ITALIAN CENTRE OF EXCELLENCE IN LOGISTICS TRANSPORT AND INFRASTRUCTURE

UNIVERSITY OF GENOA

PhD in Transport and Logistics
XXXVI series

THE ROLE OF THE PORT RENEWABLE ENERGY COMMUNITY IN DECARBONIZING THE PORT SUPPLY CHAIN

How ports can be the front runners of the energy transition?

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October 2024

ABSTRACT

The increasing energy demand originating from port activities, coupled with the need for reducing GHG emissions have urged greater attention from port decision makers on energy management issue, especially considering current institutional and normative settings which consider energy transition and port decarbonization as core goals to be achieved in the next years. As a result, the energy-intensive nature of port activities and the ongoing stricter environmental regulations at European and international levels, have increased the pressure on port authorities to find innovative solutions to reduce pollution arising from port-related activities. This decarbonization does not only consider the port as a node but considers the entire supply chain in order to solve the energy consumption and the pollution issues in a more comprehensive way.

In this vein, this PhD thesis examines the role of the port renewable energy community (PREC) in decarbonizing the port supply chain. The PhD thesis aims to assess the extent to which the introduction and development of effective PREC can enable overtaking the issues and concerns related to energy management in the port domain.

A step-by-step framework towards a PREC consisting of a theoretical part and empirical part is developed. The theoretical part introduces and discusses key strategic management theories and theoretical constructs involved in the research activities by addressing several concepts and issues such as green strategies in ports, ports as energy hub, port energy management system and PREC business model. Then, the empirical part consists of 4 papers related to the theoretical part. The first paper shows an empirical evidence of stakeholder prioritisation in Italian ports. The second paper analyses the port renewable energy hub. Then, the third paper addresses the energy management in the port as a holistic approach. Finally, the fourth paper develops an innovative business model for port renewable energy community.

The empirical research outcomes provide valuable insights for port stakeholders regarding the port supply chain decarbonization. Managerial implications for port authorities, policymakers and scholars are extensively debated to pave the way for future studies on energy transition, energy management and PREC. In this perspective, this PhD thesis would take a step forward in the research on PREC both theoretically and practically grounding on the step-by-step framework towards a PREC. This step-by-step

framework can be used as a starting point and/or as a decision-support tool for the port's long path to decarbonisation and energy efficiency.

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PART I –THEORIES, CONCEPTS & THEORETIC AL CONSTRUCTS

Ports are traditionally considered as energy hubs due to the great number of operations and activities related to energy production, storage, and consumption that take place within port areas, but also as a consequence of their geographical location which make them suitable gate for import/export different energy product such as coal, gas, carburant, electricity, LNG, hydrogen. Nonetheless, in the last decade, the increasing energy demand originating from port activities, coupled with the need for reducing GHG emissions have urged greater attention from port decision makers on energy management issue, especially considering current institutional and normative settings which consider energy transition and port decarbonization as core goals to be achieved in the next years.

The increasing energy consumptions in port areas, in fact, have led to higher energy costs for port operators as well as to unsustainable additional pollutants, greenhouse gas emissions and related environmental negative spillover within or around port areas. According to Iris and Lam (2019), energy costs represent a significant overhead for ports, terminals and other actors operating within the maritime and port supply chain: therefore, by reducing energy consumptions in port areas not only positive environmental implications are expected but also substantial cost savings and financial performance improvements for ports will be achieved.

Given the above, the present PhD thesis aims at evaluating how the introduction and development of effective port renewable energy community (PREC) can allow to overtake the issues and concerns related to energy management in the port domain. In particular, PRECs are suggested and demonstrated as a viable solution to achieve the goal dictated by the energy transition including not only the decarbonisation of the port node but the decarbonisation of the entire port supply chain.

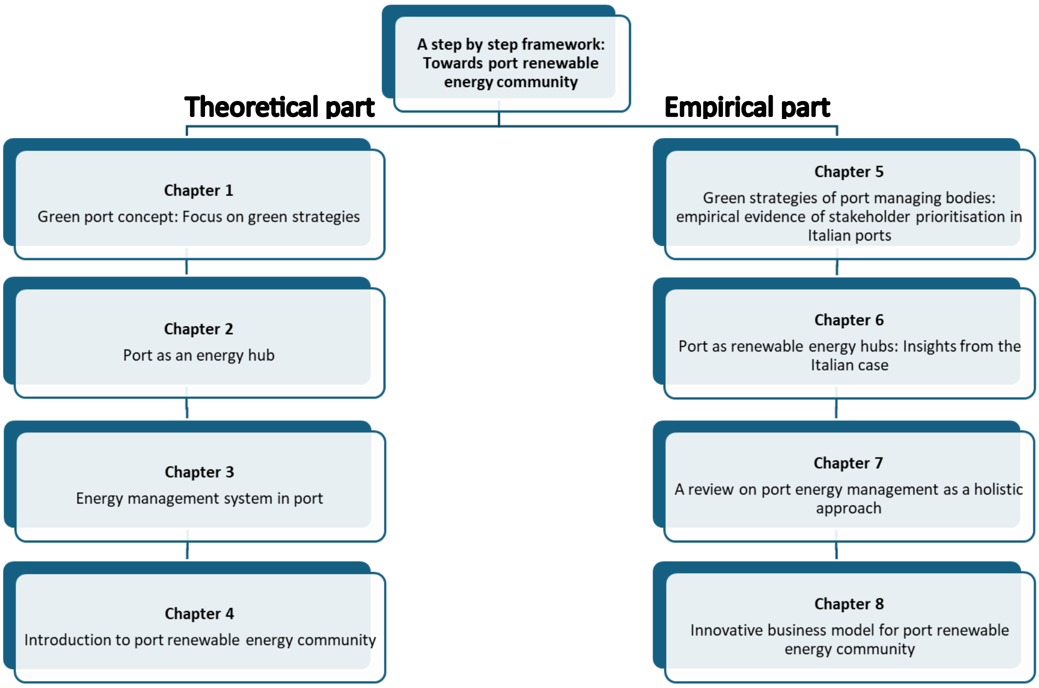
For these purposes 4 research objectives are set, as reported below:

- ***RO1***. *To identify Green Strategies (GSs) implemented by ports aiming at making port operations more sustainable, especially reducing energy consumptions and increasing energy production from renewable sources.*
- ***RO2***. *To provide a conceptual framework for supporting port decision makers in transforming ports into renewable energy hubs.*

- ***RO3***. *To evaluate the introduction of an ad hoc port energy management approach as a preliminary condition for the energy transition process of ports.*
- ***RO4***. *To propose an innovative (green and smart) business model for the establishment of effective PREC.*

For addressing these research objectives, an ad hoc research design has been set, as reported in the Figure bellow.

Figure 1*:* A step-by-step framework towards a PREC.



This research design consists of the two parts: the theoretical part and empirical part.

The theoretical part consists of four chapters and the second part, which is the empirical one includes 4 papers authored or co-authored by my myself during the PhD programme. Finally, the Thesis also includes the conclusion chapter which includes the concluding remarks and future research agenda.

Chapters 1-4 introduce and discuss key strategic management theories and theoretical constructs involved in the research activities by addressing several concepts and issues such as green strategies in ports, ports as energy hub, port energy management system and port renewable energy community. Chapters 5-8 empirically address the empirical part through four papers. The first paper which is related to the chapter 1 on green strategy addresses the first research question by showing an empirical evidence of stakeholder prioritisation in Italian ports. The second paper on "*port renewable energy hub*" is related to the second chapter, and deals with the second research objective. Then, the third research objective is addressed by the third paper on "*energy management in the port as a holistic approach*" which is related to the chapter 3. Finally, the fourth paper on "*innovative business model for port renewable energy community*", which is related to the chapter 4, addresses the last research objective.

CHAPTER 1
GREEN PORT CONCEPT: FOCUS ON GREEN STRATEGIES

1.1. Introduction: port sustainability and the green and smart port concept

In the second half of the 20th century, the topic of sustainable development assumed particular importance (Chichilnisky, 1999). Initially, the emphasis was on researching the impact of economic growth on environmental sustainability (Wołek et al., 2021). Over the past decade, the concept of sustainability has continually grabbed the attention of policymakers and local communities, who have put increasing pressure on businesses to act sustainably. Furthermore, the application of the sustainability concept demonstrates environmental and economic benefits, to the extent that today all sectors including the port sector, tend to act in a sustainable manner.

The concept of sustainability was first used in 1978 by the United Nations (UN), which defined sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs. Elkington (1997), introduces a different perspective of sustainability, arguing that the key to sustainability is through stakeholder engagement. This definition is in line with the one provided by the American Association of Port Authorities (AAPA), which defines port sustainability as strategies and activities that address both the existing and future needs of port stakeholders while also protecting and supporting the human and natural resources (AAPA, 2007). According to Wakeman (1996), the sustainable development of ports relies on an appropriate planning and management of ports, balancing environmental, social, and economic interests through mediation and open dialogue.

Today, the concept of sustainability is considered as a multidimensional issue or a triple bottom line (TBL) that includes the economic, environmental and social dimensions of sustainability (Stanković et al., 2021; Lu et al., 2016). Another interesting perspective come from Lam and Van De Voorde (2012), as they suggest a combined framework identifying four major elements of a sustainable port strategy which include: (i) stakeholder involvement, (ii) green market development, (iii) cost-effective environmental policy, as well as (iv) sustainable operations and development.

Considering the definitions of sustainability presented above, it emerges that sustainable development in ports could add value to their performance, as long as the economic, environmental, and social dimensions of sustainability are taken into account. Moreover, as concerns for sustainable development in ports continue to grow, a large amount of academic literature has emerged addressing various perspectives related to port sustainability. As a result, the increasing environmental awareness put further pressure on port managers to comply with environmental and social requirements. Furthermore, one of the port's major source of incomes comes from the stakeholders, so integrating their social and environmental concerns into the port plans and actions is beneficial for the economic aspect (Lam & Dai, 2015). This perspective is supported by Hales et al. (2016) and Parola et al. (2016) who argue that the achievement of environmental sustainability is a significant driver for strengthening port competitiveness. Consequently, the main aim of introducing the concept of sustainable development in ports is to develop a reliable, environmentally and socially acceptable approach to port management, which ensures the achievement of economic benefits (Lim et al., 2019).

With increasing socio-economic and environmental pressures, port authorities (PAs) are taking various measures to improve the sustainability of port operations (Hossain et al., 2021). These interventions, among others, include energy efficiency and conservation, environmental policy, energy management system, green incentives, shore power, LNG facilities, renewable energy production…ect. These measures are leading to a new approach of conceiving the ports of the future, known as green and smart ports.

According to Acciaro (2015), green ports are committed to proactive development, executing and monitoring practices aimed at reducing environmental effects beyond compliance. The path towards green port grounds on three key pillars, i.e., stakeholder engagement, green policies, and scientific monitoring (Lam & Li, 2019).

- Stakeholder engagement: Sakar and cetin (2012) argue that meeting the needs of external stakeholders, legislation and public policy stakeholders is fundamental to achieve long term port sustainable development.
- Green policies: Green policies are crucial for achieving the green port concept. These policies include the establishment of speed limit zones for ships, the indication of alternative fuels and maritime energy technologies, and emission control areas (ECA). These policies contribute to the reduction of harmful and greenhouse gas emission in

ports, water pollution and provide benefits like lower fuel consumption (Chang & Wang, 2012). The reduction of air pollution would then reduce the adverse health effects on the local community which include respiratory diseases like asthma, cardiovascular disease, lung cancer and premature mortality (Bailey & Solomon, 2004). In addition Port Authorities can use pricing, monitoring and measuring, market access control and environmental standard regulation to provide guidelines, best practices and tools for green port management (Lam & Notteboom, 2014).

- Scientific monitoring: it includes water quality analysis, sediment analysis, and ecological monitoring. These analyses measure the impact of port operations, focusing on the major environmental concerns that are water quality, dredging, port development, dust, and noise (Wooldridge et al., 1999). Indicators such as monitoring and estimation of carbon footprint (Mamatok & Jin, 2017) and the Drivers, Pressures, States, Impacts and Responses (DPSIR) framework (Wan et al., 2018) can be used to tackle environmental issues in the port domain and achieve the green port concept.

However, ports face several issues, such as operating errors, congestion, delays, lack of information, environmental and energy problems. These issues considerably reduce the quality of port services to users and local stakeholders and cause a domino effect that negatively impacts the entire supply chain. In order to solve these problems and decarbonize port areas, it is necessary to combine the green port concept with intelligent technologies, tools and systems by introducing the smart port concept into the design of the port of the future.

Given the stiff competition that characterizes the port industry as well as all the issues related to port sustainability the smart port concept was introduced by scholars and practitioners in the port domain in order to mitigate these issues (e.g., climate change, greenhouse gas emission, lack of energy efficiency). Smart ports are considered more capable to tackle the challenges faced by ports, international trade, logistics systems and the entire supply chain through a deeply integration of digital technologies, such as the Internet of Things (IoT), big data, cloud computing, and artificial intelligence in the port's operations (Li et al., 2023).

These digital technologies can greatly increase the performance and the competitiveness of ports by making port operations smarter and enabling optimal allocation of resources in port operations. Additionally, smart ports increase port efficiency, communication, and crew satisfaction (Zhao et al., 2020).

In the light of the above, for achieving the decarbonisation of the port industry, it is fundamental to combine the concepts of green and smart port. These two concepts include **hard components** which consist of physical interventions for port decarbonization (e.g., installation of renewable energy sources for energy production in port, installation of led lighting system, revamping of port buildings, implementation of cold ironing), and **soft components** that are non-physical interventions for port decarbonisation including green policies, methods and procedures, smart energy management systems, tools, technologies and port governance settings inspired to corporate social responsibility (CSR). Developing a governance based on CSR, ports want to appropriately balance economic, environmental and social imperatives, while at the same time addressing the expectations of the stakeholders including shareholders. The CSR concept emerged in the 70s, and in 2011, the UN provided a definition which is "*the responsibility of enterprises for their impacts on society*". This definition concerns all sectors including the port industry.

The CSR concept in port is extensively analysed in the section 1.2. the environmental issues of ports and the application of the CSR concept in the port domain; the section 1.3. addresses the green strategies (GSs) in the port, while section 1.4. addresses a new green business model of port, and the section 1.5 stresses the green finance for achieving the green port concept with focus on Eu funding scheme.

1.2. CSR and environmental issues in ports: relevant managerial theories and perspectives

Climate change represents one of the biggest challenges of this times for both public entities and private companies. Emissions from the waterborne transport sector have been demonstrated to determine significant environmental negative externalities including air pollution, greenhouse gas emissions, releases of ballast water containing aquatic invasive species, historical use of antifoulants, oil and chemical spills, dry bulk cargo releases, garbage, underwater noise pollution; ship-strikes on marine megafauna, risk of ship grounding or sinkings, and widespread sediment contamination of ports during transshipment or ship breaking activities (Wang et al., 2008; EEA, 2012; Walker et al., 2019). According to UNCTAD (2020) about 80% of world's trade volume is transported by sea, making the maritime transport the backbone of the global economy. Compared to other modes of transportation such as aviation or road transport, shipping is widely considered to be more environmentally sustainable as it is responsible only for 2.9% of global anthropogenic greenhouse gas (GHG) emissions (IMO 2020). The shipping industry releases 1.2 to 1.6 million tonnes of PM_{10}, 4.7 to 6.5 million tonnes of SOx, and 5 to 6.9 million tonnes of NOx worldwide (Nunes et al., 2017), and these emissions drastically deteriorate the air quality. Indeed, most of the environmental impacts are caused by day-by-day port activities when the ships are at the berth (Becker et al., 2018). For this reason, the effects on the air quality are much more significant in coastal areas than in the open sea (Gilbert et al., 2018), as at least 70% of ship emissions occur within 400 km of the coast generating severe consequences for local communities of maritime cities (Nunes et al. 2017). Negative externalities also originate from the energy-intensive nature of the port industry sector and the magnitude of highly impacting business processes embedded in the port area, including cargo handling, bunkering operations, waste management, and dredging (Dinwoodie et al., 2012; López-Navarro et al., 2015; Alamoush et al., 2021).

Based on the considerations above, there is an urgent need from international, national, and local authorities to take actions to mitigate climate change and improve the air quality and energy efficiency in the port sector.

In this vein, in 2015, all the United Nations Members States adopted a bold sustainable development plan, well known as 2030 Agenda for Sustainable Development. It consists of 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries both developed and developing in a global partnership. The SDG 7 Affordable and Clean Energy and the SDG 13 Climate Action are fundamental for the port sector.

In line with the Paris Climate Agreement (COP 21, 2015), the International Maritime Organization (IMO) incorporated environmental and social responsibility in its strategy, and the main goal consists of reducing the shipping carbon footprint to zero.

The European Commission took actions through the European Green Deal that refers to the necessity of achieving green and climate-neutral shipping and waterborne operations, and the importance of research and innovation in this domain. Over the last years, many green investments have been addressing innovative ship propulsion systems and alternative clean fuels consistent with the international and EU framework regulations on green issues. These investments include Integrated Electric Propulsion (IEP), which constitutes the key building block on the way to the All-Electric Ship (AES), diesel-electric engines, wind power for marine propulsion systems, and alternative green fuels, including very-low and ultra-low sulphur fuel oil (VLSFO/ULSFO), LNG, biomass energy, biofuels, green hydrogen, and ammonia.

In addition, the top 3 environmental priorities of European ports are made up of climate change, air quality and energy in first, second and third place respectively (Figure 1.1).

Figure 1.1: Top 10 environmental priorities of the port sector over the years

	1996	2009	2013	2018	2019	2020	2021	2022
1	Port development (water)	Noise	Air quality	Air quality	Air quality	Air quality	Air quality	Climate change
2	Water quality	Air quality	Garbage/ Port waste	Energy consumption	Energy consumption	Climate change	Climate change	Air quality
3	Dredging disposal	Garbage/ Port waste	Energy consumption	Noise	Climate change	Energy efficiency	Energy efficiency	Energy efficiency
4	Dredging operations	Dredging operations	Noise	Relationship with the local community	Noise	Noise	Noise	Noise
5	Dust	Dredging disposal	Ship waste	Ship waste	Relationship with the local community	Relationship with the local community	Relationship with the local community	Water quality
6	Port development (land related)	Relationship with the local community	Relationship with the local community	Port development (land related)	Ship waste	Ship waste	Water quality	Relationship with the local community
7	Contaminated land	Energy consumption	Dredging operations	Climate change	Garbage/ Port waste	Water quality	Ship waste	Ship waste
8	Habitat loss/ degradation	Dust	Dust	Water quality	Port development (land related)	Garbage/ Port waste	Dredging operations	Garbage/ Port waste
9	Traffic volume	Port development (water)	Port development (land related)	Dredging operations	Dredging operations	Dredging operations	Port development (land related)	Port development (land related)
10	Industrial effluent	Port development (land related)	Water quality	Garbage/ Port waste	Water quality	Port development (land related)	Garbage/ Port waste	Dredging operations

Source: ESPO Environmental Report – EcoPortsinSights (2022)

Although climate change only entered the top 10 environmental priorities of European ports in 2017, and it has rapidly risen up the rankings to reach the top spot in 2022.

The leading position of climate change in top environmental concerns for ports in 2022 highlights the culmination of a longer trend. This fast increase reflects a general trend in current EU and national policy discussions, as the issue related to climate change is a growing concern that continuously grabs attention of policymakers and local communities.

The increasingly visible effects of climate change as well as the inclusion of shipping in EU climate policy proposed in the European Commission's Fit for 55-package is likely to have made the issue even more of a priority for ports. Compliance with climate legislation, reducing carbon emissions and protecting port infrastructures from the effects of climate change are therefore essential for European ports. And this compliance has to be guarantee by the PAs.

With regard to the prominent role of PAs within the maritime logistics ecosystem (Van der Lugt et al., 2013; Castellano et al., 2020), they should be at the cutting edge for reducing the environmental impact of the maritime logistics activities and fostering the decarbonisation of the entire industry (Hiranandani, 2014; Bergqvist & Monios, 2019).

As regulators, PAs are called to implement international, regional, and local environmental regulations and policies as well as monitor and guarantee their compliance by carriers, terminal operators, and port users (Poulsen et al., 2018). Moreover, they are expected to act as principal performers, implementers and orchestrators, of both the hard and soft components of the green and smart port concepts to address the increasing concerns of the main port stakeholder groups (Kang & Kim, 2017; Martínez-Moya et al., 2019). They should keep monitoring their air quality, carbon footprint and energy efficiency, and provide incentives for ships that go beyond regulatory standards through differentiated port fees. The introduction of innovative technologies jointly with the optimisation of existing operations would provide an optimistic transition path away from a carbon-intensive port industry which strongly rely on fossil fuels, to a low-carbon port model based on renewable energy sources, electrification of port equipment, introduction and use of alternative fuels, application of smarter power distribution systems, and energy consumption measurement systems. This is an indispensable condition to achieve the targets set by policymakers, address the implications of climate change, and improve the air quality and the energy efficiency of ports activities.

It is clear from the preceding discussion that the PAs are aware of the urgency of decarbonising the port sector and are exercising a greater pressure on port management for greener and more sustainable solutions (Chen & Lam, 2018; Stein & Acciaro, 2020).

This pressure led to the introduction of several changes in the PAs governance process. Consequently, since the 2000s CSR aspects have been introduced in the planning activities of PAs (Dooms et al., 2013). As a result, CSR has become a crucial driver for defining PA strategies.

In this perspective, a new sustainable approach to port management has been introduced to consider not only the current, but also the future objectives of port stakeholder groups (PSGs) in the decision-making process and strengthen the environmental sustainability in the maritime logistics industry in both public and private entities (Puente-Rodríguez et al., 2016; Castellano et al., 2020). CSR practices hold the potential to create value for port users, thereby granting competitive advantages to port operators and managing entities (Stein & Acciaro, 2020).

Indeed, the European Commission defined CSR as "*the responsibility of enterprises for their impacts on society*" (European Commission, 2011, p. 6). Matten and Moon (2008) argue that CSR reflects the obligations and responsibilities that an organisation should have for its stakeholders and the broader social good. Notteboom et al. (2015), who addressed the issue of CSR in the port sector, claim that CSR is not only a legal requirement or an ethical commitment, but also a strategy to improve port reputation, stakeholder management practices, and port competitiveness.

CSR covers three main objectives that are strongly related to port stakeholder needs, which include economic, social, and environmental issues (Thierry Vanelslander, 2016). These objectives can be completed by three other objectives namely market, governance, and regulatory objectives (Satta et al., 2022). These objectives are presented below:

- <u>Environmental objective</u>. This objective includes the reduction of environmental impact, climate change adaptation and mitigation, reduction of harmful emissions and other externalities on land and water.
- <u>Economic objective</u>. It consists of business and economic growth, cost saving, port value creation, increasing the port's competitiveness, increasing operational efficiency, and reduction of costs.
- <u>Market objective</u>. It is related to the satisfaction of maritime cluster firms' expectations, effective response to competitors and market pressure, improvement of quality and variety of services in line with customer demands.

- Governance objective. It includes leadership ethics, collaboration with port stakeholders, more sustainable governance structure and practices.
- Regulatory objective. It implies compliance with national and international regulation, the definition of stricter policies and measures at port level and monitoring of their compliance by port stakeholders.
- Social objective. This objective is about legitimacy from local communities, social licence to operate, improvement of public image of the port, protection of human health, the definition of social initiatives.

