36% of GSs account for energy efficiency interventions and 23% of them refer to the development of facilities/infrastructures for electric energy supply. In addition, 22% of the sample GSs are related to renewable energy production, and 12 % of strategies regard policies and measures. Finally, 7% of the sample GSs aim to develop bunkering and storage facilities for alternative fuels (Figure 12).

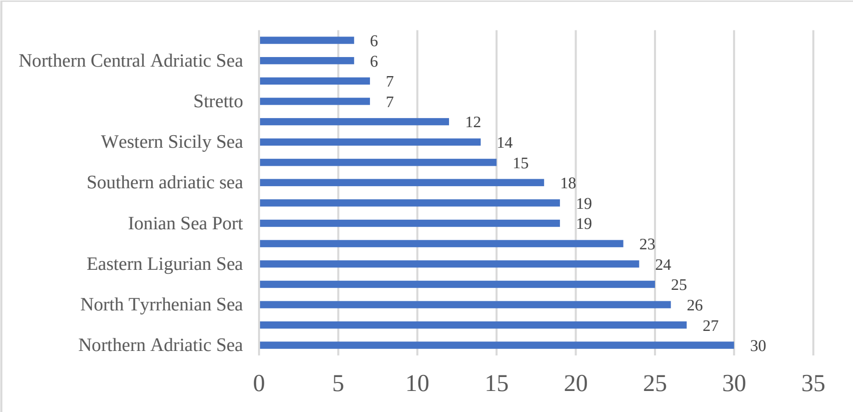
When it comes to the analysis of the sample PMBs strategic behaviour, Northern Adriatic Sea (30 GSs) and Northern Central Tyrrhenian Sea (27 GSs) emerge as the most proactive actors in the implementation GS projects and demonstrate to have reached an almost mature phase in the ongoing patterns towards their transformation into innovative renewable energy hubs. They are followed by the North Tyrrhenian Sea (26 GSs), Sardinian Sea (25 GSs), Eastern Ligurian Sea (24 GSs) and Western Ligurian Sea (23 GSs).

Concerning the financing, more than 70% of these GSs are financed by the National Recovery and Resilience Plan (NRRP)[3] and European Funds (e.g., Ealing project). The NRRP has allocated 700 million euro for the electrification of 34 Italian ports between 2021 and 2026 and 270 million euro for the implementation of environmental sustainability interventions. The rest of 30% of GSs are financed by national government, private (Terminal, Energy companies), port authorities, regional government and local government.

Figure n.12: Green strategies typologies: The "As Is" situation of Italian port



[3] The National Recovery and Resilience Plan (NRP) is part of the Next Generation EU (NGEU) program, the €750 billion package, roughly half of which consists of grants, agreed upon by the European Union in response to the pandemic crisis. The main component of the NGEU program is the Recovery and Resilience Facility (RRF), which has a duration of six years, from 2021 to 2026, and a total size of 672.5 billion euros (312.5 grants, the remaining 360 billion low-interest loans).



Source: Our elaboration

To reach a successful port renewable energy hub, Italian ports are committed take advantage of several opportunities. Italian ports are increasing green policies and measures to foster the implementation of GSs in the port domain. One of the most relevant to date is the attribution of Renewable Energy Community (REC) status to Italian ports through the conversion into law of the Milleproroghe Decree 162/2019, to foster the energy transition. In this vein, Law 84/94, which regulates Italian port organisation and activities to bring them into line with the objectives of the general transport plan, was amended by allowing Port Authorities to participate in RECs, possibly established in corporate form, by also subscribing to majority stakes.

As RECs, Italian ports can reduce their negative impacts by starting to produce at least part of the energy they consume to carry out their activities, relying on renewable energy sources.

In this way, they should lay the foundations for becoming a renewable energy community and position themselves as pioneers in the energy transition process. Specifically, given the importance of ports in the local economy where they are located (Cong et al., 2020; Coto-Millán et al., 2010), they are called upon to play a leading role in the energy transition, favouring the cluster's consumption of green energy. They are expected to play a more strategic role within the respective regional energy systems, acting as energy generation and distribution platforms. So as RECs, Italian ports could contribute to the transformation of the energy landscape by empowering consumers and contributing to energy and climate targets in terms of demand for renewable energy and emissions reductions.