In the CSR principle it is crucial to align the objectives of the port and the stakeholders (Satta et al., 2022). This allows to better meet their needs and can contribute to increasing the competitiveness of ports. This principle represents a new sustainable approach to port management to consider PSGs objectives in the planning process and face the challenges of climate change. Thus, if well implemented, CSR can contribute substantially to the overall port performance (Dooms, 2019). In other words, in addition to the high financial performance that could emerge from the adoption of CSR-related behaviour, port performance can increase globally, not only financially, but also economically, socially, and environmentally (Burke & Logsdon, 1996). This increase can lead to creation of strategic, and business-orientated benefits for ports. Therefore, PAs in their planning process must consider stakeholder objectives, and to successfully accomplish this scope, they should identify:

i) the key stakeholders who actively contribute to the achievement of strategic objectives and implementation of the mission of the ports,
ii) the specific strategies that can contribute to meet the objectives of these key stakeholders.

Several taxonomies exist in the literature for the classification of port stakeholders (Notteboom & Winkelmans, 2003; Notteboom, et al., 2015; Ashrafi et al., 2020; Satta et al., 2022). For the purpose of this work the taxonomy provided by Satta et al. (2022) was adopted. This taxonomy considers 10 groups of port stakeholders including:

- Shareholders/owners. They are public entities or private organisations with an equity share in the PA or are entitled to appoint PA board of directors or executive directors.

- Financial community. They represent the financial and credit institutions that allow financial resources to PAs to support their investment decisions and port development plan implementation.
- Employees and labour unions. They are labour unions and people working at both executive and operational levels in the PA, public institutions including customs, coast guard, etc., and concessionaires, as well as labour pools.
- Terminal operators. Consist of firms that own and/or otherwise operate a terminal through a concession.
- Other concessionaires. They are firms holding at least a concession in the port area related to warehouses, industrial areas, logistics platforms, malls, or commercial areas.
- Carriers. Represent shipping companies including shipping lines (container, ro-ro, cruise companies, etc.) and tramp operators (liquid bulk, dry bulk, etc.).
- Port users. Firms as freight forwarders, ship agents, brokers, road hauliers, railway companies, logistics providers, etc.
- Passengers. They represent the travellers on a ferry or a cruise ship who passe through the port for embarking and disembarking.
- Local community and societal groups of interests. They are people and organisations located in the proximity of the port areas and directly or indirectly affected by the port operation and business.
- Regulatory agencies. Policymakers and public institutions setting the institutional framework and governance mechanisms.

After identifying the key stakeholders, it is necessary to make a clear distinction between them. In this vein, Notteboom and Winkelmans (2002) distinguish stakeholders in internal and external. Internal stakeholders are the people closest to the organization. (e.g., board member, shareholders, employees). While external stakeholders represent individuals or groups outside the port, but who can influence or be influenced by the port activities.

Considering these internal and external stakeholders, the alignment their objectives with those of PAs in the mid and long-term is crucial for a successful implementation of CSR-oriented approach and require deep inclusion of PSGs in the port planning.

Indeed, port stakeholders continuously express their interest in having a clear view of the short and long-term strategic planning of the port for evaluating the impact of the entire port cluster on their own activities and providing a framework for private investors and operators within the port domain (Dooms, 2019).

The objectives of the PSGs are so diverse and in some cases even conflicting, that finding an agreement with the stakeholders and gaining their support is very challenging. Dooms (2019), provides six major elements contributing to more stakeholder-inclusive planning processes. In particular, the Author argues that a list of fundamental elements could be considered as a research agenda to achieve more resilience in port planning and design from a stakeholder perspective and are as follows:

- The first element regards the shift from an ad hoc inclusion approach towards continuous stakeholder inclusion. Ad hoc approaches consist of setting stakeholder inclusion only during long term planning processes that occur every 5-10 years. This approach is flawed as it doesn't provide continuous support to stakeholders during the implementation phase of master plans. The inclusion of stakeholders should be a form of progressive elaboration. More specifically, an intensive and continuous dialogue with port stakeholders, including local communities, is recommended. Tools as sustainability reports and social license to operate measurement could support this continuous dialogue.
- The second element regards a shift from a node-based planning boundary to integrative planning across the supply chain. For port planning and design, the long-term port master plans and visions should go beyond the port boundaries, considering the entire supply chain instead of a port cluster which is a node in the supply chain. This holistic approach leads to anticipation of some problems that could occur upstream or downstream in the supply chain such as bottlenecks both on the maritime and land route connecting the port area (e.g., infrastructure capacity shortage for rail, inland waterways, and road), resulting in the increase of the quality support provided to stakeholder in the broader port region. In addition, better integration of stakeholder objectives and information from a supply chain perspective could lead to stronger and supported strategic planning outputs for the local community.
- The third element is the expansion of the life-cycle cost assessment (LCA) of port infrastructure development. When applying the LCA approaches to the port infrastructure, the construction techniques to limit the maintenance costs and increase the resilience of port infrastructure against external shocks such as climate change

should not be the only guide of the evaluation. The integration of retrofitting policies as well as decommissioning of port infrastructure and the potential restitution of port assets after their economic lifetime should be take into account, in the extend that they are increasingly considered as elements to be integrated in sustainable port planning and design from a local community perspective. This consideration is based on the fact that retrofitting policies extend the lifetime of infrastructure assets in a sustainable way, limit the environmental impact of decommissioning and further reduce the environmental footprint of infrastructure over the lifetime.

- The fourth element regards the integration of adaptability and flexibility of port infrastructure development in port planning and the need for new business models. The increasingly shorter business cycles, faster technological innovation including gigantism and rapid technological disruption, and high economic volatility that characterized the maritime transport led to a high trade of flow transiting through ports. This increase in the volume of good transiting withing the port triggers the need for PA to introduce in port planning and design, the adaptability and flexibility principles, to mitigate the risk of overloading or idle of port assets. However, due to the long-term concessions or leases to private operators that characterized the current business model of most port managing bodies, this evolution seems in conflict with this business model. Moreover, adaptable, or flexible basic infrastructure also would require high investments from the port managing bodies, which seems difficult to support under the current framework of value distribution between stakeholders (where terminal operators seem to benefit the most, and port managing bodies have a limited financial/revenue based on port dues and concession fees). Therefore, despite this difficulties, new business models and approaches are needed on the current framework of value creation and value distribution in port areas, in order to facilitate the integration of adaptability and flexibility principles in port planning and design, to increase the efficient use of port assets (Taneja et al., 2010). More flexibility and adaptability lead to a more efficient use of both natural and artificial resources such as port land.
- The fifth element is the integration of business continuity principles in port planning and design, from a broader geographical perspective. It consists of extending the scope of port planning and design beyond the port area confines to integrate sources

of external risk and disruption in the planning process. For instance, port managing bodies in their process of developing policies against disruption based on climate change (e.g., flooding), should also consider the challenges of the urban areas around the port, which could, in the same way, disrupt the port activities if their policies are inadequate against external risks posed by climate change or other sources of shorter-term disruption such as high levels of air pollution pushing city government to limit transport movements. In this vein, port planning and design needs to integrate a permanent dialogue with stakeholders from the wider area surrounding the port on how to jointly face the business continuity around the port area in the context of both shorter and longer-term environmental challenges.

- The sixth element is the stronger integration of technological developments in port planning and design. Usually, technological developments often are underrated in port planning and design. This underestimation of design capacity of port assets against actual capacity use could result in stakeholder opposition when new expansion projects are proposed. Other evolutions such as autonomous or unmanned ships also provoke questions from various stakeholders on the future needs and principles of port operations and their impact on infrastructure needs and developments. On the other hand, these technological developments could significantly decrease the environmental footprint of port activities (e.g., through better planning and scheduling, limiting empty voyages of ships and trucks, and so on). Therefore, port planning and design processes should explicitly include a stakeholder-inclusive dialogue on the impact of new technologies on future port infrastructure needs and the associated environmental footprint.

This section provides the objectives of CSR and highlights the role of CSR as a driver for defining PA strategies since it can lead to the improvement of port competitiveness. However, given the different and conflicting interests of PSGs, CSR principle should align the objectives of the port and the stakeholders. Therefore, to achieve a more sustainable port development and reach the stakeholder-inclusive port planning purposes, the six major elements proposed by Dooms (2019) can be considered in future port planning and design processes. Furthermore, PAs, on their way of thinking about port of the future, are expected to act as principal performers, implementers, and orchestrators, of both the hard and soft components of the green and smart port concepts to address the increasing concerns of the main port stakeholder groups (Kang & Kim, 2017; Martínez-Moya et al., 2019). These hard and soft components refer to the implementation of Green Strategies (GSs) in the port domain. In addition, it appears relevant to link these GSs to the CSR objectives deriving from port strategies and the stakeholders needs. The next section presents the green strategies typologies and the relation with the CSR objectives within the port context to better meet stakeholder needs.

1.3. Green strategies typologies and related CSR objectives

Ports worldwide are facing huge environmental challenges related to climate change adaptation and mitigation, reduction of harmful emissions from maritime logistics activities, and compliancy to more stringent environmental regulation (Poulsen et al., 2018; Castellano et al., 2020). In this regard, introducing the "green" vision in port management and planning enables PAs to promote sustainable growth and meet the expectations of multiple stakeholders (Bergqvist & Monios, 2019) and if well-implemented leads to increased competitiveness of the port.

In the literature, GSs in the port domain has been explored from several perspectives, including managerial (Acciaro et al., 2014; Lam & Notteboom, 2014; Di Vaio & Varriale, 2018), operational (Dinwoodie et al., 2012; Puig et al., 2020), technical/technological (Davarzani et al., 2016; Martínez-Moya et al., 2019; Sdoukopoulos et al., 2019), and regulatory (Poulsen et al., 2018; Schrobback & Meath, 2020; Alamoush et al., 2021). However, a strong link with the concept and principles of CSR emerges from the literature since the environmental objectives of GSs are often extended by academics to other port management spheres, especially for managing Port Stakeholders Groups (PSGs) (Dooms, 2019).

For the scope of this study, the Green Strategies refer to all hard and soft interventions and measures including managerial, operational, technical/technological, governance, procedural, and best practices measures implemented by PAs in order to decarbonize the entire port supply chain (seaside and landside, including the hinterland), while complying with regulatory requirements, by making the port smarter and addressing the CSR objectives of port stakeholders.

Satta et al. (2022) provides an extended taxonomy that consists of 8 different GSs typologies extensively applied in both national and international ports for eliminating or at least mitigating the most significant environmental negative effects which originate from port operations and processes, i.e. energy efficiency intervention, facilities and infrastructure for electric energy supply, renewable energy production, policies and measures, digitalisation and ICT platforms, research and development, bunkering and storage facilities for alternative fuels, land use conversion. The GSs are described in detail in the next sections.

1.3.1. Energy efficiency interventions

The aim of this strategy is to improve the energy efficiency of maritime logistics activities in the port domain considering the impacts on the whole supply chain. They include all technical and technological solutions to reduce energy consumption and related GHGs and harmful emissions. They are mainly related to economic, market and social CSR objective and create value for stakeholders as PAs (shareholders), terminal operators, other concessionaires, and local communities. These interventions can be classified according to three user's categories:

- Buildings (PA headquarter, maritime and warehouse stations ect…) and other port areas (parking, roads). The interventions occurring in these areas include the installation of led lighting, the thermal insulation system and the replacement of some glazing, the revamping of port buildings and the replacement of existing windows and doors with newer, higher-performance products, together with replacement of all lighting fixtures. They also include decommissioning of the old central heating and related auxiliary systems and the installation of a hydronic heat pump sized to air-condition only the volumes used, the optimisation of lighting on/off in the port, the use of heat exchangers.
- Vehicle and equipment (truck, RTG, reach stacker, tugs). Some GSs related to this user profile are the retrofitting of the car and equipment fleets, the use of a hybrid power train, composed of flywheels and ultracapacitors as energy storage device and main energy sources, the replacement of diesel vehicle and equipment with electric ones, electrification/hybridisation of existing vehicles and equipment, the use of start-stop engines for diesel equipment and the optimisation of truck and equipment movements and arrivals.

- Port yards, quays, and seaside. Some GSs occurring at the port yard and quay include the installation of led lighting, the use of the peak shaving[1] method, the optimisation of lighting on/off in the port area, the flywheel instalment with an undersized diesel generator for an RTG, the efficient loading and unloading operations. Regarding the seaside, these GSs include virtual arrival system, which can be used to reduce a vessel's turnaround time in port, the slow steaming or reduction of ship's speed near to the port, and the use of sea water scrubbers to control exhaust gases from auxiliary engines.

1.3.2. Facilities and infrastructure for electric energy supply

The strategy is related to the construction of facilities and infrastructure for providing electricity within the port domain such as cold ironing, electric vehicle charging station and microgrid.

- Cold ironing. Cold ironing consists of transferring power supply to the ship's auxiliary engines from the local grid power at the shoreside via cable connection. The aim is to supply the necessary energy to the ships when berthing in the port. In this perspective, the ship receives power supply from the onshore utility grid and transmits it to voltages and frequencies that are in line with berthed ships. Cold ironing can be split into three main parts including the shore-side power supply, connection system, and the shipside receiving electricity (Abu Bakar et al., 2023). This technology allows to reduce the emission that is released by the auxiliary engines during the berthing period as well as tackle noise and vibration problems.
- Electric vehicle charging station (EVCS). EVCS serve to provide electricity to electric vehicles and other port equipment.
- Microgrid. A microgrid is a local energy network that aggregate distributed energy resources (DER), renewable energy source, energy storage system, and loads with the possibility to connect with the main grid, to provide a cost-effective and sustainable power supply. Nowadays, in the most cases, the electricity used for cold ironing and EVCS is mainly provided by the local grid, which does not always use renewable energy sources. In order to address the arising issue of emissions generated by the local grid that supplies cold ironing and EVCS, the electricity generated for

[1] Peak shaving are operational strategies that aim to reduce the peak energy consumption of the port (Iris et Lam., 2019).

cold ironing and EVCS can be provided by microgrid. Hence, the implementation of microgrid can lead to port decarbonization.

The main user profiles of this GS are equipment, cranes, vehicles, tractors that use electricity for to operate in the port yards and quays. The principal CSR objectives pursued are economic, market and social and the main stakeholders are particularly carriers, employees, terminal operators, other concessionaires, and local community.

1.3.3. Renewable energy production

Ports, as an energy intensive sector, are seeking alternative sources of energy. The aim of this strategy is to foster the uptake of renewable energy to meet the energy needs of ports and at the same time to decarbonise the port activities. The use of renewable energies offers several benefits: they are clean and can be used in a decentralized manner. Some renewable energy technologies include solar energy (onshore and floating PV), wind power (onshore and offshore), wave and tidal energy, geothermal power plants ect...

Both onshore and floating photovoltaics use photovoltaic panels to produce electricity, with the difference that in the case of onshore photovoltaics the system is installed on land, whereas in the case of floating photovoltaics the system is installed and fixed on a structure floating in the water.

The same reasoning is used for onshore and offshore wind energy system. Onshore wind the system is installed on land and offshore wind power plant includes a set of wind turbines that are installed on the sea. The wind speed in the sea is higher than on the coast or land. Consequently, in the same area, the generated electrical power of offshore wind turbines is more than the onshore ones (Parhamfar et al., 2023).

Renewable energies create value for stakeholders such as PAs (shareholders), terminal operators, other concessionaires, who have strong interest in economic and market CSR objectives. The main user profiles are building, parking, road, terminal, port yard and quay.

1.3.4. Policies and measures

PAs as regulators, subscribe to international, regional, and local regulations and policies on climate change (Poulsen et al., 2018). They set environmental standards and make their implementation legally mandatory for port's stakeholders as terminal operators, concessionaire, carriers, and port users including land transport (Vanelslander et al., 2014; Boile et al., 2016) and effectively monitor and guarantee compliance (Lam & Notteboom, 2014). These strategies are related to governance, regulatory and social CSR objectives and include policies and incentives to stimulate maritime logistics actors to adopt greener practices and behaviours. Some of the largely adopted and implemented measures and incentives in both European and internal ports include:

- **The adoption of information measures**, which are fundamental for the monitoring of port emissions and energy consumption, and to set the baseline for future comparison (Acciaro et al., 2014; Lam & Notteboom, 2014).
- **Incentives and grants.** The incentives refer to the differentiation of port dues from environmental perspective and grants refer to subsidies. These tools promote sustainability and internalize social and environmental externalities (Bergqvist & Monios, 2019), by stimulating the mitigation of GHG emissions and support ports, carriers, and port users (i.e., land transport operators) to offset the costs of measures (Poulsen et al., 2018; Notteboom et al., 2020).
- **Tariff change.** It is a useful tool for PAs, as it consists of preparing different pricing rates for port stakeholders (i.e., terminal operators, concessionaire, carriers, and port users including land transport), in order to encourage them to improve their carbon footprint and use green technologies in their operations. The tariff system could be based on customers' environmental performance (Van Den Berg, et al., 2017) and on port green priorities (Notteboom & Lam, 2018).
- **Market based measures.** These are measures aimed at creating funds to promote the adoption of greener technologies, improve port management and offset greenhouse gas emissions. They motivate port stakeholders (i.e., terminal operators, concessionaire, carriers, and port users including land transport) to implement measures for cutting emissions and increase the energy efficiency to avoid paying for carbon emissions. These measures allow port stakeholders to sell or buy credits (emission cap) or pay a fixed amount for each unit of pollution (emissions tax) (Notteboom & Lam, 2018). A success factor for this measure is the establishment of a robust and feasible emission monitoring system.
- **Voluntary agreements**. PAs rely on the CSR behaviour of port stakeholders to encourage them to limit their greenhouse gas emissions by signing a voluntary agreement with them. They do not represent legal obligations or compensations and have more chance of being successful (Alamoush et al., 2022). Vessel speed

reduction, virtual arrival, and the promotion of green shipping by engaging local communities represent interesting voluntary measures (Gibbs et al., 2014). A certification could be released by PAs to stakeholders who voluntarily implement these measures.

- **Concessions and licences requirement**. PAs could include in the discussion process of terminal concession contracts, technical terms that require port stakeholders (i.e., terminal operator, other concessionaire, and port users) to use measures to limit their impact on the environment (Acciaro et al., 2014; Bermúdez et al., 2019). Terminals may be required to participate in shipping emission reduction programs, and address shipping GHG emissions reduction through vessel ship reduction and provide onshore power supply and alternative fuels bunkering.
- **Port planning**. It refers to strategic and long-term development planning for different future activities of port (Bjerkan & Seter, 2019; Alamoush et al., 2022), including environmental targets (Schipper et al., 2017), such as plan for climate change mitigation. In this vein, ports define and monitor development strategies that comply with environmental regulations and other CSR objectives to limit the probability of societal resistance.
- **Training programs and awareness raising**. These measures include programs for educating and training port stakeholders (i.e., terminal operators, concessionaire, port users, employees) on the importance of efficient use of energy sources and climate change mitigation (Cuilian & Baojun, 2010; Di Vaio & Varriale, 2018). This is to ensure that their employees and port operators are environmentally aware.

1.3.5. Digitalisation and ICT platforms

The high flow of information circulating within port processes makes the introduction of digitisation and ICT platforms capable of processing this information intelligently essential. These GSs refer to the development of digital solutions (e.g., IoT, blockchain, etc.) to reduce the environmental impacts of maritime logistics activities in the port domain by improving their operational efficiency. These strategies are related to economic, market, social and governance CSR objectives and the stakeholders that mainly benefit from them are terminal operators, concessionaires, carriers, port users and employees. They also include ICT platforms, smart sensors, advanced intelligent logistics (Wang et al, 2015), container terminal automation and operation system (Lee et al., 2015;

Xin et al., 2015), engine maintenance (Cuilian & Baojun, 2010), and port city integration to improve recycling and carbon capture, storage and utilisation (Alamoush et al., 2022; Acciaro et al., 2014a; Acciaro et al., 2014b).

Regarding the land transport, ports can reduce the emissions through the implementation of emission monitoring programs, and congestion reduction through terminal appointment systems, peak shifts, and modal shifts/split (Norsworthy & Craft, 2013; Acciaro et al., 2014b; Gonzalez-Aregall et al., 2018). When it comes to shipping companies, ports can reduce ship turnaround time (Winnes et al., 2015), utilising automated mooring systems and mid-stream operations (Alamoush et al., 2022). In general, they include other technologies for monitoring emissions and environmental externalities in the port domain.

For instance, the introduction of cloud technology in port business operations can bring several benefits to port terminals. Indeed, to automatize their processes, ports and terminals are struggling to find the most efficient solution. The usage of clouds can be a solution: it can allow to develop a cloud-based platform for planning routes which enables users to share information in real time. In addition, cloud connectivity also provides a platform for Internet of Things (IoT) operating systems, enabling communication within ports as well as between ports (Mudronja et al., 2019).

Furthermore, given the high number of port and logistic actors involved in the logistic processes, blockchain appears to be a great solution for document management. Indeed, Blockchain technology can be exploited to store and transmit freight documentation, thereby ensuring accurate and consistent information about freight documentation across the logistics chain (Mudronja et al., 2019). In addition, it could also improve the coordination of activities among all participants by ensuring visibility of all processes. This would be particularly important for third parties located outside the ports such as banks and insurance companies who would have better insight into logistics processes and could reduce bottlenecks created by sequential activities such as commercial approvals (Francisconi, 2017). Drones represent another new technology to be used in the port business. Drones can be used for monitoring and controlling gas emissions, as it is easier to reach vessels at sea with drones (Xia et al., 2019). They can also be used in the logistics process as well as to perform smaller logistical operations of package delivery and warehouse management.

1.3.6. Research and Development

According to Mudronja et al. (2019), investment in research and development (R&D) creates preconditions for the implementation of more advanced and better technologies. It fosters the introduction of innovative products or production processes which can lead to higher earnings and potential economic growth. Through innovation processes in the port domain, existing resources can gain new features, new activities are expected to be generated, and new values can be created. Specifically, process allows the transformation of knowledge into a new value, and as a result, new value increases the competitiveness of the port. Research and development strategy includes projects and studies carried out by the PA (alone or with scientific/industrial partners) to achieve a sustainable port. The port authority should be central point for knowledge sharing on environmental issues. This will be possible through cooperation with objective to create a proper research and development platform (Alamoush et al., 2022). Best practice guides, lesson learned, experiences could be share with operators and, communities (Notteboom & Lam, 2018), and other ports (Sdoukopoulos et al., 2019) and disseminate to other port stakeholders.

The CSR objectives pursued by this GS are economic, market, social and governance and the main stakeholders are terminal operators, carriers, local communities, concessionaires, port user and financial community.

1.3.7. Bunkering and storage facilities for alternative fuels

Emission reduction targets are leading to the introduction of alternative fuel to be used and a range of innovative technological solutions within the shipping and port sectors. In this perspective, four major solutions have been identified for cleaner ship fuels: (i) Marine Gas Oil, (ii) Heavy Fuel Oil + Scrubber, (iii) Liquefied Natural Gas (LNG), and (iv) Methanol (Calderón et al., 2016). However, most experts recognise LNG as the most developed fuel solution, both in the short and in the medium term. This situation is justified by the fact that in 2014, the European Commission, as part of its Clean Power for Transport package, adopted a Directive on the deployment of alternative fuels, recharging and refuelling infrastructure. Nevertheless, there are several constraints that need to be addressed yet, more particularly in LNG importing countries in order to meet the future demand of the expected LNG-powered fleet. These constraints are related to facilities for storage and transhipment of LNG for fuelling berths, barges and ships within the port. In this vein, according to the Institute for Energy Economics and Financial

Analysis (IEEFA, 2023), 94 billion cubic metres (bcm) of new or expanded LNG import capacity is in the planning stage and expected to be operational by 2030. This will bring Europe's LNG capacity to 405 bcm. This additional LNG volumes will be handled via the large LNG infrastructure network of Europe which consist of 37 operational import terminals, of which eight came online and four were expanded in 2022 and 2023. In addition, there are 13 new projects under construction, and plans to expand a further four existing terminals. However, the IEEFA (2023) forecasts that by 2030, European LNG demand will not exceed 135 bcm, leaving a potential gap of approximately 265-270 bcm of unused capacity. Finally, the average utilisation rate of the EU's LNG import terminals in 2023 was 58.5%, reducing from 63% in 2022 because in 2023, the utilisation rate of eight LNG terminals was less than 50% including: Barcelona, Cartagena, Huelva, Sagunto in Spain; Piombino in Italy; Revithoussa in Greece; Inkoo in Finland and Ostsee in Germany.

The main CSR objective pursued by this GS is market and the principal stakeholders are carriers, terminal operators, and other port users. The user profiles are yard and quays.

1.3.8. Land use conversion

Coastal ports play an important strategic role on society and the economy of port cities. Indeed, in port cities, huge land use changes occur along with port evolution. In order to compensate the negative externalities stemmed from the evolution of the port and the related activities including the different forms of pollution (i.e., atmospheric, visual and acoustic pollution) and communicate a good image of the port to the local community, ports tend to convert specific port areas in favour of local communities. Specifically, this port area conversion implies for instance the construction of new neighbourhoods, parks, museums, and edutainment centres focused on the maritime logistics industry, as well as touristic attractions. The conversion of port area to be carefully planned in order to provide the maximum benefits to the community. In this vein, several approaches to forecast and simulate the future spatial patterns are thus meaningful and instructive for urban and transportation planning in port cities (Ko and Chang 2012).

The mains stakeholders of this GS are passengers, local communities, and employees. The main CSR objective pursued is social. The user profiles are mainly the port's waterfront.

However, these 8 GSs are difficult to be implemented and bring a number of issues for PAs and the stakeholders. These issues include the lack of capitals, the regulatory and policy constraints…ect.

1.3.9. Barriers for GSs implementation in port

The ongoing process directed to mitigate GHG emissions within the maritime-port industry is taking place at a slow pace (Merk 2014; Alamoush, et al., 2023) and the targeted goals are still far away, in shipping (Smith et al., 2014), ports (Sifakis & Tsoutsos, 2021) and land transport (Bergqvist et al., 2015) due to several issues such as:

- The incentives reward to port stakeholders. In the case of carriers, the incentives can give to ships better market reputation, but many ships are not able to meet the requirement of the incentive programs. In addition, all port dues represent only about 1% of voyage cost, thus, shipping incentive may not attract ship carriers to invest in these measures. Incentives can only have an impact on the decision-making process of investing in green technologies for new ships (COGEA, 2017; ESPO, 2019). As a result, the incentives do not influence the whole supply chain including shipping operations (Poulsen et al., 2018) and the impact remains scarce. Therefore, this measure turns out to be a mere marketing programme for PAs, although it could participate in raising environmental awareness (Lam & Notteboom, 2014; Poulsen et al., 2018).
- The market-based measure. For the time being, this measure represents an economic measure scarcely used to reduce shipping emissions (Christodoulou et al., 2019). Indeed, the EU indicated that shipping would be included in the European Union Emissions Trading System (ETS) from 2023 onwards, even if market-based measures have been always included under the initial GHG strategy discussions (IMO, 2018). However, stakeholders consider these measures to be excessive and strongly oppose their introduction (Cullinane & Cullinane, 2019). In this perspective, ports will definitely play a central role in facilitating market-based measures by supporting cooperation with the IMO and national and regional authorities.
- Implementation scheme limitations. The implementation schemes refer to policy instruments and tools used by ports and policymakers to foster the adoption of innovative technologies and operational strategies in port and the increase of the related investments to reduce GHG emissions in ports (Alamoush et al., 2022).

However, the technical and operational measures to reduce GHG emissions within the port and beyond are considered inadequate. Alamoush et al. (2022) argue that PAs should not expect port stakeholders to adopt technical and operational measures, but efforts should be focused on encouraging policy instruments and management tools to enhance their implementation. These implementation schemes bring out several issues and challenges. First, ports are not standardized and are different in terms of business and management and governance models, size, functions, financial circumstances, and regulatory power (Acciaro et al., 2014). Therefore, the types and the related utilization of the implementation schemes vary considerably. Second, the implementation schemes vary a lot due to the health issues created by harmful emissions of port activities. Third, many ports do not know how to implement effective green strategies to reduce both GHG emissions and energy consumption (Spengler & Wilmsmeier, 2019). Therefore, a specific port GHG emissions reduction strategy, including the implementation schemes, rarely exists, although it should be simple to include one in ports environmental strategies.

- Financial barriers. Generally, as port stakeholders hold businesses based on the profit maximization in the short term, they are reticent to uptake technical and operational measures, and plans on sustainability seem to be secondary in the long term (Alamoush et al., 2022; Bjerkan & Seter, 2019). Indeed, some GSs strategies such as cold ironing, bunkering facilities or measures which involve the physical change of emission sources for newer, cleaner, and energy-efficient engines need a huge amount of financial resources for their implementation, and these resources are not always available to PAs and their stakeholders. In addition, capital expenditure (Capex) costs, operational expenditure (Opex) cost, maintenance costs are high, and the payback period is long. This lack of financial resources makes the investment difficult to be implemented. Thus, PAs must find suitable funding schemes as well as valuable business models to support such investments.
- Other barriers. In addition to high costs associated to GSs implementation, issues as low perceived contribution of green technologies (Notteboom & Lam, 2018), and organizational, institutional, and information barriers (Johnson & Andersson, 2014), limit the adoption the GSs.

This section addresses the different typologies of GSs by linking them with the CSR objectives (Table 1.1).

Table 1. 1. Green strategies and related CSR objectives

Green strategy typologies	Related-CSR objectives	Stakeholders	User profiles	Barriers
Energy efficiency interventions	Economic, market and social	PAs (shareholders), terminal operators, other concessionaires, and local communities	Buildings, vehicle and equipment, port yards, quays, and seaside	The incentives reward to port stakeholders The market-based measure Implementation scheme limitations Financial barriers Other barriers
Facilities and infrastructure for electric energy supply	Economic, market and social	Carriers, employees, terminal operators, other concessionaires, and local community	Equipment, cranes, vehicles, tractors	
Renewable energy production	Economic and market	PAs (shareholders), terminal operators, other concessionaires	Building, parking, road, terminal, port yard and quay	
Policies and measures	Governance, regulatory and social	Terminal operators, concessionaire, carriers, and port users including land transport	All the users	
Digitalisation and ICT platforms	Economic, market, social and governance	Terminal operators, concessionaires, carriers, port users and employees	Port technologies	
Research and Development	Economic, market, social and governance	Terminal operators, carriers, local communities, concessionaires, port user and financial community	All the users	
Bunkering and storage facilities for alternative fuels	Market	Carriers, terminal operators, and other port users	yard and quay equipment	
Land use conversion	Social	Passengers, local communities, and employees	Port's waterfront	

Source: Author's elaboration

In addition, the main stakeholders benefiting from each GS, user profiles as well as the barriers to the implementation of GSs are presented. To face the issues related to the implementation of GSs, ports may adopt a new governance model in line with CSR objectives for an effective implementation of GSs. According to Pallis et al. (2022) strategic objectives that can guide the choice of port governance model consist of maximizing: the traffic throughput, the return on investment, the profits for shareholders, traffic throughput subject to a maximum allowable operating deficit and economic development prospects at the local or national levels. The next section presents a new business model for port governance.

1.4. Towards a new green business model in ports: The role of governance settings

According to Ferrari et al. (2015), up to the 1980s port activities were closely linked to the city's economic activities, due to their well-known positive impact on the regional economy and their social effects on the local industrial context. At the time, port activities, particularly port services, were essentially labor-intensive. The management of the activities was a monopoly, and almost all employment was provided by the public body and efficiency was not the priority objective of the port managers.

Subsequently, the introduction of innovative technologies in the shipping and port sectors, triggered a growing demand for the privatization of terminal operations and even the entire port. As a result, the 1990s marked the beginning of the implementation of port reforms especially in European countries, characterized by the introduction new organizational frameworks and governance mechanisms (Goss, 1990a, 1990b).

However, port governance is different for each PA since they have different port business and management models, port revenues stream, regulation implementation, and funds allocation for developing environmental and climate measures. Within this context, the port governance, based on different business models and management, can either be, mixed public-private partnership (landlord), or private, and thus, ports, or public authorities, e.g. municipal, central, and federal government, lead the regulatory functions in all these models (Brooks, 2004; Suykens & Van de Voorde, 1998). Table 1 reports the port governance model, some applications and their relative strengths and weaknesses.

Table 1. 2. The main port governance models

Governance model		*Some applications*	*Strengths*	*Weaknesses*
Private Port		New Zealand, Australia, United Kingdom	Flexibility, market oriented	No vision for the community and local development
Landlord	***Latin tradition***	France, Italy, Spain	Community and local development oriented, PPP development	Rigidity, bureaucracy, scarce proactivity of the PA
	Hanseatic tradition	Belgium, Germany, The Netherlands	Community and local development oriented, Flexibility, PPP development	Possibility of having a limited vision for the local development
Tool Port		South Africa	Central planning, private involvement	Rigidity, absence of private partnerships (PPP), public financing
Public Port		Ukraine, Israel	Central planning, Coordination among various national ports	Not market oriented, rigidity, absence of PPP possibilities, heavy bureaucracy

Source: Ferrari et al. (2015).

The governance models reported in the table constitute a taxonomy of governance models provided by the World Bank (2001) and differ in their relative levels of private and public ownership and operation. Especially, the main difference between these models is related to the possibility for both private and/or public companies to be involved in port operation management and organization, and participation in port activities.

- In the **public port model**, the PA is responsible for the management and planning of port areas, with the ultimate goal to ensure traffic growth, social and economic wealth, by directly carrying out commercial activities.
- **For the tool port model**, the public sector is dominant as it owns the land, the infrastructure and the equipment, and private sector activity is limited to some operations, most commonly cargo handling performed using equipment owned by the public authority. Equipment and land are rented out on a short-term contract basis to the private sector, which then provides services.

- **The landlord port model** is currently the most adopted governance model. In this model, the PA is the owner of the land and the infrastructure, and leases them to private operators as a concession, leaving the equipment and operations in the private sector's hands. The PA is responsible for the management and planning of port areas, and its ultimate goal is to ensure traffic growth, social and economic wealth, without directly carrying out any commercial activities (Van Hooydonk, 2002; Meersman et al., 2009).
- Regarding the **private port model**, contrary to the public port model all lands, infrastructures and equipment is owned and operated by the private sector. The latter manage and plan the port areas and carry out all the commercial activities.

In practice, each model must be tailored and modified to ensure suitability to the port context and the local needs of port stakeholders (Caballini et al., 2009). This is because the characteristics of each PA model are heterogeneous with regard to the type of legal entity, corporate governance approaches, relations with local and central government, financing schemes, port size, etc. For instance, the growing involvement of private firms in the landlord model and the reduction of the PA's commitment in stevedoring operations limit the possibility for the PA to collect first-hand information, thus reducing the PA's possibility to monitor private operator's activity and generating potential information asymmetries (Ferrari et al., 2013).

In the same vein, Wang and Slack (2002) argue that social and cultural variables should be included in port governance with great importance. The notion of port governance they developed includes three axes, namely spatial-jurisdictional scales, stakeholder community, and logistical capabilities. All these variables lead PA towards a cluster approach to port governance.

In a different perspective, a corporate governance approach has been suggested for analysing the port governance (Baltazar & Brooks, 2001a, Baltazar & Brooks 2007b). This approach includes strategic management, organisation theory, and configuration theory and mainly focused on the interactions of two institutions, the responsible government department (ministry or other relevant policy-actors) and the port authority responsible for the management and operation of the port. The authors argue that the port governance model is defined by the configuration of three inputs: (i) the strategy of the port which represents the objectives, the decisions about its product-market scope, and the plan for their implementations; (ii) the structure, which is the result of government regulations and policies, and the strategy chosen by the PA; and (iii) the environment where the port operates including endogenous and exogenous factors. These inputs produce port performance, the quality of which results from the consistency or adequacy of the inputs when taken together.

According to Pallis et al. (2022) port governance is the adoption and enforcement of rules governing conduct and exercising authority and institutional resources to develop and manage port activities to benefit society and the economy. In the absence of a perfect port governance prototype, the features of the applied port governance models can deeply differ. In fact, the diversity increases as decision-makers adjust port governance and reevaluate the existing configurations. The most recent approach to port governance is the integration of sustainability into the governance of ports, with a broader stakeholder involvement and a multi-modal vision of ports and their governance. This governance approach is presented in the following section and implies a transition towards issues concerning the environment in the decision making, philosophy, ecological responsibility, and general tools of organizations (Sharma et al., 2010).

1.4.1. The green business model in port

A business model reflects the strategic choices of a company and describes the rationale of how this company creates, delivers, and captures value, in economic, social, cultural through core competencies and capabilities, in order to reach a positional advantage that are different from those of competitors (Shafer et al., 2005).

From this definition, it appears that the objective of business model is to create, deliver and capture value to reach the competitive advantages compared to competitors. In this section, the evolution of the concept of value will be presented, together with the changes observed in the port domain.

The concept of value has been historically considered as "value-in-exchange" and "value-in-use" (Smith et al., 1776). Value in exchange refers to the monetary value of a commodity and value in use is the utility received from the consumption or holding a commodity. Then, between the 1960s and 1970s, the concept evolved to refer to "added value" (Brewer, 2001). Successively, the concept of value creation takes the sense of value co-production, which refers to the active participation of the customer in the company value creation (Grönroos, 2011).

Nowadays, value creation represents the cornerstone of the business model research flow (Zott et al., 2011). From this point of view, two main perspectives emerged: the conventional perspective of value creation, which concentrates on the created value for the target customer and business, and the sustainability-oriented perspective, which also includes environmental and social aspects for the creation of benefits for stakeholders (De Martino, 2021). As a result, stakeholder theory can be considered as a complementary perspective of value creation (Freudenreich et al., 2020).

As anticipated previously, until the 1980s, efficiency was not the priority objective of the port managers, over the time PAs began to consider efficiency as important. To create more value for their stakeholders, port authorities and their key stakeholders are expected to reorganise themselves by aligning their objectives through the introduction of sustainable business model in port sector. The sustainability-oriented model appears to be a great solution as it has been introduce in the latest research in the port literature and recent studies (Freudenreich et al., 2020).

1.4.2. Sustainable-oriented business models in the port domain

The objective of this business model is to provide a comprehensive corporate sustainability measurement framework to support PAs in assessing value creation in economic, social, and environmental perspective (Stein & Acciaro, 2020). This sustainability measurement goes beyond the port boundaries by also considering the port–hinterland interactions (Gonzalez-Aregall et al., 2018) the port cities (Zheng et al., 2020), and the adoption of circular regeneration approach (Williams et al., 2019). In this regard, stakeholder engagement is pivotal for the conflicts minimization and for achieving win-win strategies for the long-term benefit of a port city (Lam & Yap, 2019).

In the sustainability-oriented business model, the value creation framework for the stakeholder interaction is a key element in designing sustainable business models. It underlies new value propositions for stakeholders with and for whom value can be created, core value creation activities and resources, as well as potentially allows for alternative governance forms, including collaboration, public private partnerships, or social businesses, thus overcoming profit-maximizing models (De Martino, 2021). In the port domain as well, the stakeholder relation management considering the stakeholders' perspectives has been introduced in thei governance model, (Notteboom & Winkelmans, 2002). According to De Langen (2002), due to the difference between port governance, the analysis of the combination of stakeholder management approaches in the port cluster would contribute to the understanding of competition and port performance. Marcella De Martino (2021) provides a sustainability-oriented model for value creation in the port domain (Table 2). This model includes the business model aspects, the impact on the port service supply chain and on the external environment.

Table 1. 3: Sustainability-oriented value creation model

Business Model Aspects	Port Service Supply Chain	External Environment
STAKEHOLDER (with and for whom value is created)	Customers, business partners, and financial stakeholders	Civil society and port authority
ACTIVITIES AND RESOURCES (value creation sources)	Efficient and effective competencies for new and improved transport and logistics services. Digital and green technologies (low- and zero-carbon technologies). Human resources: training courses; new skills and capabilities.	Responsible use of natural and local resources. Utilization of renewable resources. Digital port ecosystem. Resilient digital and physical infrastructures. Circular economy.
RELATIONAL MODEL (power relationships and patterns of value capture)	Vertical integration and strategic alliances. Selection of services providers based on environmental and social factors. Co-production and collaborative networks with customers and business partners for sustainable innovation.	Partnerships with port authorities, universities, and innovation incubators. Consultation and interactions with local stakeholders. Information sharing with local agencies and public.
VALUE CREATED (economic, social, and ecological)	Customer satisfaction: costs; frequency; reliability, service quality. Growth in the turnover and profitability. Growth in the market share. Growth in return on investment and dividend. Increase in safety and security. Increasing social well-being and cohesion. Reduced consumption and waste of raw materials, water, and energy sources.	Increase in the employment in the port-related activities and in the regional ecosystem. Growth in the number of creative and circular businesses in the regional ecosystem. Improved image and green reputation. Social cohesion and trust in the port community. Air, water, and noise pollution reduction.

Source: De Martino (2021)

However, Lam and Notteboom (2014) emphasise the need to incorporate sustainability in planning stages of port strategies, for example in expansion projects. In the same vein, the World Port Climate Declaration revealed that ports need to plan and explore how CO2 emission in ports, ships, and land transport can be reduced in the future (Fenton, 2017). Port plans should not only contain designs for green and sustainable port (Vanelslander et al., 2014; Asgari et al., 2015), but also environmental and energy management systems (Acciaro et al., 2014; Boile et al., 2016), shipping emission reduction in ports (Gibbs et al., 2014), and CO2 emission reduction in expansion projects.

In addition, the increasing importance of environmental sustainability led to the introduction of the green marketing in the corporate governance (Dangelico & Vocalelli, 2017), including the port domain. The green marketing is a holistic management process that aims to identify, anticipate, and satisfy the requirements of customers and society, while ensuring environmental and economic sustainability (Peattie, 1995). The objective of green marketing is to fulfil customer, stakeholder, organizational and legal requirements. The framework embeds sustainability in three hierarchical levels of green market planning which are marketing strategies, structures, and functions (Karna et al., 2003). Strategies consists of using environmental strengths as a competitive advantage compared to competitors. The implementation of these strategies relies on marketing structures and functions. Structures instead is related to the management systems of the organization, and functions are principally the communication and advertising aptitudes of the organization. By integrating sustainability into their strategies, structures and functions, ports can use green marketing as a promotional tool to claim green ports status, which can increase the port's competitiveness (Lam & Li., 2019). In addition to the traditional marketing goals related to customer and organizational satisfaction, green marketing ensures the compatibility with the ecosystem.

In summary, in considering the port business model, and in order to create value for port stakeholders in the best way, it is fundamental to consider the high organizational complexity that characterized the port activities due to the conflict of interests between public and private port companies. This complexity determines different levels of analysis of competitiveness between port companies within the same port, between ports of the same range, and between port authorities (De Martino, 2021). Furthermore, ports can have different roles in the sustainable business model, depending on the long-term strategy they want to pursue.

1.4.3. Roles of port authorities in the green business model

In the green port business model, PAs can be considered as implementers, and developers. As implementers, PAs represent policymakers responsible for the creation and the execution of the ISs to drive the polluters (i.e., port stakeholders) to adopt innovative technologies and operational measures for GHG emission reduction (Alamoush et al., 2022). As the key policymakers, PAs have to perform one or various port functions which consists of:

- Providing basic infrastructure to port operators (**landlord**),
- Fixing tariffs, environmental standards and regulation for concessionaires and operators (**regulator**),
- Owning and running the cargo handling equipment and operations (**operator**), and

- Collaborating with port stakeholders to improve performance and operation (**community manager**) (Acciaro et al., 2014).

As developers PAs must be the drivers of innovation in port, and centres of knowledge sharing (PIANC, 2014). Besides PAs, public authorities such as the municipal or central governments can also play major roles in port management and governance, particularly with regard to the negative impact of port activities on local communities and port cities. They generally play a pivotal role in developing and implementing measures to reduce port emissions. (Cui & Notteboom, 2017).

Whether PAs are implementers or developers, integrating sustainability into port green business model leads them to become green marketers. Green marketers can be categorized as proactive or reactive, according to the degree to which they consider environmental issues in their market planning. For both types of marketers, the objective is to reach the competitive advantage through sustainability, with the difference that the proactive green marketers believe in the free-market system whilst the reactive green marketers wait for government interventions (Karna et al., 2003). Nevertheless, according to Sheth and Parvatiyar (1995), the proactive corporate marketing and proactive government interventions are the sine qua non condition for achieving the sustainable development.

Moreover, according to Lee and Lam (2022) marketing orientation of green marketers can be derived. They argue that companies can use a strategic approach by seeking innovation or can use a tactical or short-term approach by mitigating negative environmental impacts when they occur. Concerning the ports, proactive government intervention would come through port authorities or relevant government agencies (Lee & Lam, 2017).

However, whether ports have the title of implementers or developers, they need funding to implement a sustainable business model given the capital-intensive nature of green strategies.

1.5. Green finance for achieving the green concept: focus on Eu funding schemes

As previously stated, management and policy instruments are needed to encourage adoption of innovative technologies and support investments in technical and operational measures in the port. Besides these instruments that mainly refer to the ISs, PAs and ports stakeholders also need funding to encourage the uptake of innovative technologies and financially support the implementation of GSs not only in the port domain but throughout the supply chain by working with the key supply chain members. This necessity derives from the pivotal role of port in environmental protection both in seaside and landside operations.

Indeed, this funding results in grants and incentives and work as a carrot compared to the stick of the environmental pollution taxes and additional charges. The grants and incentives could partially or completely derive from the PAs, or Public (e.g., governmental, international, and intergovernmental programmes). For the scope of this study, some European funding schemes will be presented. These funding schemes belong to the EU's 2021-2027 long-term Budget and NextGenerationEU and Interreg 2021-2027. They represent very important economic incentives as they can fully or partially cover Capex, Opex and maintenance costs related to the implementation of GSs throughout the port and logistic supply chain.

1.5.1. EU's 2021-2027 long-term Budget and NextGenerationEU

Europe suffered a lot from the damage of the coronavirus pandemic. To boost the economy of Europe, the European Commission launched the EU's 2021-2027 long-term Budget and NextGenerationEU with the objective to fix these economic and social damages and drive Europe towards a modern transition, resilience, and sustainability. Specifically, the NextGenerationEU budget aims to:

- Power up clean technologies and renewables
- Renovate energy efficiency of buildings.
- Recharge and refuel sustainable transport and charging stations.
- Scale up data cloud and sustainable processors.
- Connect roll-out of rapid broadband services.
- Modernise digitalisation of public administration
- Reskill and upskill education and training to support digital skills.

Implementation covers all sectors, including the port and related supply chain. Some programmes that mainly finance projects in the maritime and port sectors will be present in the next sections.

1.5.1.1. Horizon Europe

With a budget of EUR 95.5 billion, the Horizon Europe programme represents the EU framework for research and innovation. The objective is to foster excellence in research and provides a vital support to most successful researchers and innovators to drive the necessary systemic changes to ensure a green, healthy, and resilient EU.

The Commission makes available to excellent researchers, funding in the form of grants, prizes and procurement in order to support their research activities. This funding also serves for the development of research in infrastructure including port and hinterland to foster mobility within the EU. It also encourages partnerships between Member States, industry, and stakeholders for the common development of research and innovation projects.

The type of projects included in this programme mainly include research and innovation projects addressing societal challenges with focus on EU industrial leadership, resilience and recovery, the green and digital transitions including high-performance computing, artificial intelligence, data and robotics, smart cities, carbon-neutral and circular industry, blue economy, etc.

This programme favour actions that includes networking and coordination, research, innovation, pilot actions, market deployment actions, training and mobility actions, dissemination and exploitation of results, and the main recipients are scientists and academics, research entities, universities, industries, small and medium-sized enterprises, students, etc. Finally, the programme is implemented directly by the Commission or through funding bodies that the Commission designates responsible.