However, Italian ports remain vulnerable to several threats including energy price, the uncertainty related to renewable energy production, the uncertainty of energy demand, the limited capacity of energy storage system and the slowness in implementing of laws.

In the Italian port system, the national energy network is the main input used within the port and major efforts are being made to increase the share of energy produced from renewable sources. Given the constant changes that characterized the GSs regulatory landscape at the EU level, Italian PMBs need to stay tuned to these changes and keep up to date regularly in order to implement policies and measures in line with the needs of port stakeholders.

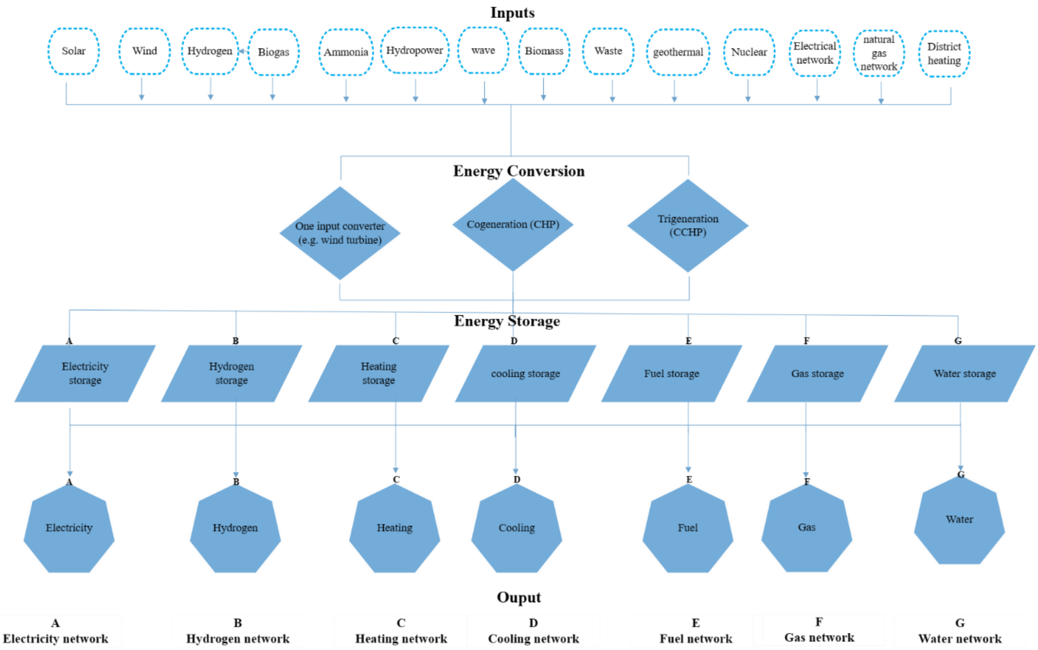
5. Discussion

The paper provides a structured framework made up of four layers including the market-based component, the technical components (Energy hub configuration), the financial aspect and the opportunities and the threats for supporting PMBs in setting their agenda for transforming ports into innovative renewable energy hubs.

The paper applied the framework to the Italian port case in order to assess the As Is situation of the implemented, ongoing, and under development GSs planned in Italian ports. As a result, GSs are very scattered, thus, there are still many interventions to be implemented to achieve the energy transition in the Italian Ports. Funding sources are mixed but dominated by European and national public funds, which play a key role in financing the current GSs port projects. The need for a public support is predominantly due to the high financial requirements which originate from capital-intensive investments as well as the long payback period that characterized these investments. In addition, the Italian ports still strongly rely on the national energy networks (electricity, gas, heat) as input and accordingly, are highly exposed to fluctuations in energy prices. However, they show a clear intention to increase the use of renewable energy sources but GSs investments related to energy conversion and storage systems are very low. This situation can be justified by the fact that energy storage is expensive and still cannot store the whole energy produced by renewable energy sources which constitutes a limitation for the renewables. Interventions related to policies and measures are limited, therefore it is urgent to increase GSs related to policies and measures.

Then a PREH configuration that includes all the technical components is provided in Figure 13. This configuration includes the energy production, conversion, storage and consumption.

Figure n.13:PREH configuration.