1.5.1.2. Connecting Europe facilities (CEF)

As it is understandable from the programme's name, the CEF programme was created to connect Europe. The objectives of the CEF programme are to faster investments in the transport, energy and digital infrastructure networks of Europe. The finality of these investments is to encourage the dual green and digital transitions, by contributing to the European Green Deal and Digital Decade infrastructure targets. It will be possible thanks to the disbursement of the EUR 20.73 billion budget.

The funding is primarily disbursed in the form of grants, with different joint financing rates based on the project type, to the following three main sectors: transport, energy, and digital. In this vein, it fosters the development of digital connectivity projects of common interest and encourages the development of trans-European networks highly performing, sustainable and efficiently interconnected in the transport and energy sectors.

The programme fosters actions with the highest value for all of Europe, in particular those which complete missing cross-border links, remove bottlenecks or deploy EU-wide systems. The principal recipients are industry, small and medium-sized enterprises, research organisations, other public and private entities established in a Member State or in a non-EU country associated with the programme, or created under EU law, as well as international organisations. The programme is directly implemented by executive agencies and through a combination of grants, procurements, and financial instruments.

1.5.1.3. European Maritime, Fisheries and Aquaculture Fund (EMFAF)

The EMFAF programme was born for providing support to develop innovative projects to ensure the sustainable use of aquatic and maritime resources. For the time frame 2021-2027, the budget for the EMFAF programme amounts to approximately EUR 6.11 billion. This budget will be used to achieve the objectives of the programme which is to promote the use and management of marine resources in sustainable manner, to develop of a resilient blue economy, and foster international cooperation towards sound and safe ocean management.

In particular, funding is essentially disbursed in the form of grants and procurements and encourage actions and investments that aim to protect the marine biodiversity and promote a sustainable and low-impact fishing and aquaculture activities. Moreover, it also fosters the production and supply to European consumers, top quality, and healthy seafood products, encourage the development of a sustainable blue economy in coastal communities, and participates to maritime oversight and international cooperation on ocean governance.

The type of projects supported by the EMFAF fund include actions that support the improvement of fishing equipment, facilities, and practices; the action to make the blue economy sector sustainable and innovative; action for improving the aquaculture facilities and greening of the sector; as well as actions to ensure quality and sustainability of marine food sources.

The main recipients are the stakeholders involved in the exploitation and management of marine resources, such as fishers, aquaculture farmers, coastal communities, civil society organisations, marine scientists, and public authorities (e.g., PAs). The 87 % of the budget is implemented under shared management and the 13 % is implemented under direct management.

1.5.1.4. Programme for environment and climate action (LIFE)

With a budget of EUR 5.43 billion the LIFE programme's objectives are to move towards a resilient and circular economy with sustainable, energy efficient, green energy based and climate neutral features. The purpose of the programme is to protect, restore and improve environment quality, including the air, water, and soil, to stop and reverse biodiversity loss and to tackle the degradation of ecosystems.

The implementation of the financial allocation of the LIFE programme is guaranteed by four subprogrammes including nature and biodiversity, circular economy and quality of life, climate change mitigation and adaptation, and clean energy transition.

The types of projects funded within this programme consist of actions that aim to conserve the nature, develop the circular economy, promote clean energy transition and fighting against climate change; encourage the uptake of innovative technologies; develop best practices; coordination and capacity building; and foster the development and implementation of environmental and climate plans at regional, multiregional, or national levels. The main recipients are EU national or local authorities, private commercial organisations, and private non-commercial organisations (e.g., non-governmental organisations). Finally, the budget of the LIFE programme is implemented through direct management and funding is paid in the form of grants, procurements, and prizes.

1.5.2. Interreg 2021-2027

The Interreg programme represents a key European Union instrument for strengthening cooperation between regions and countries within the EU. It belongs to the EU's Cohesion Policy and is pivotal for the promotion of regional development, cohesion, and reduction economic disparities. For the 2021-2027 period, Interreg focuses on addressing current challenges like climate change, digital transformation, and social inclusion.

With the budget of EUR 10 billion the programme intends to reinforce cooperation with partner countries via Interreg IPA and Interreg NEXT and includes a dedicated strand for EU outermost regions and surrounding countries.

During the planned period, the programme aims to enable investments that make Europe and its regions: i) more competitive and smarter, by innovating and supporting small and medium-sized businesses, the digitisation and digital connectivity, ii) resilient and greener, through the reduction of carbon, iii) more connected through the improvement of mobility, iv) more social, by effective supporting more inclusive employment, education, skills, social inclusion and equal access to healthcare, and the promotion of the role of culture and sustainable tourism, v) closer to citizens, by supporting local and sustainable development of urban areas across the EU.

1.5.2.1. Interreg Central Europe

Interreg CENTRAL EUROPE represents a European Union funding programme for cohesive regional development. The objective of the programme is to find the best solutions for commonly tackle challenges like climate change and digital transition. The budget of the programme to reach these objectives is around EUR 224 million. It is at the heart of Europe and cover an area that include nine EU Member States: Austria, Croatia, Czech Republic, Germany, Hungary, Italy, Poland, Slovakia and Slovenia. This programme consists of 4 thematic priorities:

- **Priority 1: Cooperating for a smarter Central Europe**

Within this priority the funding will help cities and regions to jointly address innovation challenges related to strong functional links across the programme area derived from the long-lasting cooperation on trade as well as on investment and industry issues. The program aims to facilitate the cooperation across borders to develop and test innovative solutions that foster the transition to a green and digital Europe.

- **Priority 2: Cooperating for a greener Central Europe**

This funding will help cities and regions to work together to tackle the challenges such as climate change, industrial activities and unsustainable consumption and mobility patterns that threatened the natural heritage and the biodiversity of the programme area countries. The solutions consist of boosting the efficient use of resources, protecting and restoring biodiversity as well as cutting pollution.

- **Priority 3: Cooperating for a better-connected Central Europe**

This funding will help cities and regions to address transport challenges by fostering sustainable, intelligent, and intermodal transport in the Central Europe area including connections to the trans-European transport network (TEN-T).

- **Priority 4: Improving governance for cooperation in Central Europe**

This funding will help cities and regions to jointly address governance challenges through the improvement of public authorities' capacities. The aim is to set up and implement integrated territorial development strategies through cooperation in the programme area.

Strong cooperation beyond borders can lead to the development and testing of inspiring solutions that will make territorial development in central Europe more integrated.

1.5.2.2. Interreg Italy-France Maritime

Funded by the European Regional Development Fund (ERDF), the Interreg Italy-France Maritime 2021-2027 aims to promote territorial cooperation in the EU for the 2021-2027 period. With a total budget of €193,296,077, the principal objective of the programme is to improve cooperation between participating regions of the programme area and create a competitive and sustainable area within Europe and the Mediterranean. This programme is based 5 challenges to address:

1. Sustainable growth, competitiveness, and innovation
2. Environment and territory
3. Accessibility
4. Human capital
5. Cross-border cohesion

Besides these challenges, the program gives particular importance to transversal themes such as digitization, insularity, climate neutrality, ecological and industrial transition, and supports priority sectors that include navigation, shipbuilding, innovative and sustainable tourism, blue and green biotechnologies, and blue and green renewable energy.

In conclusion, this chapter has addressed the concept of green strategies in the port domain. Specifically, the relevant theoretical constructs embedded in the CSR managerial theories have been introduced and discussed also providing a well-established taxonomy of green strategies applicable to the port domain. Then, a green business model applicable to port and some green finances for implementing this green business model have been presented and proposed in an overall conceptual framework which constitutes the base for next chapters. This chapter has also allowed to highlight the energy intensive nature of port activities, making ports an ideal field for evaluating energy consumptions and business opportunities originating also from energy production. In this vein, ports can be considered as energy hub due to the energy-intensive nature of day-by-day port-related activities. The next chapter addresses port as energy hub aiming at evaluating the benefits that a well structure energy management perspective could bring to ports and port stakeholders.

CHAPTER 2
PORT AS AN ENERGY HUB

2.1. Introduction to energy hub

National governments and public entities worldwide are struggling to meet their energy needs by working hard to find the best solution to optimize their energy consumption, supply, exchange, and storage. The increase in the world's population and consequently in the demand for energy has accentuated issues related to energy poverty and cost. Energy poverty refers to the lack of alternatives to access adequate, affordable, reliable, high-quality, safe, and environmentally friendly energy services to support economic and human development (Mikel González-Eguino, 2015). This lack of alternatives makes the energy issues more relevant for the global economy and the related user profiles. The user profiles which consist of residential, industrial, and commercial consumers need various forms of energy services provided by different infrastructures to ensure their well-being, their mobility, and for carrying out their daily activities (Granell et al., 2016). Typically, the principal form of energy used are coal, oil and derivatives, biomass, and energy coming from the national grid including electric power, natural gas, heating and cooling. But the very long physical distance between the production and the consumption sites of these forms of energy represents critical concern faced by energy consumers as in most of the time, energy must be transported from locations where it is extracted/produced to the place of consumption through transmission systems and then distributed between end users at the place of consumption through complex distributed systems.

Moreover, the energy supply chain which includes distribution systems and related energy infrastructures are facing different problems such as inflation, global geopolitics issues, the high investment costs of transmission and distribution infrastructures leading to substantial losses, as well as the security problems related to protection and control of these infrastructures. As a result, these problems have caused a significant increase in the marginal cost of energy systems to the extent that today, countries around the world are working hard to tackle energy poverty through the definition of new strategic energy plans to achieve energy security (Iakovou et al., 2010).

Energy security aims to equitable provide energy services to end-users that are available, affordable, reliable, efficient, environmentally friendly, proactively governed and socially acceptable (Sovacool & Brown 2010). According to Laldjebaev et al. (2015), the achievement of energy security should follow certain energy use patterns based on environmental sustainability. These use patterns are based on the energy sovereignty concept in which institutions and local people, in determining their energy systems must use constraints that are culturally relevant and ecologically sustainable.

In this vein, the achievement of sustainable energy systems becomes a pivotal challenge for the global economy to be achieve in the future. Usually, the energy systems including the various infrastructures for providing energy service are considered, managed, and scheduled separately. But according to Geidl et al. (2007) the combination of these systems can lead to several advantages. Combining infrastructures means coupling them, thus enabling the energy exchange between them as well as the pursuing of significant savings, synergies and related benefits. Couplings are made by conversion devices that transform energy into other forms. This 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, combined cooling, heat and power (CCHP) etc.

Nevertheless, in addition to the electricity, the energy systems may address other forms of energy including thermal energy, cooling, fuel for achieving sustainable energy system. Therefore, a crucial element for achieving sustainable energy systems is to introduce multi-energy systems (MES), where different energy vectors interact in an optimal way and at different levels (Mancarella, 2014). As a result, the optimal performance of MES can lead to technical, economic, and environmental advantages such as the increase of system reliability, the reduction of operating costs, fuel consumption and plant emissions (Mohammadi et al., 2017).

The successful performance of these systems can be guaranteed by an integrated managerial framework aimed at ensuring an optimal integration and usage of the various components. According to Favre-Perrod (2005), energy hub (EH) represents a promising option for the optimization of MES and maximization of the benefits originating from the adoption of a comprehensive model for sustainable energy systems.

EH represents an entity where multiple energy carriers can be converted, conditioned, and stored (Geidl et al., 2007). It consists of four major components which are inputs, converters, storages, and outputs. Within the EH, the power is consumed at the input ports that can be connected to inputs such as electricity and natural gas, with the aim of providing at the output ports some energy services (output) such as electricity, heating, cooling, fuel ect. EH also converts and manages energy through converter technologies such as combined heat and power technology, transformers, power-electronic devices, compressors, heat exchangers, and other equipment. Finally, the energy converted can be stored by using for instance electricity, gas, heating, fuel storages.

The main purpose of the introduction of the EH concept is the move toward MES, to capture the synergistic benefits stemming from different energy carriers, non-hierarchical structure, and integrated management of different energy infrastructures (Geidl et al. 2007). Valuable synergies can be obtained among various energy carriers by harnessing their specific virtues. However, achieving these synergetic advantages raises several questions concerning the devices to be combined, their operation and the identification of the optimal configuration.

Answering these questions is crucial to identifying the best energy hub configuration to the extent that it is fundamental to develop models and methods to find the optimal coupling and power exchange among multiple energy carriers considering various criteria that include cost, environmental emissions and potential negative spillovers, energy efficiency, availability, security, and other key parameters.

Empirical concrete examples of potential energy hubs include among others industrial plants (steelworks), large building complexes (shopping mall), rural and urban districts, small isolated systems (trains, ships, planes) and transport/logistics hubs (ports, airports) etc.

In this perspective, ports are argued to be among the most interesting and promising cases of potential energy hub. Indeed, ports can be successfully considered (and therefore managed) as EH due to the energy-intensive nature of day-by-day port-related activities. Recently both scholars and practitioners have started to consider ports as ideal locations for the implementation of innovative energy generation systems which include centralized distribution, grounding on the economies of scale principle (Notteboom et al., 2022). This perception is 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 the ongoing stricter environmental regulations at European and international level, indeed, have increased the pressure on port authorities to find innovative solutions to reduce pollution arising from port-related activities. The growing demand for energy in port areas has led to higher energy costs, higher pollutants, and specifically additional greenhouse gas emissions. Relatedly, energy costs represent a significant overhead for ports and terminals: as a result, their reduction determines substantial cost savings driving to significant improvements in ports' economic and financial performances (Iris & Lam., 2019).

Given the above, Port Authorities are urged to improve their energy management strategies to mitigate energy consumption and, when possible, balance 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 third 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.

Port needs smart energy systems capable to successfully and efficiently manage energy fluctuations through the conversion and storage of energy, to meet the energy demands of the port community. These energy demand may take the form of electrical load, thermal load, alternative fuel, hydrogen…etc.

Therefore, an EH approach need to be developed in the port domain and to be applied to the design and operation of a green energy management system network or to the retrofit of an existing one by introducing of new energy technologies.

This approach implies expanding the use of distributed energy generation in the port by gradually increasing renewable energy and the related innovative technologies, which can lead to the creation of smart energy networks (SEN) (Akorede et al., 2010). Indeed, the benefits of SEN derive from its ability to meet energy demand more efficiently than traditional energy infrastructures, thanks to the integration of renewable and non-renewable energy generation technologies in different energy carriers. Therefore, SENs may be used in the port to ensure the effective utilization of renewable energy necessary to address the current issues related to the growth in energy demand, climate change, and the need for energy security (Maroufmashat et al.,2015).

In addition, a network of energy is considered to lead to the optimization of energy conversion and storage while providing environmental benefits to the port. The use of combined heat and power (CHP) as a component of a SEN, can improve its energy efficiency. Then, the reliability of the network increases thanks to the ability to generate energy (e.g., electricity, heat, fuel) during power outages that can occur in the entire energy system. The SEN is capable of diverse advantages including a reduction in GHGs, an increased flexibility to meet fluctuating energy demand, a reduction of fossil fuels use, an increased renewable energy development, and integration to the national energy system.

Overall, according to Moghaddam et al. (2015), nowadays, EH is feasible due to 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 CHP systems, electric heat pump, absorption chiller, thermal energy storage and electrical energy storage jointly with smart control and measurement equipment, integrated operation for energy management.

Hence port energy hub needs a configuration 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 economic and financial sustainability.

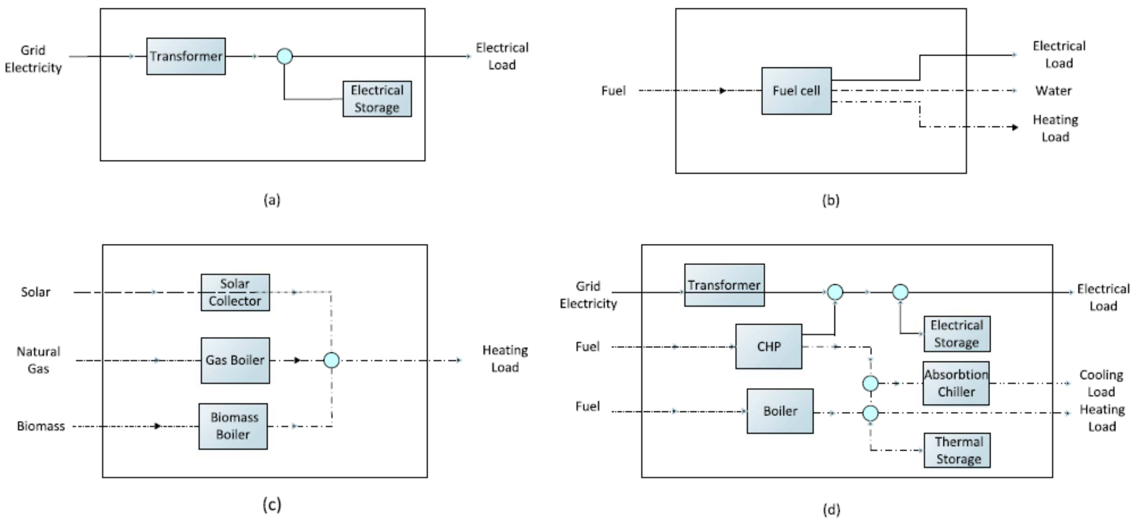
Given the above. this chapter analyses the literature review on energy hub (section 2.2), then presents the main technical components of port energy hubs (section 2.3) and finally provides the main drivers of ports energy hub (2.3), according to technical, managerial and financial perspectives.

2.2. Literature review: the energy hub concept

The energy hub concept was firstly introduced by Patrick Favre-Perrod (2005), referring to energy hub as an interface between different energy infrastructures and/or loads. This means that EH can be considered as a unit which function is to produce, transform, condition, and store several kinds of energy. In this vein, the introduction of technologies capable of transforming, conditioning, and storing energy in the energy hub confirm it role as an interface between different energy infrastructures at its input ports, such as electrical distribution system and natural gas distribution system, and end-user energy demands including electrical, heating, and cooling demands at its output ports.

According to established academic literature, the definition of energy hub includes at least three components. Some Energy hub structures include the inputs (energy production), converters and outputs (energy consumption) without storage, others include inputs, storages, and outputs without conversion. However, the most complete configurations are those that are in line with the definition provide by Mohammadi et al., (2017), that consider EH as a place where **production**, **conversion**, **storage**, and **consumption** of different energy carriers take place (Figure 2.1).

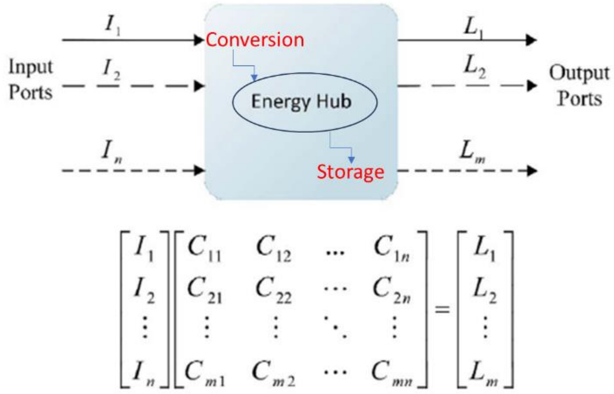
Figure 2. 1: Types of energy hub technical structures



Source: Mohammadi et al. (2017).

Indeed, energy hub structure grounds on modelling and analysis using multi energy carrier and multi energy system. Convertors inside energy hub integrate energy carriers and convert them to required energy for consumers from diverse alternative paths. The modelling is performed through the matrix model, which allows to communicate various energy carriers at the input and output via the coupling matrix. Each of the matrix elements represents EH interior features and include connection and transform coefficients of the internal components of EH (Figure 2.2).

Figure 2. 2: Modelling the transformation of Multi Energy Carrier



Source: Mohammadi et al. (2017).

Overall, the aim of EH is 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). Other authors argue that the main goal of creating an energy hub is to meet several types of demand at the same time and to increase the flexibility of the system (Han et al., 2023).

Several research contributions have been conducted on the use of EH. Different types of EH exist in the literature including renewable energy, smart energy hub, dynamic energy hub, multi-energy hub…etc. These types have been classified based on the types of inputs used in the EH (e.g., electricity grid, natural gas network, renewable energy source or hybrid), the introduction or not of smart technologies, tools, and software for increasing the EH efficiency and flexibility.

2.2.1. Traditional energy hub

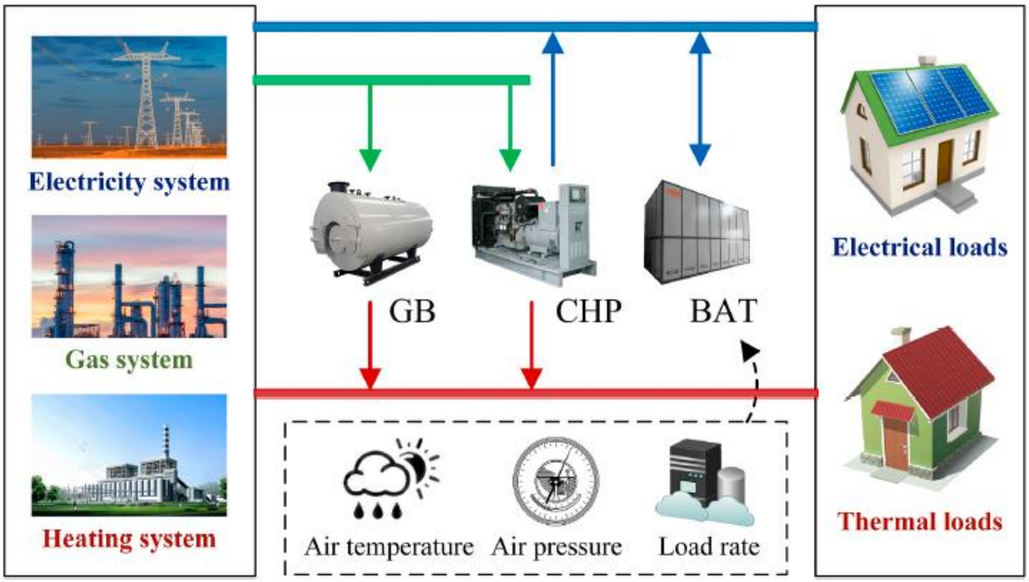
These energy hubs use national electricity grid and national gas network as inputs and have a very simple configuration (Figure 2.3). They increase the flexibility of the energy system and allow the multi energy demand satisfaction but suffer from some problems such as the uncertainty of electricity and gas price, the energy planning and optimisation problem. In addition, these EHs do not contribute to the pollution reduction issues. Nevertheless, several interesting contributions in the literature proposed some technical solutions for improving the operational performances of these typology of energy hub. In a regional context, Wang et al. (2022), for example present an EH as a station for energy interaction between regional-level energy system and park-level energy users. For this aim they propose an improved unified modelling and linearization method for energy hub station to obtain an optimal dispatching of energy.

Yang et al. (2022), instead, 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. Moreover, Li et al. (2018) introduces and discuss a decentral framework for the optimal dispatch of integrated power distribution and natural gas system in networked energy hubs.

Wu et al. (2022) propose the adoption of a joint planning of an integrated energy system employing a group of cooling, heat and power as an effective approach in order to increase the energy efficiency of the energy supply in an energy hub. They also address a standardized construction method for modelling EH and apply it to a residential area with cooling, heating, and electricity system to verify the effectiveness. Finally, Wang et al. (2021) develop 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.

Although 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 entire energy system. This has led to the development of hybrid energy hubs.

Figure 2. 3: A traditional energy hub technical structure



Source: Xu et al. (2022).

2.2.2. Hybrid Energy Hub

The hybrid nature of this type of EH derives from the exploitation of a mix of inputs which may include among others renewable energy resources and national electricity grid or/and gas network. It partially addresses some of the challenges associated with traditional EH (Figure 2.4). Using renewable energy resources, they can contribute to reducing 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 (Mohammadi et al., 2017).

A number of academic contributions have already addressed some of the key issues related to Hybrid energy hubs, mainly focusing on the optimisation of the entire energy system and cost savings which could be obtained by introducing this technological solution.