Source: Our elaboration

The aim of this configuration is to make available to PMBs a technical structure of renewable energy hub applicable to a real multi energy system such as ports. Due to the nature of the port as a multi-energy system, an interconnection of different energy carriers through the use of energy conversion and storage technologies is mandatory in order to optimize the energy system, but this leads to a modelling problem. However, modelling and management of such multi energy system results to be a difficult task, but it is inevitable due to the necessity of integrating different energy carriers and infrastructures. Therefore, the introduction of PREH is a good option to solve this problem as it is able to consider all the connections and optimal manage these systems.

Specifically, the PREH can use different inputs. From the results of MoSCoW, the most important inputs are solar and wind (Table 2) while the most important outputs are electricity, hydrogen, and heating. The conversion and storage systems result to be fundamental in PREH configuration. Thus, each port after identifying the best input-output mix, should deductively choose the best energy conversion and storage systems for the best coupling of the different energy loads.

Table n.2: The "must have inputs" and the related energy network.

PREH elements	Mo					
Input	**Solar power**					**Wind power**
Conversion	Solar thermal energy (STE)	A solar thermal collector (STC)	Solar Photovoltaic (PV)	Concentrated Solar Power (CSP) Systems	Solar Fuel Production	Wind turbine
Storage	Heating storage	Heating storage	Electricity storage	Electricity storage	Fuel storage	Electricity storage
Output	Heating	Heating	Electricity	Electricity	Fuel	Electricity

Source: Our elaboration

Solar can be converted into heat (output) by using technologies such as solar thermal energy or solar thermal collector. Solar as input can also be converted into electricity (output) by using the Solar photovoltaic (PV) or the concentrated solar power (CSP). With the CSP, electricity is generated when the concentrated light is converted to heat, which drives steam turbine (which is a heat engine) connected to an electricity generator. Solar can also be used to produce fuel by using the solar fuel production technology. Regarding the wind it can be converted into electricity through the use of the wind turbine.

The “should have” inputs of the configuration are hydrogen, biogas, ammonia, hydropower and wave. Fuel cell can be used to convert hydrogen, biogas, ammonia into hydrogen. A combined cooling heating and power (CCHP) can convert biogas into electricity, cooling and heating. Hydropower and wave can be converted into electricity by using hydropower turbine and wave energy converter respectively (Table 3).

Table n.3: The "Should have" inputs and the related energy network.

PREH elements	S					
Input	**Hydrogen**	**Biogas**		**Ammonia**	**Hydropower**	**Wave energy**
Conversion	Fuel cell	CCHP (Internal combustion engines and turbines, Gas turbines and micro turbines, Engines, fuel cell, absorption chiller)	Fuel cell	Fuel cell	Hydropower turbines (Reaction Turbines, Impulse Turbines, Hydroelectric Generators)	Wave energy converter
Storage	Hydrogen storage	Electricity/ heating, cooling storage	Hydrogen storage	Ammonia/ hydrogen storage	Electricity storage	Electricity storage
Output	Hydrogen	Electricity/ heating, cooling	Hydrogen	Hydrogen	Electricity	Electricity

Source: Our elaboration

The “could have” inputs include biomass, waste, geothermal and nuclear (Table 4). To produce electricity and heating, biomass, waste and geothermal can be converted by using biomass boiler, the incineration plant, and steam turbine respectively. These converters are forms of combined heat and power (CHP). Then, gasifier can be used to convert biomass and waste into hydrogen. While nuclear is the last input and can be converted by using the nuclear reactor to produce electricity.

Table n.4: The "could have" inputs and the related energy network.

PREH elements	**Co**					
Input	**Biomass**		**Waste**		**Geothermal**	**Nuclear**
Conversion	CHP (Biomass boiler)	Gasifier	Gasifier	CHP incineration plant (furnace)	CHP (Steam turbine, heat exchangers)	Nuclear reactor
Storage	Electricity/heating storage	Hydrogen storage	Hydrogen storage	Electricity/ heating storage	Electricity/ heating storage	Electricity storage
Output	Electricity/heating	Hydrogen	Hydrogen	Electricity/ heating	Electricity/ heating	Electricity storage

Source: Our elaboration

As renewable energy source suffers from uncertainty, national energy networks could be used as a backup system (Table 5). The electricity network can be used to provide electricity by using the transformer for conversion; it can also be used to provide heating and cooling by using electrical boiler/heat pump and absorption chiller.