Qiao et al. (2022), for example, 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. First, they present an EH-based combination model of gas turbines for the selection of combination schemes of multiple gas turbines, and then develop an EH-based configuration optimization model of integrated energy system to determine the optimal configuration schemes of energy devices by considering the economy, energy efficiency, and environmental benefits.

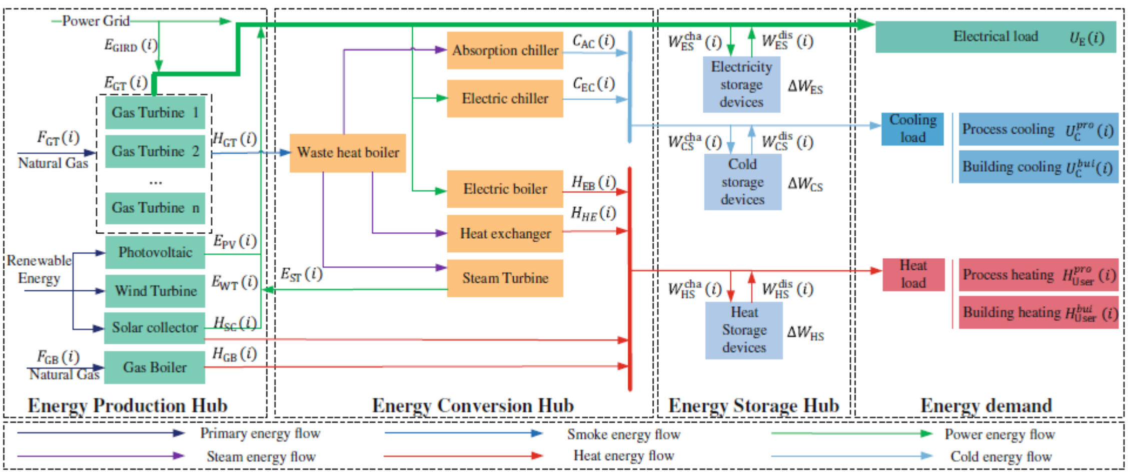
Han et al. (2023) investigated the presence of an electric vehicle parking in an EH considering the components such as combined cooling, heating, and power (CCHP), a photovoltaic unit in the presence of demand response programs, and its effects on optimizing power consumption to reduce cost. They use 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 represent 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 for managing the EH with multi-energy flows and multi-type energy storage systems (MESSs). While Ma et al. (2022) consider 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 energy hubs (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 include the uncertainties of demand forecasts, wind power forecasts, and solar power forecasts. This strategy considers several energy converters, such as conventional and renewable electricity generators, gas furnace, and combined heat and power generator to supply different electric, heat, and gas loads in the output.

In addition to the uncertainty of energy demand and energy resources, Dolatabadi et al. (2018) also consider the uncertainty of energy price in their empirical analyses 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 high performances of the EH in terms of flexibility, cost reduction and energy efficiency, it is argued that the right energy storage and conversion systems have to be identified. Indeed, the right combination of energy storage and conversion can lead to a successful EH. Relatedly, some academic contributions have investigated specific energy conversion and storage systems to be included in each type of energy hubs, given their core role in shaping the overall operational and economic performances of the EH.

Figure 2. 4: A hybrid energy hub technical structure



Source: Qiao et al. (2022).

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

The success of EH relies on the presence of the right energy conversion and storage systems in the configuration (Figures 2.5 and 2.6). Due to the pivotal role of these systems, some authors introduced some specific converters and storages that bring several benefits for energy hubs.

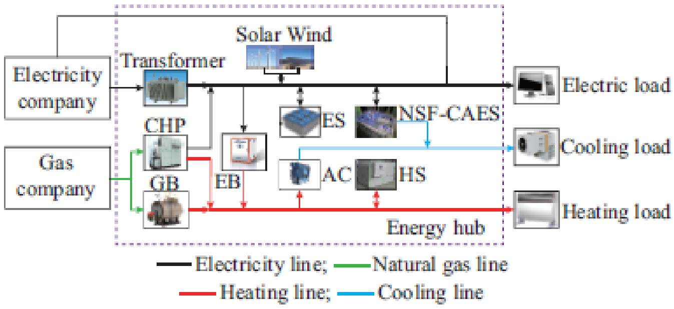
According to Zhao et al. (2020), EH can be also considered as a multiple-input and multiple-output energy conversion system, where energy is converted, stored, and consumed. They claim that the most used energy conversion systems are combined heat and power, absorption chiller, fuel cell, furnace, gas boiler, air-conditioning, and bi-directional AC/DC (alternative current/direct current) converters for the conversion of the AC/DC in the electrical hub. Samanta et al. (2023) argue that the combination of several converters such as Solid Oxide Fuel Cell (SOFC), Molten Carbonate Fuel Cell (MCFC), in a unique EH can led to generate several different outputs. In this perspective, they proposed an EH that generates electrical power, heat for district heat network, methanol, and oxygen by developing a conceptual framework for an advance integrated multigeneration energy hub by combining solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC), proton exchange membrane (PEM) electrolyser and methanol production unit. They concluded that system proposed has a highest exergy efficiency and a lowest levelized cost of energy.

Regarding the energy storage system, according to Zhou and Hu (2022), compressed air energy storages (CAESs) represent a new cleaner energy hub to be used 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. They test the effectiveness of the method through a real simulation.

Li et al. (2021) propose a hybrid optimization strategy for micro-energy grid dispatch. For enhancing the ability to support new storage equipment, they suggest an energy hub model by using the non-supplementary fired compressed air energy storage (NSF-CAES). This enables flexible dispatch for cooling, heating, and electricity. Based on the unique characteristics of the NSF-CAES, they used a sliding time window (STW) method for simple and effective energy dispatch.

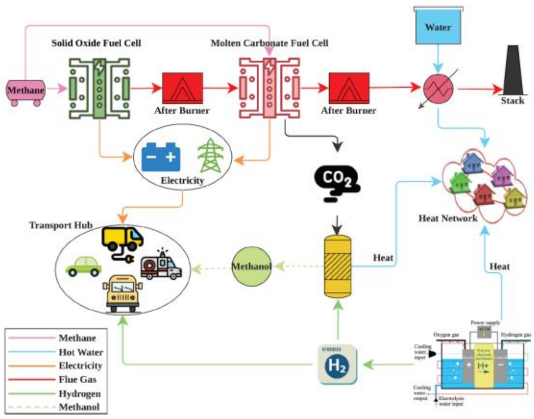
And Bai et al. (2021) investigated the external characteristics of advanced adiabatic compressed air energy storage (AA-CAES) and exploits its ability to analyse the daily self-dispatch of the energy hub in presence of uncertainties of load and ambient temperature. They used a data-driven stochastic dynamic programming model to allow a rolling horizon implementation. The results confirmed the effectiveness of the proposed dynamic programming method.

Figure 2. 5: Non-supplementary fired compressed air energy storage (NSF-CAES) energy hub.



Source : Li et al. (2022).

Figure 2. 6: Fuel-cell driven integrated energy hub for transportation decarbonization.



Source : Samanta et al. (2023).

2.2.4. Smart energy Hub

The flow of information existing in an EH is such an important element: the proper and smart use of these data and information has been argued to significantly contribute to the success of the EH. For a better processing and management of this flow of information, the integration of information technologies is crucial. Together with multi-carrier energy systems, these information technologies introduce the concept of Smart Energy Hubs (SEHs) (Figure 2.7).

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, it is pivotal to introduce stochastic modelling of intermittent renewable energy resources and fluctuating demands. In this perspective, several excellent works dealing with this topic are available in the literature. Ding et al. (2022) provide a comprehensive review of available EH optimization and control studies. They 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 (2022) suggest 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. Furthermore, they perform an optimal shifting of electrical, heating, and cooling loads to further reduce the operational costs of SEH considering a price-based demand response program (DRP).

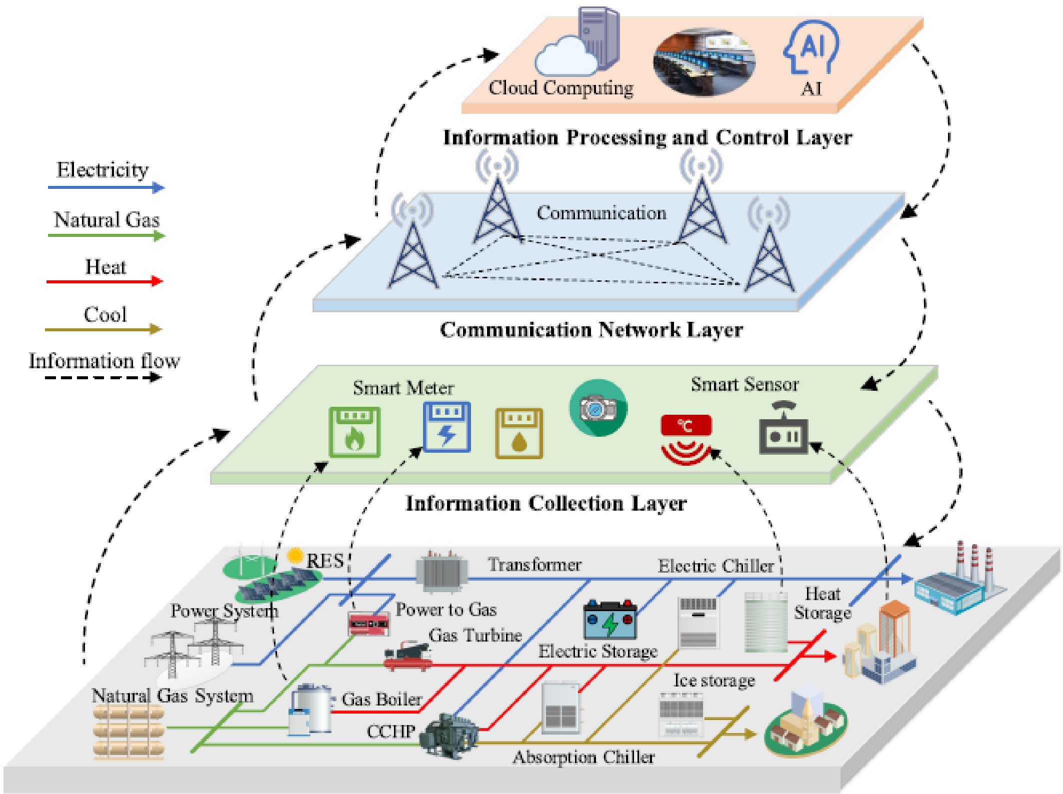
However, energy saving appears to be a great challenge faced by this type of EH. And to address this challenge, Dwijendra et al. (2022) analyse energy efficiency in an EH based on smart grid technologies and energy demand management. They proposed two-layer energy management necessary for implementing energy saving. The first layer consists of optimising the energy demand such as electrical, thermal, and natural and then, optimized energy demand is applied in 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. The research objective includes both the reduction of operation costs and emission polluting related to energy production side and the reduction of loss of energy supply probability (LESP) in demand side, as well as the optimal shifting of electrical and thermal loads in the day ahead. The proposed SEHS incorporates interconnected multi-energy system infrastructures such as electrical, thermal, wind, solar, natural gas, and other fuels to supply many types of electrical and thermal loads in a two-way communication platform.

Regarding the pollution issue faced by SEH, George-Williams et al. (2022) propose a technical solution which encompasses Vehicle-to-Grid (V2G) charging, photovoltaic energy generation, and hydrogen storage. They argue that these technologies represent emerging technology with the potential to reduce the negative impact of electric vehicles

(EV) on the electricity grid. Specifically, they provide a novel Monte-Carlo-based modelling and computational framework for simulating the SEH operation for a holistic evaluation of their technical and financial viability.

Figure 2.7: A smart energy hub technical structure.



Source: Ding et al. (2022).

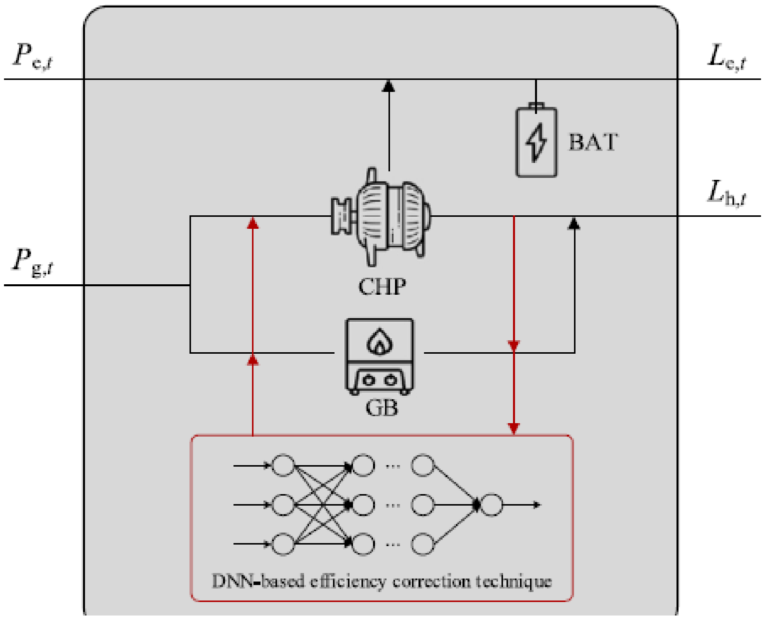
2.2.5. Dynamic energy hub

In integrated energy system, the uncertainty related to efficiency of energy devices that operate under tough and changing working conditions that threaten the operation of the system. In this perspective, Dynamic EHs are considered to be the solution for such of issues since they are design 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.

Xu et al. (2023) propose a low-carbon economic dispatch method for the integrated energy system that takes into account the uncertainty nature of energy input included in the system. In particular, the Authors design a dynamic energy hub (DEH) through the integration of 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. Moreover, to minimize operational costs, they formulated a low-carbon economic dispatch model. In addition, Xu et al. (2022) have also addressed the economic-environmental dispatch (EED) problem which originates from integrated energy system under off-design conditions through the integration of an efficiency correction process into the traditional EH model. They first developed a DEH model for adapting the EH to variable energy conversion efficiencies. Then, they formulated a multi-objective 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) define a multi-objective optimization model for determining the optimal operational scenario in an energy hub. For this purpose, they develop a dynamic energy storage hub (DESH) concept that includes an interconnected short and long-term electricity storage facilities. Then, they stress the synergistic benefits that derived from the connection of thermal and electrical storage units through the DESH scheme. Finally, they analyse the technoeconomic advantaged which drifts from storing surplus power in hybrid energy systems by using ammonia as the energy carrier in presence of renewable energy sources.

Figure 2. 8: Dynamic energy hub structure



Source : Xu et al. (2022).

2.2.6. Multi-energy hub

EH incorporates different types of energy production equipment and loads necessary for improving operational efficiency, but at the same time, faces an uncertainty phenomenon related to energy demand, renewable energy resources, energy price…etc.

To address these uncertainty factors that characterised the EH, some authors consider the multi-EHs as the best technical solution from operational, economic and environmental perspective (Figure 2.9). In particular, according to He et al. (2023) multi-EH has more advantages than the single-EH operation. Relatedly, they proposed a cooperative game-based coordinated model applicable to multiple EHs that consider different risk preferences.

Farshidian et al. (2021) investigate the energy hubs planning by considering the competition between the hubs. They propose a model for planning multi-hub in an energy system considering the competition between the hubs. By interconnecting the hubs via an electric transmission system, they build a linear model to determine the optimal planning and operation strategy for energy hubs in a multi-period planning horizon to meet the heat and electricity demand for the considered load zone. The problem is formulated and solved using Karush-Kuhn-Tucker (KKT) conditions and the model is then applied to 3-Hub and 5-Hub energy systems.

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. In addition, Arsoon et al. (2022) analyse a peer-to-peer (P2P) energy swapping framework for enhancing the resilience of networked energy hubs (NEHs) against extreme weather events.

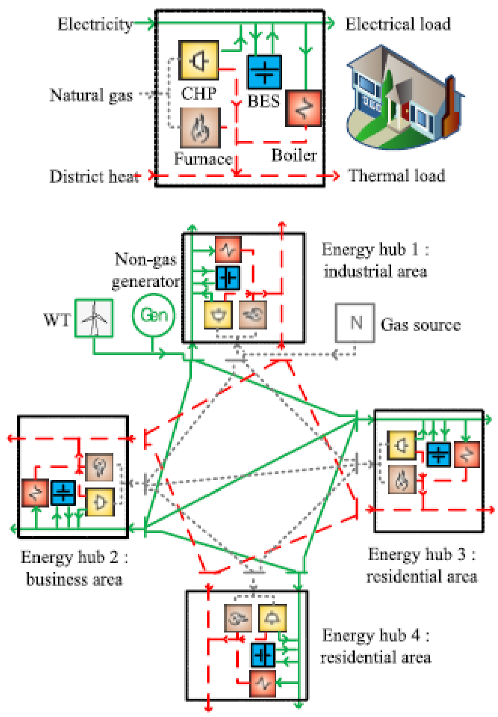
Some authors addressed other challenges related to multi-energy hub, such as energy efficiency, cost and congestion reduction faced by network of energy hub. For instance, Wu et al. (2023) addressed a distributed energy trading scheme with non-discriminatory pricing for a cluster of networked energy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

In the multi energy hub, congestion problems might occur in distribution networks with the gradual the penetration of distributed energy resources.

Hu et al. (2021) investigated the complementarity of multiple energy resources in EHs to solve possible distribution network congestions. They consider EH with components as combined cooling, heating and power units and heat pumps and integrate 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. The uncertainty of renewable energy resources is also considered through a scenario-based stochastic programming.

According to Xu et al. (2019), EHs can also act as distributed decision-makers and highlight the synergistic interactions of energy generation, delivery, and consumption of coupled electrical, heating, and natural gas energy networks. For this scope, they propose a distributed multi-period multi-energy operational model for the multi-carrier energy system.

Figure 2. 9: A multi-energy hub technical structure



Source : Xu et al. (2020).

2.2.7. Renewable energy hub

In the previous sections, various types of EHs have been presented. From traditional EH which consider only inputs that include electricity grid and natural gas networks, to hybrid EHs that consider as inputs both renewable energies along with traditional EH's inputs. Then, smart EH, dynamic EH and multi EH have analysed, each with their own specificities. However, due to the high amount of emission deriving from the various industrial activities, new models and technical solutions are urged to reduce these emissions and align with the ambitious target set out in the EU's plan for a green transition, better known as "Fit for 55" Package. In this perspective, an increasing number of academic and practical studies recently started to focus on renewable energy hubs (REHs) (Figure 2.10).

In this vein, Van Binh and Phap (2022), define REH as a geographically bounded area that holds technical conditions for exploiting renewable energy sources such as wind and solar on a large and concentrated scale. They claim that REH bring important economic efficiency per unit of land use and supply the power to the utility grid, and as consequence, can positively impact the sustainable growth of a considered area (e.g., city, municipality, port…etc.). In this regard, they develop a set of 30 criteria to identify, monitor, and evaluate the development process of a sustainable REH and present them as tool for supporting policymakers in their decision-making process, and as a result can operate more effectively, easily analyse the strengths and the weaknesses of REH's main parts.

Wan et al. (2023) and Kountouris et al. (2023) discuss the concept of power to X energy concept (P2X), which is an energy hub that encompasses a converter that transforms power produced by renewable energy sources (e.g., wind, solar, hydropower) into several outputs such as hydrogen, heat, into methanol, ammonia…etc.

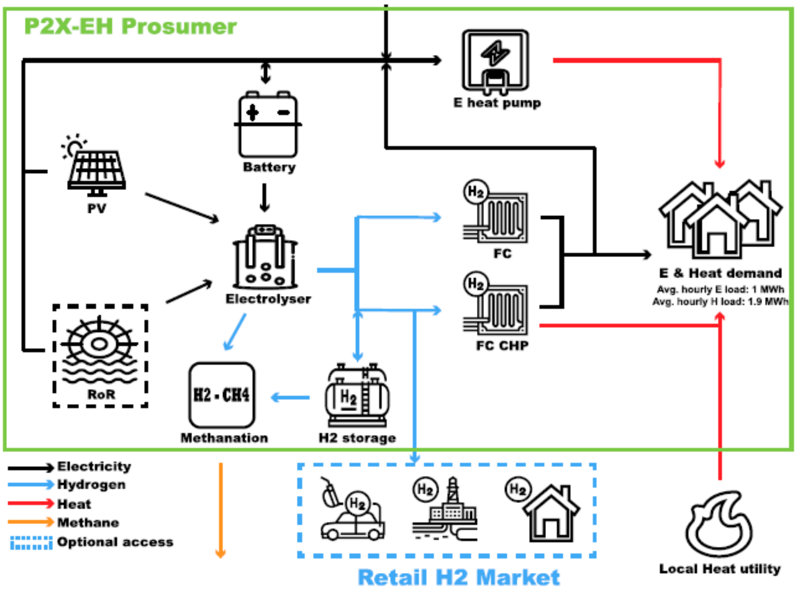
Wan et al. (2023) evaluate to which extent P2X energy hub can trade in an optimal way in the electricity market and its capability to satisfy local energy demand under the assumption of a long-term strong climate scenario in year 2050. They also quantify the key conditions for profitable operations of a P2X energy hub. Kountouris et al. (2023) instead investigated 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.

by applying a market-related 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 have debated on hydrogen based-energy hub. Qiu et al. (2022) argue that 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. In this perspective, they propose a multi-stage flexible planning method for the regional electricity-HCNG-integrated energy system (E-HCNG-IES), which takes into account the medium and long-term dynamic features of the E-HCNG-IES.

Zare Oskouei et al. (2022) introduce 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). Considering the challenges related to the development of a comprehensive market-based mechanism by distribution network operators with respect to grid code considerations in the presence of hydrogen-based facilities, they provide a multi-objective framework for representing a risk-constrained operation problem for the distribution networks in the day-ahead scheduling process.

Figure 2. 10: A renewable energy hub technical structure



Source: Wan et al. (2023).

Globally, factors such as energy policies, renewable energy intermittency, market prices, energy surplus selling are vital in evaluating the system's benefits and viability. Typically, the energy surplus is fed back to the grid during non-business periods such as weekends, holidays, and summer vacations. However, storing electricity is expensive and a market focused on using such clean energy is still lacking. In this vein, is fundamental to encourage energy policies that support the penetration of RES, such as Feed-in-Tariffs (FIT), Feed-in-Premiums (FIP), and quota obligations, as they can lead to increased demand for electricity. In addition, instead of selling the energy surplus to the actual retailer market, it can be used to charge electric vehicle (EV) at a more competitive price than those offered by the retailer market (Cavalcante et al., 2023).

Figure 2.11 presents the types of EH presented in this section. From the analysis of these EHs, it emerges that the technical components of energy hub are same (i.e., inputs, conversion, storage and output) even if can differ in their constitution. In the next section the different technical components of EH will be deeply presented.

Table 2. 1: Type of energy hubs

Type of Energy hub	Short description	Benefits	Possible Issues
Traditional energy hub	Use national electricity grid and national gas network as inputs to produce output.	Flexibility and multi energy demand satisfaction	Fluctuation of electricity and gas price, energy planning and optimisation problem, pollution
Hybrid Energy Hub	Exploitation of a mix of inputs which may include among others renewable energy resources (e.g., wind, solar) and national electricity grid or/and gas network.	Pollution reduction, energy planning solutions, flexibility.	Uncertainty of renewable energy, forecasting errors and lack of cost-effectiveness.
Energy hub based on energy converters and energy storage	Any type of inputs (renewable or not) can be used, but emphasis is on the energy conversion system for transforming input into output and storage system for storing output before use.	Flexibility, stability, reliability, reduction of uncertainty of renewable energy.	High investment costs, capacity shortage of storages system.
Smart energy Hub	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 energy system.	Highest level of performance, optimization of energy planning, reduction of forecasting errors.	High investment costs, uncertainty of renewable energy, fluctuation of electricity and gas price.
Dynamic energy hub	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 uncertainty related to efficiency of energy devices that operate under tough and changing working conditions that threaten the operation of the system.	Increase of the energy efficiency, reduction of operationg costs and pollution.	High investment costs, uncertainty of renewable energy, fluctuation of electricity and gas price.
Multi-energy hub	It consists of bringing together several energy hubs to form a network in order to exploit the synergetic benefits that can result. An example might be to put together three energy hubs consisting of an electricity energy hub using the national grid as inputs, an electricity energy hub using renewable energy as inputs and a gas energy hub using the gas network as inputs.	Increase of the energy efficiency, reduction of operationg costs and pollution.	High investment costs, uncertainty of renewable energy, fluctuation of electricity and gas price.
Renewable energy hub	Use renewable energy as inputs to produce output.	Foster sustainable growth, Economic efficiency, energy efficiency, flexibility.	High investment costs, uncertainty of renewable energy.

Source: Author's elaboration

2.3. The main technical components of an energy hub

According to Mohammadi et al. (2017), EH represent a place where production, conversion, storage, and consumption of different energy carriers take place. From this perspective, EH encompasses four major components including input, conversion, storage and output. In this section, each of these EH components are discussed based on the literature review provided in section 2.2.

2.3.1. Input: energy resources

The inputs represent the energy resources from which energy is produced. These energy resources consist of non-renewable energy resources such as district heating, national power grid, natural gas network, fossil fuels and renewable energy resources including wind, hydropower, biomass energy, solar, wave power, and geothermal power for meeting energy demands of consumers (Kiliç, 2006).

According to Global Change Data Lab, a nonprofit organization and a registered charity in the education sector, in 2022, non-renewable energy resources represented the primary energy source in the world. Oil and Coal are the main energy sources with respectively 31.6% and 27.6% of the world energy production. Renewable energy accounts only for about 16% of the world energy production of which 7% is produced from hydropower, 2.6% from wind, and 2.4% form solar. Regarding the extreme dependency of the world energy system to non-renewable energy sources and the related issues, there is an increased attention to RES with the intention to move towards the 100% renewable energy systems in Europe.

In 2020, renewable energy sources accounted for 37% of gross electricity consumption in Europe (Global Change Data Lab). Wind and hydropower accounted for more than two-thirds of the total electricity generated from renewable sources (36% and 33%, respectively). The remaining one-third of electricity came from solar power (14%), solid biofuels (8%) and other renewable sources (8%). Considering the difficulties faced by hydropower such as high start-up costs, environmental damage that can come from interfering with a river's natural course there is a more focus on alternative renewable energy solutions such as wind and solar. Solar power represents the fastest-growing source as in 2008 solar energy only accounted for only 1% of the electricity consumed in the EU. According to International Energy Agency, renewable electricity capacity in Europe is expected to increase nearly 60% between 2022 and 2027, stressing the commitment of European countries to move towards renewable energy system. In this perspective, Connolly et al. (2016) propose a scenario for a 100% renewable energy system in Europe by the year 2050. They argue that the introduction of smart energy system approach is the technical solution necessary to achieve a 100% renewable energy system in Europe. They claim that coupling the electricity, heating, cooling, and transport sectors can create a flexible energy system that enables an intermittent and progressive penetration of renewable energy of about 80% in the electricity sector. Although this solution is nearly 10 - 15% higher than the current energy supply scenario, it could lead to the decarbonization of European energy system by fostering local investments which will allow the creation approximately 10 million additional direct jobs within the EU.

Renewable energy source (RES) in the energy hub context enables the production of various types of energy carriers. Photovoltaic, wind, geothermal energy can be used to produce some energy loads such as electricity, heat, and water. Biomass can serve for producing electricity and heat. In addition, biomass can also be converted to renewable and clean fuels like hydrogen and ethanol, which can be used in transportation.

In this vein, waste represents a valuable potential input for renewable EH as this solution mitigates environmental issues occurring from disposal waste (Mohammadi et al., 2017). In addition, it leads to lower emissions, higher energy efficiency and higher share of renewable energy. In the same perspective, Münster and Meibom (2011) have published an empirical analysis demonstrating the potential usage waste in CHP systems as a viable solution for energy production.

Hydrogen is also considered a promising energy carrier for renewable EH, as it can play a pivotal role in providing renewable energy for various energy sectors. However, the hydrogen, when produced from fossil fuels, doesn't solve the problem of greenhouse gas generation and implies the use of carbon capture systems. This emphasizes the urgent need for innovative technological solutions capable to produce hydrogen from RES, in a sustainable way. Nonetheless, given the technological solutions available and the current market conditions, the production of hydrogen from RES still appear very expensive, especially when compared with alternative energy options in the market.

However, according to Mohammadi et al. (2017) the use of waste, biomass, and energy surplus generated from RES for hydrogen production can allow the costs reduction and represent an interesting solution for hydrogen production from RES.

According to established academic literature focused on this phenomenon, the most used inputs are national electrical grid and gas network.

EH concept represents a suitable model for the integration of different energy infrastructures and bring several benefits stemmed from the synergy of different energy carriers. However, this should not be restricted to the integration of traditional energy resources by only considering current infrastructure related to the electricity and natural gas networks. EH models need to move towards the uptake of sustainable and clean sources such as renewables renewable energy. To produce multi energy and achieve realistic EH, inputs have to be converted and stored.

2.3.2. Energy conversion system

Energy Hubs are expected to couple different inputs in a multi energy system to satisfy different form of energy demand. The incoming energy into the EH can derive from different sources including district heat network, electricity from national grid, natural gas network, or other type of inputs like fossil fuels, solar and wind power, hydrogen, biomass, biogas, geothermal heat, waste, etc. Some of these inputs like electricity, and gas can be directly used as output without any conversion while other need to be converted to the desirable output depending on the type of energy demand.

Given the above, the two major input-output connections in EH are direct connections and conversions. Indeed, direct connection typically delivers energy carrier to the output without conversion or change in its initial quality. Converters instead transform energy carriers into other types of energy. The conversion doesn't only consist of transforming a specific input into a different output (e.g., conversion of wind energy into electricity through wind turbines). There are also cases where the input and the output are the same, but the converter has only the role to change a specific characteristic of the input in order to have the output that satisfy the energy demand. For instance, the transformers allow to transform 230V low voltage alternating current into a different voltage, which is needed by household appliances; inverters convert direct current (DC) into alternating current (AC); or heat exchangers facilitate the process of heat exchange between two fluids that are at different temperatures.

Several other typologies of energy converters exist such as electric machines that convert electricity to mechanical power, gas turbines that convert gas to mechanical power, fuel cells that can convert fuel into electricity…etc.

These converters are used to change the input carriers and getting them to the required quality and quantity, according to the energy demand and usage. Example of converters for renewable energy are wind turbines for transforming wind in electricity, PV cells for transforming solar energy into electricity. Many converters mentioned previously convert one type of energy carriers. Nevertheless, as one of the aims of energy hubs is to couple different energy carriers to meet various energy demands, the introduction of converters that can transform one or more inputs to more output is crucial. This can lead to higher efficiency, lower primary energy consumption and lower operating costs of the entire energy system (Gholizadeh et al., 2019).

Also known as cogeneration systems, combined heating, and cooling (CHP) systems are the most diffused technical solutions for transforming an energy input into several energy outputs. CHP is a system that produce simultaneously electricity and heat from a unique energy source. According to Mohammadi et al. (2017) the use of CHP significantly grew over the past two decades due to its high efficiency and flexibility to meet different demands. With CHP, the system can rely on the electricity grid in off peak periods while in peak periods when the electricity price is high the system can use the CHP to meet the electricity need and even the excess electricity can be sold to network.

In addition to the co-generation system, polygeneration systems also exist and enable the contemporaneous production of power, heat, and other energy products in a same and unique integrated process. In polygeneration systems more products like cooling, domestic hot water, hydrogen, ethanol, etc., can be produced. According to Rong & Lahdelma (2016), polygeneration is fundamental to reducing energy imports and fostering the optimal use of local resources. An example of polygeneration is CCHP generation system that allows to simultaneous produce cooling, heating, and power. In CCHP the role of the main engines as the power generation unit (PGU), is to generate electric power, and the related wasted heat generated by the PGU is recovered by the heat recovery system (HRS). Then the cooling is produced by a refrigeration system as absorption chillers or electrical compression chillers. In the case that the heat demand is not satisfied by the surplus of heat generated by the PGU, a boiler is used to compensate the lack of heat demand. In EH, absorption chillers are preferred compared to compression chiller due to its capability to use heat as input and minimal use of electricity. A solar collector system can be used along with a CCHP system. This solar collector system serves as a provider of part of the heat demand. Hybrid CCHP-solar collector system presents several benefits as lower fuel energy consumption, lower operating costs, and higher probable income from the selling of electricity surplus with respect to a simple CCHP system (Ebrahimi & Keshavarz, 2015).

Fuel cells also represent a very important and promising renewable system that can be used in polygeneration system. Several different typologies of fuels such as hydrogen, biogas, methanol, natural gas, etc can be used in fuel cell. In a hydrogen-based fuel cell, using hydrogen and oxygen as inputs electricity, heat and water can be produced. Fuel cells present several benefits including greater efficiency, easy installation, lower emissions, and reliability of operations.

In conclusion, all the converters mentioned above have different role. Boilers is principally used as an auxiliary energy source with the CHP to compensate the lack of recovered heat for the supply of heat demand. So, it has been most widely used in EH models after CHP. The transformer is primarily involved in the conversion electricity bought from the national grid and it represents the possibility of using the electricity grid in an EH and in a renewable EH, the electricity grid can be used as a backup to compensate for any anomalies that can occur in the system. Absorption chiller can be used alongside with CHP to convert the waste heat into cooling.

When it comes to renewable energy converters, the most used technologies in EH are the photovoltaic panels, small wind turbines, and solar collectors. These technologies have a high technology readiness level and are already widely commercialized. In addition, these technologies are user friendly, convenient for on-site power generation, easy to be installed and the related installation costs are lower.

Heat exchangers are useful in district heating networks while heat pumps can be used for heating and cooling in EH models. For the reduction of operating cost and achieving higher flexibility in an EH heat pumps can be used for converting excess electricity into thermal energy and storing it in thermal storages.

Biomass boilers allow the conversion of biomass into heat, while biomass reactors allow the production of electricity from biomass, and gasification reformer allow the generation of biofuels from biomass. The converted energy can be used immediately or stored before its usage. For this reason, it become fundamental to consider the diverse technical solutions available for storing energy in diverse EH configurations.

2.3.3. Energy Storage System (ESS)

Energy producers face several challenges from the current energy market. These challenges mainly regard the uncertainty of the energy demand and the fluctuation of energy price. To address these challenges, energy users can rely on renewable energy sources such as solar or wind to produce their own energy. But the RESs bring some operational and technical issues and the main ones are the intermittency, the fluctuations and uncertainties that characterized their production, and as a result it is difficult to control and schedule them. To really integrate the production of RES in an energy hub and to align them to the consumption pattern of the hub they belong to, Energy Storage Systems (ESSs) result are the technical solutions available and capable to reduce the discrepancy between production and demand.

Indeed, ESSs are used to capture energy at a given moment for using it at after when required by users. Besides the reduction of the imbalance between energy demand and energy production, ESSs provide many other benefits such as increasing system efficiency, as they can allow to reduce environmental pollution and cut fossil fuel emissions. ESSs can be installed locally, where the consumption takes place or elsewhere to achieve the greatest controllability.

According to Palizban and Kauhaniemi (2016), the introduction of ESSs in an EH derives from the need to achieve three fundamental goals namely: i) improving reliability and facilitating the integration of RES (Abbaspour et al., 2013); ii) improving resilience of the system and increasing its performance; iii) pursuing the benefits of smart energy systems and goals optimization.

i) Improving reliability and facilitating the integration of RES

The uncertainty of the energy demand that can suddenly increase and the uncertainty of the energy production and transmission that can suddenly drop represent the two main drivers of the mismatch between energy production and demand. National power grid is designed to be able to quickly respond to power shortages and power frequency drop due to their synchronous machines that allow the utilization of potential spinning reserve.

In an isolated systems instead, particularly in RES-based systems, this imbalance can tarnish the reliability of the entire system due to the restrictions related to the size of installed units and the lack of spinning reserve. Therefore, ESS can be used to stabilize the system and establishing a balance between production and demand (Moradi et al., 2016) Accordingly, the use of ESS increases the reliability in off-grid mode and facilitate the integration of RES to the system. In addition, ESS enables the tracking of the energy market prices, to reduce system's cost in grid-connected mode.

ii) Improving resilience of the system and increasing its performance

ESS can be used for the stabilization of the energy system through the reduction of fluctuations and uncertainties of power. In addition, it represents a support for the energy system since it can be used to lighten up the system, by using it for ancillary services to improve the power quality and the operation condition of the system.

The ESS can facilitate the implementation of the load shifting strategy in various energy price period. This strategy consists of storing energy during off-peak periods and use it

during on-peak periods, and consequently it leads to the reduction of operating costs of the system, the achievement of peak shaving and the improvement of the load curve.
Overall, the advantages of using the ESS in power systems are the improvement of the network inertia to respond to fluctuations, the frequency and voltage regulation, the volatility reduction, the preservation of the network synchronization, the supply of direct voltage in the case of faults, the supply of necessary energy to black start, the supply of spinning reserve, the reduction of the necessity for more infrastructure and the optimization use of existing capacity (Mohammadi et al., 2017).

iii) Pursuing the benefits of smart energy systems and goals optimization

The third goal for the using of ESS is the realization of EH and smart energy systems with intelligent technologies to move towards sustainable energy systems. The use of local ESS on the demand side alongside with smart technologies for demand-side management programs increase the optimization of equipment and resources (Del Granado et al., 2016). They argue and demonstrate that, in presence of variable pricing program (i.e., real-time pricing and green pricing), ESSs follow the energy price changes and are capable to meet a higher share of energy demand.
Regarding the goals optimization, after the determination of the goals, it is fundamental to clarify the criteria for choosing the ESSs that are in line with the goals. These criteria include, among others, investment costs, size (capacity), storage power, effectiveness, technology readiness level (TRL), technological lifespan, time response, charging duration, discharge losses, etc…
The determination of the size and type of ESS to be used (long term capacity decision) is very important since this variable can significantly influence the over performance of the system in achieving an optimal energy planning. The "size" variable refers both to the energy and power capacity of ESS: they are determined according to various parameters such as the type of connection and the location ESS.
ESS can be installed locally, where the consumption takes place or elsewhere to achieve the greatest controllability. For this reason, it necessary to develop a suitable control strategy for a better scheduling of charging and discharging of ESS. For reaching an optimal control of ESS, several different factors including technical constraints, anticipated production capacity, energy markets, energy pricing plans, demand, weather conditions, etc. must be considered. Such strategy can include the restriction on charging

the ESS, that can improve the performances of the system in the long term as well as the peak shaving.

The introduction of ESSs is argued to significantly increase the productivity and performance of the other components of the energy hub/system. The thermal ESS improves the performance of CCHP in the presence of RES, reduces primary energy consumption and increases the efficiency (Chesi et al., 2013). Moreover, Stoppato et al. (2016) demonstrate that using pump storage along with the battery, decreases the battery discharge rate, increases its longevity, and reduces the costs of the system.

Rivarolo et al. (2013) present a thermo-economic methodology for assessing the impact of ESSs on the performance of a real polygeneration system. They argue that thermal storage with the CHP lead to lower costs and less energy purchase from the grid.

In conclusion, based on the literature, the most widely used ESS is thermal storage as it has lower cost compared to electric storage. Storage of excess heat is implemented to effectively use the waste heat for increasing the reliability of the system. However, these are not the only options for storage systems in EH. One of the local ESS technologies, which recently emerged in smart systems, is a plug-in electric vehicle (PEV). These vehicles can directly deliver power to the grid thank to the high charge and discharge rates of modern batteries embedded in these vehicles.

Coelho et al. (2016), stress the high PEV's potential for peak shaving in the system due to their ability to connect to the electricity network to deliver power from the vehicle to electricity network.

The other ESSs that are currently used in many EH are electric and thermal storage. In EH, the installation energy storage can occur on the input or output side based on the needs. Specifically, the incoming inputs can be directly stored in input-side storages or in alternative can transit to the conversion units for consumption or for been saved in output-side storages. Gas storage is usually installed on the input side while electric and hydrogen storage can be installed on both the input and the output side.

Overall, increasing the size of storage and the length of the forecast horizon are pivotal drivers for the success of EH as participate to lowering the operating costs.

2.3.4. Output: Energy demand and users

As mentioned previously, the energy demand is subject to high fluctuations and forecast errors, and for these reasons has to be addressed and evaluate carefully within the overall system. In EH, it is necessary to identify the type of energy demand (e.g., electricity, cooling, heating, fuel…etc.) for adequately satisfying energy needs related to the final users. Besides the identification of the nature of energy demand, it is fundamental to predict it as precisely as possible to avoid the issues that can result from a forecast error such as capacity shortage or poor reliability and instable system.

In this perspective, several approaches exist for modelling and forecasting energy demand including, among others, time series, regression, fuzzy methods, etc... The objectives of these methodologies are namely: to predict the actual consumption trend and to reduce forecasting errors. Consequently, current and future energy systems aim to introduce more flexible demand management, reach a greater demand controllability and use innovative technologies such as distributed energy resources (DERs).

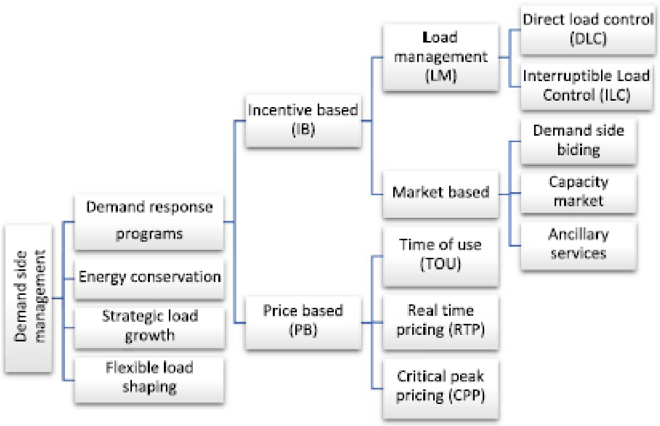
Indeed, for an effective management of energy demand, demand side management (DSM) is considered to be a great solution. DSM is a strategy used by energy providers to control energy demand by encouraging consumers to modify their level and pattern of energy usage. Typically, DSM is tailored to a user and include monetary incentives to encourage consumers to buy energy-efficient equipment as well as, or lower prices if they agree to reduce usage during peak times of demand. It has four valuable and modular features which include among others: i) load growth, ii) energy savings, iii) energy efficiency, iv) demand response program (DR).

i. Load growth includes programs used for increasing the load level, through electricity supply.
ii. Energy savings consider actions and interventions for reducing the energy consumption.
iii. Energy efficiency consists of using technologies to reduce the energy consumption
iv. Demand response programs encourage consumers to change their consumption behaviours to balance the energy demand and energy production through price changing or incentives. These strategies are usually use when the energy wholesale market price is high, or the reliability of the system is in peril. DR programs bring

several benefits such as incentives, bills amount reduction for consumers, increasing of system reliability, better market performance and lower infrastructures costs.

Specifically, demand response programs consist of incentives-based (IB) and price-based (PB) programs. IB programs refer to load management (LM) and market-based programs including for instance capacity market and demand side bidding. PB program instead refer to dynamic pricing programs which can be time of use (TOU) pricing, real-time pricing (RTP) and critical peak pricing (CPP). Besides peak shaving, which is the main benefits of DR program, other benefits such as load shifting, and valley filling can be realized in these programs (Figure 2.12).

Figure 2.11: Demand side management programs



Source: Mohammadi et al., (2017).

In EH, customers /users that participate in the DR programs, can optimize their energy demand planning, in addition to optimally plan their energy production, therefore, increase the flexibility in the energy system. This increase in flexibility is due to the possibility to switch between different energy carriers or different converting and storage technologies in EH.

This concept is well known as integrated demand side management (IDSM) and is defined as a generalization of DSM programs.

These programs increase benefits for both energy consumers and power supply companies. Subscribers participating at EH in DR program, in bullish market conditions (high price of the energy), have the capacity to provide a portion or all their electric demand through CHP, even without shifting or lowering their loads. As a result, they receive the same quantity of energy from a cheaper source which lead to lower energy costs. Overall, the customers comfort is maintained, their energy costs are lower which lead to a reduction in peak demand and a flatter curve in the entire network.

However, most EH focuses on meeting electricity and heating demands, and less attention is put on other energy such as fuel and cooling, hydrogen, GNL…ect. But in a real energy hub like port EH, the energy demand can also include alternative fuels, cooling, hydrogen, ammonia, to completely meet the port's energy demand. The next section focuses on port as renewable energy hub, by providing the drivers and a conceptual framework that can be used to develop a port renewable energy hub.

2.4. Ports as renewable energy hub: Main drivers

In real and complex energy hubs/systems (such as it happens in ports), in addition to electricity and heat, several other typologies of energy needs such as cooling, fuels and compressed air emerge and have to be taken into account. In this sense, considering only the generation of electricity and heat within the port does not reflect a real model of port energy systems. Therefore, future EH models, to achieve a sustainable energy system, need to pay attention to multi-generation technologies for integrated supply of various demands. In this perspective, Acciaro et al., (2014) consider ports as energy hubs as they represent geographical locations 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.

According to Notteboom et al. (2022), 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. Therefore, ports as energy hubs require new configurations capable to include renewable energy sources, innovative technologies, conversion and storage system for integrating energy infrastructure and obtaining the advantage of synergies deriving from the coupling of different energy carriers. In the next sections the main drivers of ports as energy hub will be presented, then a new conceptual framework for renewable energy hub applicable to port will be provided.

2.4.1. Port as energy hub: main drivers

Although the energy sector is not the main sector of ports, they dispose of 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. For these reason ports are constantly trying to better manage their energy system in order to increase the energy efficiency. Before presenting the configuration of a port renewable energy hub, it is useful to highlights the main drivers that make a port an ideal field for the establishment and the design of an energy hub perspective. Below, we report these key drivers:

- Geographical location. As logistic node ports have preferential position, space for performing energy intensive maritime logistic activities.
- Multi energy demand. Various form of energy is consumed for carrying out energy intensive maritime logistic and port activities.
- Energy production/supply. For guaranteeing energy efficiency, environmental, economic and social sustainability port produces part of its energy need, if possible, using renewable energy source.
- Energy storage. Ports have terminal, tank for energy storage.
- Energy transit. Huge amount of energy transit within the ports through import and export activities. So, port have a good familiarity with energy management activities.
- Emission hub. Maritime logistic activities emit GHG and other emissions PM2.5, nitrogen, sulphur, …ect.

Overall, different forms of energy demand are consumed for carrying out port's activities including electricity, heating, cooling, fuel etc... This means that the port is a multi- energy system. To be more efficient, it is essential to introduce the energy hub concept into the port, as this is an appropriate model for integrating the energy infrastructure, and many benefits can be generated by the synergy of the different energy carriers.

But this should not be narrowed down to the integration of traditional resources by considering only current infrastructures such as the electricity grid and natural gas networks, renewable energy sources should be considered since they can lead to several benefits for ports.

Port renewable EH models require moving towards the use of sustainable and clean sources including renewables, especially in the form of distributed energy resources

(DER) (Mohammadi et al., 2018). 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. 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. in the next section a conceptual framework for designing a port renewable energy hub configuration for environmental, economic, and financial sustainability of port is presented.