Table n.5: PREH back up system

PREH components	**Backup system**						
Input	**Electrical network**			**Natural gas network**			**District heating**
Conversion	Transformer	Electrical boiler, heat pump	absorption chiller	CHP	CCHP	Gas boiler	CHP
Storage	Electricity storage	Heating storage	Cooling storage	Electricity/ heating storage	Electricity/ heating storage	Water storage	Heating storage
Output	Electricity	Heating	Cooling storage	Electricity/ heating	Electricity/ heating, cooling	Hot water	Electricity/ heating

Source: Our elaboration

The natural gas network can be used to produce electricity and heating by using a CHP conversion, to produce electricity, cooling and heating by using a CCHP and to produce hot water by using gas boiler. The district heating can be used to produce electricity and heating by using CHP.

Regarding the storage system, the size and the type should be assessed on the basis of the characteristics of coupled loads and generation plant. The storage system allows for temporal shifting of the local production in order to maximize the self-consumption when the power loads and generation trends differ significantly (e.g., in the case of photovoltaic production with contextual low load during day hours and evening peak). After the identification of the optimal input-output mix, each port deductively chooses the best storage systems to couple the different energy loads considering criteria as cost, availability, flexibility, technology readiness level, installation effort, capacity.

Overall, the configuration of PREH provided by this paper should have the present characteristics:

- Hybridisation of the inputs. The inputs should be constituted by renewable energy and the national energy network. However, the goal might be the reduction of the share of energy produced by the national energy network in favour of renewable energies, with the aim of achieving a fully renewable energy system.
- Energy hub based on energy converters and storage. Energy conversion and storage are fundamental for the success of PREH, as they bring flexibility and reliability in the energy system. They also enable cost reduction and energy efficiency.
- Smart. The PREH should be smart and able to manage the large amount of information flowing through the energy system by using technologies, tools, software such as IoT, big data.
- Dynamic. PREH should be able to operate under tough and changing working conditions of the port energy system. This implies the introduction of technologies, tools, software to increase the efficiency of EH devices and reduce the related cost and pollution.
- Modularity: The PREH should be a multi energy hub made up of multiple generation and storage components, creating multi energy systems.

6. Conclusion

The paper first provides a structured framework made up of four layers including the market-based component, the technical components, the financial aspect and the opportunities and the threats for supporting PMBs in setting their agenda for transforming ports into innovative renewable energy hubs. Then the conceptual framework is applied to the Italian port case in order to assess the As Is situation of the implemented, ongoing, and under development GSs planned in Italian ports. Finally, the paper provides, the most important components that constitute a successful PREH configuration by applying a stakeholders' perspective to achieve environmental, financial and economic sustainability.

The paper contributes to the academic debate on energy transition in the port domain from an energy hub perspective by providing a classification of energy hubs applicable to port. This energy hub perspective represents a transformative approach for the management and optimization of port energy systems, for aligning with the global shift towards sustainability and renewable energy sources.

From the managerial perspective, the PREH framework developed, represents a decision support system tool for developing and implementing strategies for achieving environmental, financial, and economic sustainability by exploiting the EH concept. Through energy hub approach, PMBs could maximize the environmental, financial and economic sustainability of the port as this approach brings several benefits including flexibility, reliability, cost saving, energy efficiency etc. However, the maximisation of this environmental, financial and economic sustainability is conditioned by several threats such as uncertainty of energy demand and energy price, limited capacity of energy storage, reluctance of the local community towards the implementation of the PREH concept. Therefore, the port in applying the EH approach, must address these threats and meet the needs of the stakeholders in the best possible way.

Moreover, through the proposed framework, the paper provides policy makers with valuable insights that can serve as a springboard to fuel the continued development of renewable energy systems in the port. These insights can result in fostering the development of PREH, supporting the implementation of GSs, promoting green finance, taking advantage of opportunities of each port and reducing or eliminating the threats that can hinder the implementation of PREH.

However, it is essential to acknowledge the specific limitations of this paper, which provide opportunities for future research. The conceptual framework only provides the layers for the development of a PREH configuration in term of inputs and output without providing clear indication on how to analyse these layers. In addition, the classification of the PREH technical components is based on expert opinions, which are subjective, therefore, the answers can be influenced by personal biases, leading to potentially skewed or inaccurate information. The limited sample size can limit the generalizability of the findings.

Addressing these limitations will strengthen the empirical analysis. It is recommended that future research deeply address the four layers of PREH and ensure a more holistic approach with a wide sample. The conceptual framework should be applied to other contexts to increase and test its robustness and generalisability.

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