2.4.2. Port renewable energy hub configuration: Conceptual framework

The objective of this section is to provide a conceptual framework for the selection of the ideal configuration for diverse typologies of renewable port energy hub, capable to take into account several selection criteria which include among others: cost, emissions, energy efficiency, availability, security, and other key variables and parameters. The conceptual framework proposed, in particular, includes four parts:

i) the market needs the energy hub configuration is expected to satisfy;
ii) the technical components to be included in the selected energy hub configuration);
iii) the economic and financial dimensions related to the energy-hub configuration;
iv) the evaluation of opportunities and threats related to each potential configuration.

2.4.2.1. The market-based components

These components essentially include the port energy demand. The main energy load consumed in the port are electricity, heating/cooling and fuel. These energy loads are used in the port's buildings, common area, for cold ironing, yard and quay vehicles, port equipment and refer containers.

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. This implies for example cranes, RTG, RMG, automated guided vehicle running on electricity and/or solar power or yard trucks, running of LNG, hydrogen. Electricity represents the most consumed energy in the port. Lighting consumes about 3-5% of total energy in ports while the percentage of energy consumption from reefer containers ranges between 20% and 45% (Iris & Lam, 2019).

In the same vein, for a low-automation container terminal, reefer containers and quay crane respectively consume up to 40% and 40% of total consumption (Wilmsmeier et al., 2014). Meanwhile, the fuel is mainly consumed by yard crane (68%) and horizontal transport of containers (30%).

Since energy consumption in the port is subject to various variations due to handling volumes variations, continuous modification of ship calling patterns, variation of seasons, and fluctuations in the port stay times it is fundamental for port to meet the energy demand in the best way possible.

2.4.2.2. Technical components

Technical components included in the energy hub configuration encompass all the elements necessary for meeting the port energy demand. These elements are input, conversion, storage and have been exhaustively presented in the section 2.3. Energy from the input can be converted and then stored before being used, or it can be stored before being used without conversion. The energy hub configuration depends on the energy needs of the specific port, the energy production and consumption patterns related to the port area and the economic and social actor located inside it and several other endogenous and exogenous variables. The proposed energy hub configuration essentially used renewable energy sources as inputs. As the main energy consumption involved in port activities refers to electricity, fuel, heating and cooling, the choice of the inputs for their production has to be based on a set of heterogeneous criteria which include production cost, environmental emission, energy efficiency, energy availability, energy security and operational flexibility. Other potentially relevant parameters to be taken into account when selecting the best energy hub configuration are the share of energy produced by each RES and the fluctuation of energy, the technology readiness level, the installation effort, the utility and the reliability. And the same criteria have to be used to prioritize the output choice. When it comes to the conversion and storage system, the best ones will be deductively chosen for the better coupling of energy loads considering criteria as cost, availability, flexibility, technology readiness level, installation effort, capacity.

2.4.2.3. Financing components

This component is crucial to support the implementation of green strategies in ports. Indeed, green strategies are well-known to be capital-intensive and 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, opex and maintenance costs resulting from the implementation of green strategies. A wide range of funding can be considered. From international funding (e.g., from the European Commission), funding from national, regional and local governments, private funding (terminals, energy companies, banks) and self-financing. In order to foster the uptake of renewable energy, several incentives can be used including:

- Financial incentives which can consist of European, national and local funding scheme to cover high Capex, Opex and maintenance costs for the implementation of the RES. Other incentives also include low-interest loans and grants for renewable energy projects (e.g., Australia).
- Feed-in tariffs (FIT) which can allow to ports that produce renewable energy to sell any additional energy to the national grid. With the feed-in tariff system, renewable energy producers are guaranteed to sell this additional energy at a fixed rate per kilowatt hour for electricity fed into the grid. (e.g., Australia, Germany).
- Tax incentives for energy-efficient renovations. This incentive allows ports to claim reimbursement of a certain percentage (e.g. 20 %) of renovation costs up to a certain amount (e.g. EUR 45.000) if they replace inefficient doors or windows or purchase new heating and insulation systems (e.g., Germany).
- Value-added tax (VAT) exemption for renewable energy systems including PV (e.g., Germany, Netherlands).
- Tackle permitting barriers by simplifying procedures, reducing the duration for the issue of the permit and revisiting the threshold for permitting (e.g., Greece, Spain).
- Credit incentive. It consists of providing credits to RES producers (e.g., 2.000 euro) for installing a heat pump and credits for a new electric vehicle (e.g., 7.500 euro) (e.g., USA). This incentive can be extended to other renewable energy sources and related technologies.

2.4.2.4. Opportunities and threats

Opportunities represent the elements that can be consider for a successful port renewable energy hub such as:

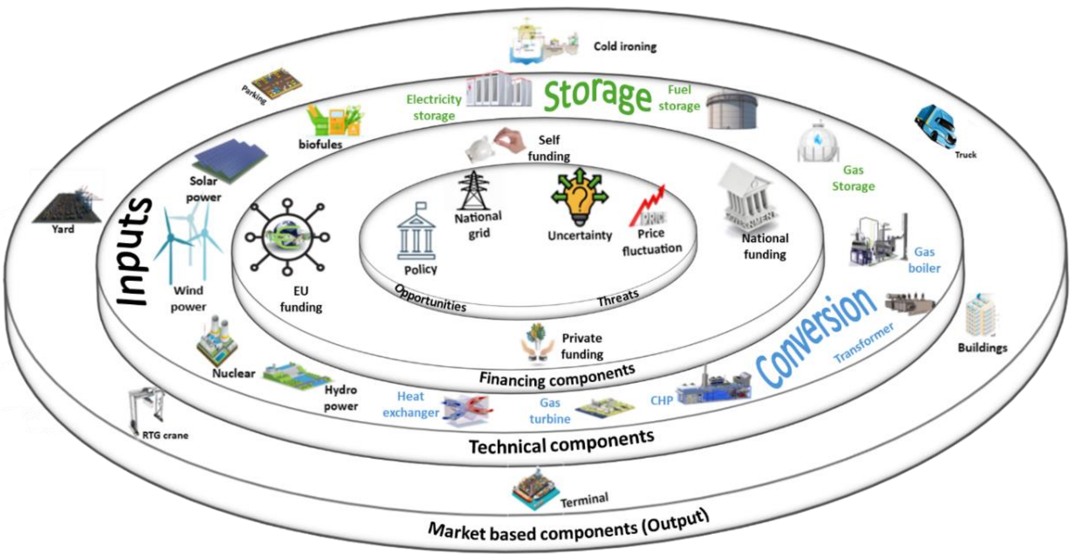
- Using the electricity grid as a backup to compensate for any anomaly.
- Introduction and compliance to policies and measures for decarbonising the port's activities.
- The use of tools, techniques, software, technologies such as demand response programs (e.g., incentive-based and price-based program), energy conservation, strategic load growth and flexible load shaping.

The threats instead regard all the difficulties that can obstacle the success of port renewable energy hub such as:

- Uncertainty of energy demand
- Uncertainty of renewable energy production
- Fluctuation of energy price
- Limited capacity of energy storage system
- Regulatory vacuum
- Lack of energy trading criteria from peer to peer in EH

This section provides the 4 components that can form a port renewable energy hub framework (Figure 2.13).

Figure 2.12: The conceptual framework for developing port renewable energy hub configuration.



Source: Author's elaboration

The reported framework provides a decision support system (DSS) tool supporting port decision makers with a fundamental approach for achieving environmental, financial, and economic sustainability by exploiting the energy hub and energy management system concepts. As multi energy systems which integrate different energy systems such as electricity, natural gas and district heating networks, ports integrate different types of energy generation loads and energy transformation technologies that can be used to improve the energy efficiency of port operations. Combining these energy systems as a network and creating an exchange energy between them provide both financial and environmental efficiency benefits (Maroufmashat et al., 2015). The coexistence of different types of energy production and supply makes the port a multi- energy system. The integration of multi- energy systems in the port energy system is seen as promising and economically feasible energy system compared to conventional decoupled energy systems. As such, port energy management systems (PEMSs) should be based on the energy hub approach in order to be smart and capable to manage energy fluctuations through conversion and storage solutions for meeting volatile port energy demand and specific energy needs. The next chapter addresses the energy management in the port using the energy hub approach.

CHAPTER 3
ENERGY MANAGEMENT SYSTEM IN PORT

3.1. Introduction

Real energy systems are usually planned and managed independently. However, several studies on energy hub concept prove that considering different energy carriers in an energy system can lead to better performance than systems which are independently planned and controlled (Mohammadi et al., 2018). For this reason, future energy systems are expected, to be managed as a network due to different benefits that can arise from this management approach. Indeed, this new technical approach to energy system management can bring several benefits that arise from the integration of energy infrastructure such as electricity, natural gas, and district heating networks thanks to the development of technologies such as efficient multi-generation system. In these systems, different energy carriers and systems could be integrated in a synergic way by using the energy hub approach. Indeed, the main purpose of the energy hub (EH) approach is the move toward multi energy system (MES), with the aim to capture the synergistic benefits stemming from different energy carriers, non-hierarchical structure, and integrated management of different energy infrastructures (Geidl et al., 2007). As multi energy system, ports integrate different types of energy generation and energy transformation technologies that can be used to improve the energy efficiency of port operations. Combining these systems as a network and creating an exchange energy between them provides both financial and environmental efficiency benefits and increases the reliability of the system (Maroufmashat et al., 2015).

This coexistence of different types of energy supply makes the port a multi energy system. The integration of multi energy systems in the port energy system is considered to be a promising, operationally and economically feasible energy system compared to conventional decoupled energy systems. As such, port energy management systems (PEMSs) are expected to be smart and capable to manage energy fluctuations through conversion and storage solutions for meeting volatile port energy demand and specific energy needs. PEMS consists of energy demand and energy supply planning, and smart energy management system that link interactively demand and supply for balancing them in an efficient manner (Iris & Lam., 2019). According to Nguyen et al. (2022) PEMS also integrates renewable energy. Therefore, the energy management process involves the analysis, monitoring and optimization of energy resources, and lead to a correct administration of energy consumption for achieving the economic and environmental benefits. This process consists of 4 phasis: i) assessment, ii) planning, iii) execution and iv) reporting. In the assessment, energy needs/consumptions are assessed, collected and analyzed by using technologies as smart sensors. The planning phase identifies opportunities to save energy and sets strategic energy related goals and key performance indicators (KPIs). Execution consists of taking action to save energy and reporting is implemented for tracking progress and ongoing improvements through reporting systems and benchmarks.

In the light of the above, for an effective implementation of PEMS, ports should be able to measure and estimate the energy consumption in a very precise way. In addition to that, energy management systems require an established management strategy based on well-established frameworks and standards.

3.2. Policy frameworks and certification for port energy management

The energy-intensive nature of port activities has placed energy efficiency as a crucial goal for ports to be achieved. The relevance of this objective is illustrated by the third place that energy efficiency holds among the 10 environmental priorities for European ports (ESPO 2023). Increasing the energy efficiency of port operations and related industries should contribute to reducing emissions in ports. With 76% of ports monitoring energy efficiency, European ports clearly demonstrate their commitment to seriously reduce their energy consumption through the introduction of innovative technologies and the optimization of existing operations.

This will lead to a feasible transition path towards a low-carbon port energy system model based on the introduction of renewable energy sources, the electrification of port equipment, the use of alternative fuels, the shift towards smarter energy distribution and energy consumption measurement systems and the design of new policy frameworks for a good management of port energy system. This framework includes the most effective policies, standards and strategies to address energy consumption and management issues in port areas.

3.2.1. ISO 50001 Energy Management System

The ISO 50001 energy management system standards provide to organizations an effective tool for establishing systems and processes aiming to reduce their energy consumption and consequently improve energy efficiency. ISO 50001 can be used by small and large organizations including ports, and bring several benefits such as environmental impacts reduction, port reputation enhancement, lower costs, and competitiveness improvement. It follows the Plan-Do-Check-Act (PDCA) improvement cycle which is a process for continual improvement of port energy performance and is configured as outlined below:

- PLAN. The objective of this phase is to design the Port Energy Action Plan, that will govern the port's path towards decarbonization through an excellent energy management framework. This plan consists of developing a policy for more efficient use of energy within the port. It starts by carrying out an audit aiming at reviewing the AS IS situation of the port energy context and determining the baseline that will be used as the reference energy data during the process. Then, the port energy strategy is defined, and "SMART" (specific, measurable, achievable, relevant and timebound) energy reduction objectives and the related targets are set. Finally, a dashboard that includes a set of KPIs for energy performance evaluation is designed.
- DO. Also known as the implementation phase, it involves collecting data on the port's energy consumption to better understand the critical issues, in order to ensure an informed decision-making process on energy use in the port that reflects reality. This involves the implementation of the technological and operational measures included into the action plan.
- CHECK. During this phase, paving on the policy defined in the Port Energy Action Plan, the port's relevant and energy-intensive activities, processes and operations are monitored to verify the alignment with the established objectives and targets. This is for measuring the results obtained and reviewing the effectiveness of the policy.
- ACT. From the results obtained in the CHECK, strategic decisions translated into corrective actions, are implemented to ensure the continuous improvement of energy performance of port.

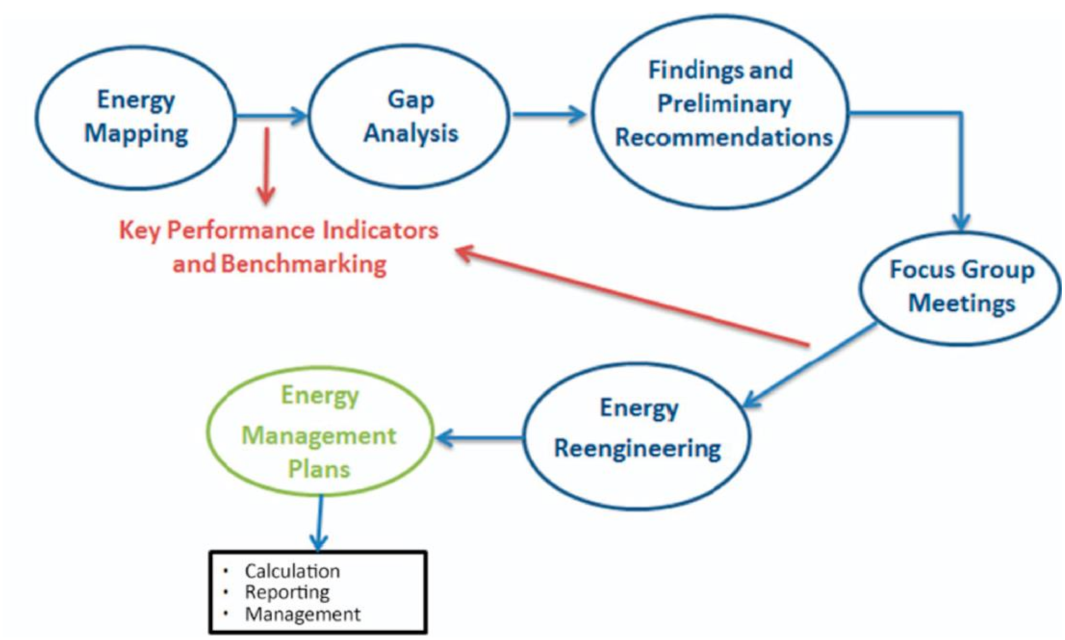
ISO 50001 represents a challenging standard as it requires a systemic, fact-based, and real data-driven process for effectively supporting the continuous improvement of energy performance of ports. As a result, the current rate of adoption of this standard in the port domain is still scares and only few port authorities including Hamburg Port Authority in Germany, Port of Antwerp in Belgium, Port of Felixstowe in the UK, Port of Arica in Chile, Baltic Container Terminal in Poland, Noatum Container Terminal Valencia in Spain, have been certified with the ISO 50001 (Iris & Lam., 2019).

As a result, most ports around the world rely on corporate policies and energy management plans to define their energy efficiency goals and establish related energy frameworks.

3.2.2. Port Energy Management Plans (PeMP)

An increasing number of European Port Authorities have recently introduced energy efficiency programs to reduce their energy consumption. In 2016, 75% of European ports had energy efficiency programs to meet their energy needs. This percentage reached 80% in 2017 and 2018 and has remained stable since 2019 at around 76% (ESPO 2022). Globally this percentage increased for 11% from 65% in 2013 to 76% in 2022 showing the commitment of European port to improve the energy efficiency. By doing so, ports can rely on the PeMP proposed by Boile et al. (2016) (Figure 3.1).

Figure 3. 1: Process for the development of a Port Energy Management Plan



Source: Sdoukopoulos et al. (2019).

The first step consists of mapping the port energy consumption to set the KPIs and benchmark indicators that will serve as the baseline. In this vein, energy efficiency audit schemes, voluntary implemented by ports can be performed to identify the gap. This energy consumption mapping activity follows a three-level top-down approach: analysis, selection and evaluation. In the first level, the overall total energy consumption in terms of electricity, heating/cooling and fuel is analysed. In the second level, the process blocks including operations, support/maintenance functions and buildings are selected, and the associated physical processes are mapped. The third level evaluates the energy consumption for any previously mapped process activity, also considers equipment deployment and time of operation.

Then, the results of this first step of energy mapping led to the second step, i.e. the identification and analysis of the existing gaps, and consequently, targeted recommendations for addressing them are developed. Successively, the recommendations are communicated to port key stakeholders through channels as focus group meetings to reach a clear consensus regarding the necessary actions to be taken in the next phases.

Subsequently, the necessary re-engineering processes are then identified and implemented, and the PeMP is developed selecting the right KPIs as previously mentioned. In this PeMP encompasses the actions to be implemented for improving the energy efficiency of the port, including the respective time bound and the related costs of each actions as well as the person responsible for the implementation.

Given the challenges related to the implementation of the ISO 50001 energy management system standards faced by European ports, this methodology could be used as an intermediate step towards the accreditation of European ports to get closer to these standards. In this perspective, this approach has been applied and tested in several Mediterranean ports including Valencia, Marseille, Livorno, Venice, Koper and Rijeka Ports (Sdoukopoulos et al., 2019).

3.2.3. Environmental Management System (EMS) standards for addressing port energy management.

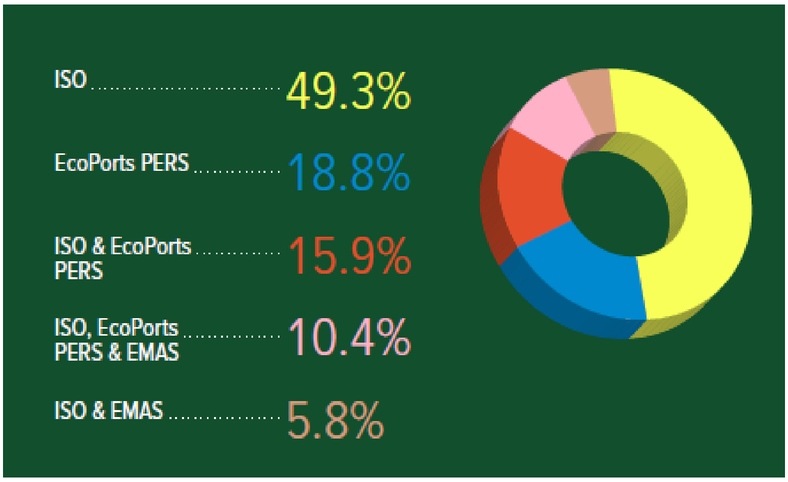
Three major standards for Environmental Management System (EMS) are recognized internationally, namely the Ecoports Port Environmental Review System (PERS), ISO 14001 and Eco-Management and Audit Scheme (EMAS) (ESPO, 2022).

- <u>Port Environmental Review System</u> is recognized to be the only specific international environmental management standard applicable to the port sector. It represents a certification developed by ports for ports and provides the proof of compliance of port to the environmental requirements. It is a voluntary certification, independently audited by Lloyd's Register. A growing number of ports are getting certified with PERS. This unique port-specific environmental standard, in 2022 has been adopted, by 18,8% of surveyed EU ports (Figure 3.2).

- ISO 14001 represents one of the most popular standards adopted in the port sector, according to ESPO (2022). In Europe it is the most adopted standard with 49,28% of port certified in 2022. This standard provides to organizations tools aimed at improving their environmental performance. Specifically, it determines criteria for an environmental management system by mapping out a framework that ports can follow to set up an effective environmental management system. It is also in line with the Plan-Do-Check-Act (PDCA) improvement cycle for guaranteeing a continuous improvement of port energy performance.
- EMAS is a voluntary environmental management instrument developed in 1993 by the European Commission that provides to organizations including ports, tools for effectively assessing, managing, and continuously improving their environmental performance. To register with EMAS, ports have to meet the requirements of the EU EMAS-Regulation. In 2022, it represents the third most adopted standard by European port after ISO 14001 and PERS.

Globally, among 75% of ports authorities with an EMS certification, almost half of them have chosen the ISO 14001 (49,28%), followed by the EcoPorts PERS (18,84%). By coupling the other available standards together with PERS, almost nearly half of surveyed ports (44,9%) are PERS-certified in 2022. As unique international port sector-specific environmental management standard established in the market, EcoPorts PERS is increasingly recognized and promoted in the maritime sector globally. The international quality EMS standard EcoPorts PERS is recognised by important organizations in the maritime and port domain such as ESPO, AAPA, IAPH, WPSP, World Bank (European Investment Bank, and European Bank for Reconstruction & Development), United Nations Environment Programme, African Ports Association, Arab Sea Ports Federation, Taiwan Ports International Corporation and InterAmerican Committee for Ports (Organization of the American States) (ESPO, 2022). Representatives from major insurance companies argue that a port's environmental performance and especially its policy for risk prevention is factored-in for calculating the premiums; therefore, standards such as PERS constitute a responsible approach. This standard is becoming very important insofar as it represents a condition of funding to help the development of ports and terminals.

Figure 3. 2: Percentage of ports holding an EMS certification in 2022



Source: ESPO Environmental Report (2022).

The standards and strategies presented in this section aim to measure the port energy consumption and supply. Thus, a Port energy management plan covers energy consumption analysis as well as energy supply analysis. The port energy management plan aims at improving energy sustainability, reduce carbon emissions, and ensure timely completion of energy related projects within the port. It should be flexible in order to respond in real-time to energy and environmental requirements, and encourage collaboration with stakeholders to improve energy resiliency, availability, reliability, efficiency, and sustainability of the ports. To reach this objective port should have the ability to plan their energy demand and supply accurately. In this vein, the next sections will address models, tools, technologies, instruments for energy demand and supply planning.

3.3. Energy demand planning

Energy demand planning involves forecasting and managing the port energy requirement to ensure a reliable and sustainable supply. The port energy demand represents the energy requirements needed to carry out port activities. However, it is subject to some issues such as uncertainties due to sudden changes in energy demand which can lead to forecast errors as capacity shortage, poor reliability and instable system. Despite the efforts to address these uncertainties related to the sudden change in energy demand by increasing energy production, the issues of system reliability and stability still persist. This situation arises from the inherent discrepancy between the pace of growth in energy demand and the ability of production capacity to keep up, resulting in occasional failures to meet demand. For these reasons, the port's energy demand needs to be planned as accurately as possible. For this purpose, ports should ineluctably measure their energy consumption. Indeed, if port authorities don't have an historical data on port energy consumption, the energy demand planning remains a great challenge. Specifically, in front of a lack of proper information on the energy consumption, it will be very difficult to identify which operation, equipment or area requires greater attention in terms of business process management or re-engineering related to energy consuming activities or specific actions/interventions. In contrast, if energy consumption is properly measured on a daily basis, several benefits can emerge including cheaper energy purchase prices, better plan of energy demand in order to make port activities more efficient. As a result, the port's energy requirements can be more realistically predicted and managed. According to Akpahou et al. (2024) energy planning models are thoroughly developed using different computer-based energy modelling tools. In this perspective, in the next subsections the most established methods for energy demand modelling as well as the most innovative technical solutions available in the market, are introduced and discussed including:

i) Statistical techniques,
ii) Machine learning (ML),
iii) Metaheuristic methods,
iv) Stochastic/fuzzy/grey,
v) Engineering-based methods.

3.3.1. Statistical Techniques

This category includes regression and time series analysis (TSA) methods (Friedlingstein & Solomon 2005; Debnath & Mourshed, 2018). These methods have a prove application in econometrics to study the correlation between energy demand and economic development (Ha-Duong et al., 1997).

Regression analysis is used to estimate the relationships between a dependent variable (also known as outcome or response variable) and a unique or several independent variables (also known predictors, covariates, explanatory variables or features). Verwiebe et al. (2021) provides some statistical regression methods for energy demand planning including linear, nonlinear, logistic, quantile, and ridge regression. However, there also exist non statistical techniques for non-parametric regression especially machine learning (ML) techniques, such as artificial neural networks (ANN), kernel regression, or regression trees based of data for deriving the functional form and regression parameters (Zhang et al., 2009; Meng & Niu, 2011).

Time series analysis (TSA) uses a historic time series such as historical energy consumption data to derive forecasts and predictions. Many TSA methods represent regression models as the predicted value is estimated grounding on one or several previous values. This category includes univariate time series models such as autoregressive moving average (ARMA) models, autoregressive integrated moving average (ARIMA) models for non-stationary time series, seasonal autoregressive integrated moving average (SARIMA) models for seasonality, and ARMA models with exogenous variables (ARMAX) (Ekonomou, 2010). This category also considers vector auto-regression (Tso & Yau 2007), exponential smoothing models and ARCH techniques (Debnath & Mourshed, 2018).

TSA plays a pivotal role in energy forecasting and planning. It analyses historical energy data over time of the port with the aim to identify patterns, trends, and seasonality related to the port energy consumption. Then, factors such as weather conditions, economic indicators, and historical energy usage are considered as input in order to create accurate and efficient predictions for better port energy planning and management. Port energy planners can used innovative TS to improve energy efficiency, reliability, and sustainability of port operations.

3.3.2. Machine Learning Techniques

Machine learning techniques are widely used for energy demand modelling and forecasting. It can be divided into supervised and unsupervised learning methods.

Supervised learning method relies on labelled training datasets which aims to derive a function that describes a relation between inputs and outputs based on examples of input-output pairs (Russell & Norvig, 2010). The application of this method depends on the type of problem and the variable to which it is applied. For regression problems it can be applied to numerical variables while for classification problems it is applied to categorical variables. This group also incorporates other methods such as decision trees, Bayesian algorithms, and ensemble learning approaches, such as gradient boosting machines (Hong & Fan 2016).

Regarding unsupervised learning methods, they are usually applied to clustering problems, in which specific algorithms are used to deduce structures in a set unlabelled of input data such as similarities finding (Brownlee, 2016).

Machine learning plays a breakthrough role in the energy demand planning of ports and offer a range of applications that can enhance efficiency, reliability, and sustainability of port activities such as:

- Energy Demand Prediction: By monitoring changes in the port's energy consumption, machine learning can accurately predict the port's energy demand and optimise energy production, thereby achieving energy efficiency and cost reduction.
- Predictive Maintenance: By analysing historical and real-time data on the port's energy consumption, machine learning algorithms predict potential equipment failures, enabling timely maintenance and reducing downtime of the port's energy system.
- Managing port energy system: machine learning balance power generation and demand of port, especially for renewable energy system, for improving durability and stability of the energy system.

3.3.3. Metaheuristic Techniques

In energy demand planning, optimization problem is a big challenge to solve. Metaheuristic techniques are identified in the established academic literature as a valuable option to solve optimization problems including energy demand planning problems. Fallah et al. (2018) argue that this technique can be included into other techniques to strengthen performance. This category includes algorithms that study evolution, in other words, algorithms that emulate mechanisms inspired by biological processes, such as reproduction, mutation, recombination, and selection (Verwiebe et al., 2021). It encompasses particle swarm optimization, bee colony optimization, firefly algorithms, genetic algorithms (Tzanetos & Dounias, 2019).

Metaheuristic techniques can significantly contribute to the port energy demand planning, enabling port authorities to make conscious decisions and improve forecasting accuracy. These techniques efficiently explore space of improvement in the port energy system in order to find near-optimal solutions. They are customizable, since the algorithms can be adapted to specific energy system problems. This is valuable for ports energy demand planning due to the different changing conditions in which port operate.

In order to face the increasing energy requirements, ports can develop hybrid energy system by using the national energy network together with renewable energy. But this hybrid model brings some issues such as uncertainty related to renewable energy. To solve such issue metaheuristic and uncertainty techniques can be integrated into hybrid models in order to combine the strengths of different systems to enhance accuracy and robustness of the hybrid model. This integration helps ports to reduce reliance on fossil fuels and fosters sustainable energy generation. The hybrid model aims at optimizing the port energy system efficiency, reliability, and sustainability by considering factors like technical feasibility, environmental impact, and economic viability.

3.3.4. Stochastic, Fuzzy and Grey Systems Theory Techniques

Port energy demand planning also depends on several factors, such as climate variables, climate change and its uncertainties. These factors can deeply influence the outcomes of port energy demand planning. In addition, port energy systems with high shares of renewable energies are thereby especially vulnerable to changing climate conditions. In order to assess the changing climate and its uncertainties in port energy system modelling these techniques can be used. According to Zimmermann (2000), uncertainty in a decision logic context consists of a situation in which decision-makers have no information about the possible states of nature that will occur. He distinguishes several uncertainty methods including the probability theory that describes the randomness of the occurrence of an event, and the fuzzy set theories that describes an event's ambiguity (i.e., the extent to which an event occurs).

Indeed, probability theory serve to describe stochastic problem where future in a system is characterized by past states and a random change. When it comes to the energy demand modelling, Markov chains are example of stochastic process used to forecast and simulate the load profiles (Duan et al., 2019; Verwiebe et al., 2021).

Fuzzy set theories are used in the fuzzy time series form (Ismail et al., 2015), fuzzy regression models (Hong & Fan, 2016), fuzzy clustering (Laouafi et al, 2016), and adaptive neuro-fuzzy interference systems (ANFIS) (Mollaiy-Berneti, 2016).

3.3.5. Engineering-Based Techniques

According to Verwiebe et al. (2021), these techniques follow a bottom-up approach and use a set of external and internal parameters to scrutinize and describe in a detailed manned the energy consumption patterns of a specific energy system (Bhattacharyya & Timilsina 2009; Fallah et al. 2018). Engineering-based models useful for planning and designing of technical systems such as port energy system, since they are able to simulate a system's behavior under conditions, for which little historical data has been recorded. As energy consumption of port also depends on season and weather, geographic information systems (GIS) are an example of engineering-based technique for demand planning in a system (Domínguez & Amador, 2007). GIS can be used to visualize and map the energy consumption in the system. These techniques are considered very promising innovative solutions which will be capable in the next years to strengthen the inclusion of demand-side management strategies in energy demand planning Sancho-Tomás et al., 2017; Ye et al., 2019).

3.3.6. Demand-side management strategies.

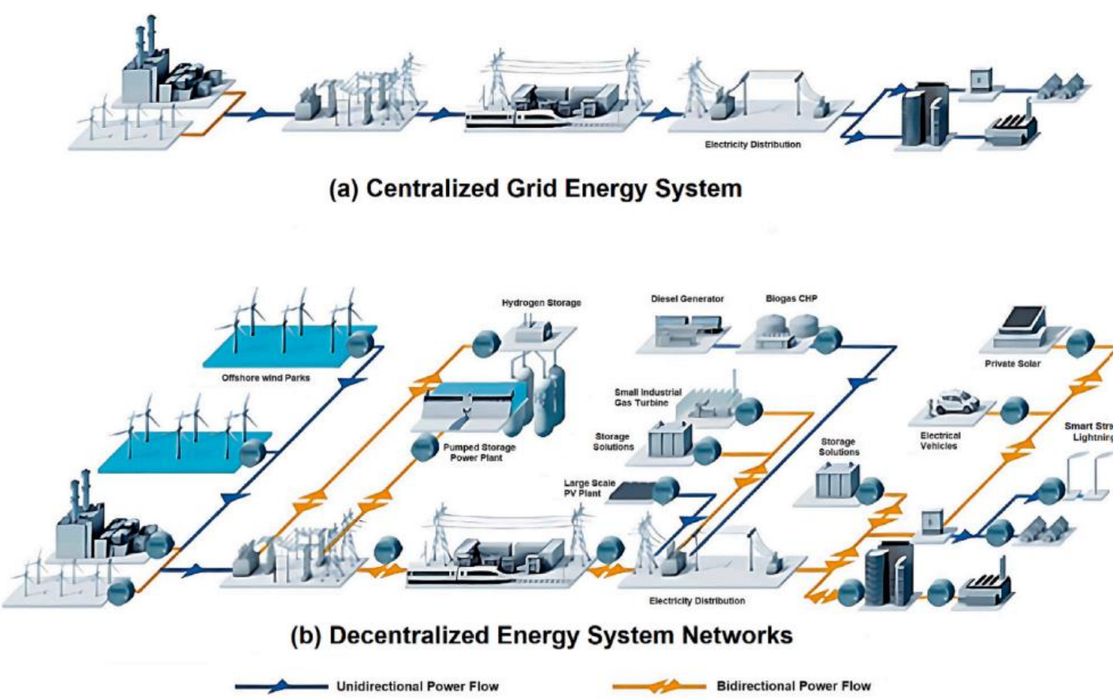
For a long time, energy management systems were focused only on the production side management. However, despite the efforts to address the issues of the sudden change in energy demand such as production increasing, the issue of system reliability and stability always persists. This is due to the fact that increase in production capacity cannot always match the speed of growth and change in demand and sometimes production fails to meet demand. For these reasons, current energy systems are introducing flexible demand-side management and control to guarantee the stability and the reliability of the system (Mohammadi et al., 2017). In this perspective, energy demand management for the prediction of demand and consumption patterns becomes a core element for ensuring optimal allocation of energy resources. Due to the characteristics of ports as multi energy systems, it is fundamental to use a generalized form of demand side management. This generalized form called integrated energy demand side management (IDSM) considers programs for optimal demand scheduling through the optimal use of different energy carriers, energy conversion, and storage technologies.

3.4. Energy supply planning

Energy supply planning consists of finding a set of energy source, conversion and storage equipment to optimally meet the energy demand. However, energy supply planning remains a great challenge for port, especially when ports face sudden increases in energy demand. Relatedly, the introduction of new technical and technological solution for improving the management of supply planning activities is urged within the port domain. This implies the use of renewable energy technologies and the use of distributed energy systems (DESs).

In this perspective, to meet their energy demand, ports are increasingly using distributed energy system based on RES (Hiremath et al., 2007). In DESs configuration, energy production plants are located close to the consumption site. DESs can be used in two different configurations: i) grid-connected configuration where DES is used as a measure to support the existing centralized energy system based on a bidirectional power flow arrangement (in this configuration, the DES can feed the grid with the potential energy surplus); ii) off-grid configuration, which has no connection to the central grid (Figure 3.3).

Figure 3.3: Centralized vs decentralized energy system.



Source: Nadeem et al. (2023).

The location of the energy production close to the consumption site presents several advantages such as:

- The reduction of pollution by using clean energy for carrying out port activities.

- The cost-effective supply of energy, as the energy is produced locally, accordingly lead to the reduction or the elimination transmission and distribution costs.
- The increase of energy efficiency in the system.
- The supply of clean energy through renewable energy production.
- The reduction of peak load demand of the port by supporting the central grid.
- The improvement of energy security in the port.
- The reduction of high maintenance costs for the replacement of transmission and distribution systems.
- The creation of a better resilience against natural disasters including floods and storms.

However, DESs also bring several issues including:

- The intermittency of renewable energies, so grid stability can be negatively affected.
- Energy quality issues in terms of grid connectivity, especially in the case of renewable-based systems.

In DESs renewable energy sources together with energy conversion and storage systems are used in order to provide all the expected benefits. Renewable technologies consist of solar energy, wind power, hydropower, bioenergy, geothermal energy, and wave & tidal power…ect. Renewable energy systems produce electrical energy and thermal energy and need conversion and storage systems to guarantee the flexibility and the reliability of the system due to their intermittent nature. Electrical energy can be produced using solar PV, wind turbines, biomass energy, hydroelectric power, geothermal, fuel cell, wave energy and tidal energy, while thermal energy can be generated through solar thermal heaters, biomass fuels, geothermal energy and fuel cells. Other technologies that can be used in DES include internal combustion engine, combined heat and power, combined cooling, heating and power, gas turbines, micro-turbines, and fuel cells.

In energy supply planning, the coupling between strategic and operating decisions is still difficult to figure out. Coupling strategic and operational decision creates a multi-scale problem to be solve. Therefore, the port energy planning need to be as precise as possible given the growing use of intermittent energy resources like wind turbines and solar panels in the port domain. In addition, energy supply planning is characterized by different type of uncertainties including the uncertainty of energy demands and feedstock supplies, the uncertainty of technologies' costs as some technologies still present a very low TRL, limiting the availability of data and information related to economic and financial performances as well as other technical and operational dimensions.

Globally, energy supply planning is complex and generally involve multiple decision-making processes and criteria. In addition, the uncertainty that characterizes energy demand and the entire planning process, creates the need of decision support systems (DSSs) for enabling automatic and rapid information processing. Accordingly, the utilization of computers programs based on mathematical methods result to be a great solution to tackle the uncertainty (Hiremath et al., 2007).

According to Rojas-Zerpa and Yusta (2014), the modelling of energy supply systems is a multidimensional problem, mathematically expressed as a multi-criteria and multi-objective problem. These authors identified seven categories of mathematical models for energy supply planning: Linear Programming, Multi-Criteria Decision Making (MCDM), Multi-Objective Programming, Non- Linear Programming, Dynamic Programming, Enumerative Optimisation and other such as Life cycle cost analysis.

MCDM are widely used in decentralized energy supply planning as they ensure better results during the energy supply systems planning process. In addition, this methodology provides several advantages when the energy supply planning problem is directly related to the assignment of energy resources, the choice of technologies, the determination of an energy supply mix configuration as in the case of ports.

So, for a good energy planning, port authorities need to find a good solution for balancing strategic and operational decisions, must stay tuned on incoming policy on energy in order better evaluate the benefits and the challenges of new energy policies, and innovative mathematical methods and technologies as distributed energy system (DES) and smart energy management systems have to be used for a better balancing of energy demand and supply.

3.5. Smart energy management system for an optimal supply-demand connection

Smart energy management system (SEMS) represents computer-based system developed for monitoring, controlling, measuring, and optimizing energy consumption by increasing communication between port energy consumers and energy suppliers (Barberis et al., 2016; Mohammadi et al., 2017). In this vein, Iris et Lam (2019), in particular, propose 4 pillars for smart energy management systems, namely:

i. Energy supply management which encompasses on-site renewable energy generation, combined heat and power, grid and other technologies form port energy supply.
ii. Energy demand management that adopts real-time energy consumption measurement, electrified equipment, and onshore power supply to increasing the energy efficiency of ports.
iii. Energy storage capacity such as batteries. An optimal sizing of the energy storage capacity allows a short-term balancing of energy which leads to a smart operation of energy reserves. It also increases the port energy system flexibility and stability, reduces or defers investment in new transmission and distribution lines and allows long-term energy storage and system restoration after blackouts.
iv. Optimal management and communication of the active resources via tools as optimization methods, load diagram control, peak shaving, utilization management in the grid.

SEMS include among others microgrids and smart grids, are used for balancing energy supply and energy demand in a smart and optimized manner, grounding on innovative technologies.

3.5.1. Micro grid

A microgrid represents a decentralized electricity system, designed to operate in a limited community area. This SEMS can work autonomously in island mode (i.e. power plants operate in isolation from the national or local electricity distribution network) and take two forms:

i. the "stand-alone form”, where there is no connection with the electricity grid;
ii. the “connected form”, where a connection exists with the electricity grid in parallel mode and can be used as a backup power system during grid repairs or other emergencies that lead to widespread power outages.

Based on the latter form (connected form), microgrid can increase the electricity supply security of ports due to its ability to change the powers between the island and connected modes. Microgrids are the best source of local energy where the transmission is centralized.

Since many ports around the world have centralized energy transmission (German-Galkin & Tarnapowicz, 2020), microgrids can be a good starting point for reducing environmental concerns while increasing the quality of energy supply service. According to Parise et al. (2015) microgrid promotes higher levels of:

- Energy efficiency of the grid, due to consideration of the losses of the system.
- Load diagram control by considering energy management strategies such as utilization management, load shedding, storage management, advanced drive system for the port cranes in order to optimize the energy absorptions, etc..
- Energy quality through safety and emergency supply.
- Safety in the system due to the guarantee of the energy supply service continuity, distribution with nontraditional voltage levels, the use of TN systems with local transformers toward a global grounding system.

3.5.2. Smart grid

Contrary to microgrid, smart grid is a large-scale power supply network designed to operate on large community power supply technology. The smart grid is an electric grid that has various operations and energy measures. This system provides power through two-way digital communication, where two or several parties exchange data, messages, or other kinds of communication. It is digital-based technology and helps to analyse, control, and monitor communications. This kind of system is extremely important for ports as they can operate within the entire supply chain and improves efficiency effectively. It can lower the cost and maximize the transparency of the supply chain.

The primary goal of the smart grid is to maximize the throughput of the electricity system with reduced energy sources (Guerrero et al., 2014). Energy-saving, fraud detection, better customer service, and reduced cost are some benefits of the smart grid (Hamilton & Summy 2010). Smart grid offers a port-grid integrated platform that include:

- Electricity grid technologies. Smart grid includes relevant aspects such as electronic power conditioning and control of production.
- Sensor technologies used for implementing the sensors in the port domain for detecting and responding to physical stimuli such as motion, temperature, pressure, light, sound…ect.
- The smart grid has self-healing properties as it can detect, act, and react to problems occurring within the system, showing its capacity to solve multiple issues contemporaneously.

- Advanced smart meters that use fiber optic routers to increase efficiency and to measure power consumption of port activities.
- Real-time monitoring systems for continuously tracking and recording the performance of the energy system.
- Control tools, battery technologies, and communication technologies. The data flow in the smart grid happens through digital communication technology.

Moreover, Liang et al. (2014) propose a roadmap for a smart grid project in ports which consists of the initial stage and the installation stage. The initial stage includes the analysis of load equipment, the analysis of the smart grid scenario, energy balancing, and benefits analysis. While the installation stage encompasses the renewable energy sources analysis and the assessment of their daily fluctuations, the optimization of peak shaving and demand response planning, the energy storage planning and the management of tariffs and costs.

Globally, smart energy management systems for an optimal supply-demand connection brings several benefits in port energy systems including the use of renewable energy source, the increase of energy efficiency, the reduction of cost...ect. However, these information systems can be combined with operational strategies to optimise the port energy system. The next section presents some operational strategies for port energy efficiency.

3.6. Operational strategies for energy efficiency in port energy management system

According to Iris & Lam (2019), the operational strategies include methods that aim to reduce energy consumption of port equipment, lower the time for processing port operations, use non-peak hours for operating equipment, and use energy price to optimize operations.

3.6.1. Energy-aware optimization of port operations

The operational efficiency of a port depends on their capability to efficiently manage the energy resources. By reducing the duration of day-by-day berth or yard operations, such as ship turnaround times and container transport time in the yard, for example, ports can increase their energy efficiency. When it comes to the efficient usage of energy, the energy-aware planning become a valuable solution for energy consumption optimization. In fact, it is formulated as a mathematical model that uses energy consumption as the objective function. The functional areas of the port where these models are applied include quayside, yard side and landside.

The energy-aware optimization of the quayside resources such as berths or quay crane, the integrated berth allocation and the solution of the quay crane assignment problem can be formulated by using the energy consumption of quay crane as the objective function (Chang et al., 2010). In this vein, the research objective is to find an optimal solution considering the energy consumption and lateness costs of operations. Another mathematical problem can consist of the trade-off between time saving and energy-saving in quay crane operations. This problem includes the working energy consumption and non-working energy consumption of quay cranes. The working energy consumption regards the number of moves per hour and the energy consumption during loading and unloading. While the non-working energy consumption is function of auxiliary units and illuminations.

In the yard side, the planning is mainly about the transport and containers stacking. Yard allocation problem and yard handling equipment planning are examples of some problems solved in an energy-aware perspective. In the study presented by Sha et al. (2017), these problems include vehicle routing problem, and they argue that in such problem, the energy-savings can increase of about 25.6% for all yard crane compared to the practical results. It results that the energy-aware scheduling of yard crane prioritizes positions in the same line.

Another problem for energy-aware optimization regards the predictive model problem developed in automated container terminals. This method aims to balance the throughput and energy consumption of each quay crane with automated guided vehicle and automated stacking crane (Xin et al., 2013). A hybrid automation representation is used to simulate the discrete-event and continuous-time dynamics. The suggested method obtains the same makespan with less energy consumption since the method allows vehicles to slow down in the yard.

A different energy-aware optimization problem for port operations that has been demonstrated to reduce energy consumptions refers to the integrated scheduling of quay cranes, yard trucks and yard crane, small shifts of truck arrival times, and the efficient scheduling of waterborne automated guided vehicle for the inter-terminal cargo routing

(Iris & Lam, 2019). Besides energy-aware optimization of port operations, peak shaving represents another operational strategy for energy efficiency in port.

3.6.2. Peak energy demand management

Electrification is becoming more popular in the port domain due to its capability to reduce emissions derived from port operations. Accordingly, ports are increasing the number of new equipment that use electricity as an energy source. To reduce their electricity consumption, ports can also use peak energy demand management. Indeed, peak energy demand management is considered a key aspect for energy conservation and cost reduction. It involves managing energy usage during peak hours of the day to reduce energy costs (Parise et al., 2016). Various methods can be used to manage peak energy demand and consequently reduced port energy consumption:

- Peak shaving or load shedding: which consists of turning off non-critical loads during peak periods for reducing energy consumption. This strategy can be implemented through time-based pricing, where energy companies can offer a lower electricity rate during different times of the day, in order to encourage ports to shift their usage to off-peak hours when electricity is less expensive.
- Power sharing: this method consists of using an energy storage during peak energy demand periods.
- Load shifting: which is a method where the energy demand is shifted from peak periods to non-peak periods, through demand response programs for example.

As quay cranes consume a huge amount of electricity in the port, limiting the number of quaycranes lifting at the same time allow to reduce the energy consumption of the ports. According to Geerlings et al. (2018) the synchronization of the quaycranes by not to lifting all of them at the same moment lowers the peak electricity demand even if the average processing and waiting times increase.

Parise et al. (2016) analyse a peak shaving for quay crane considering double hoist and twin lift technologies. For peak shaving, they suggested two keys technological and operational tools, namely the coordination of cranes work cycles which include a power optimization tool and an energy storage system. They concluded that simple postponement for 21 s between the start time for each quay crane during loading and unloading cycle leads to peak energy demand reduction of about 4.38 MW compared to traditional mode of operation without postponement. In addition, the energy stored can be used in the peak periods and can lead to the further reduction of the peak energy demand to about 2.63MW.

Regarding the refer containers terminal, two peak shaving solutions, namely intermitted distribution of electricity between reefer batches and limited allowance on the electricity consumption for reefer batches, result to be viable solution for increasing the energy efficiency of the terminal (van Duin et al., 2018). The former method can lead to a reduction of peak energy demand for reefers of about 62.8%, while the latter method can lead to a peak demand reduction of about 7.2%.

Overall, the theoretical lens introduced and discussed in the Chapter has allowed to disentangle the various aspects of energy management (i.e., energy demand and production planning, smart energy system, energy storage, energy optimization) in ports, grounding predominantly on the "energy hub" perspective for identifying and mapping the synergies stemming from different energy carriers coupling a "non-hierarchical" structure with an integrated management of the different energy infrastructures. As multi-energy systems, ports integrate different types of energy generation and energy transformation technologies that can be used to improve the energy efficiency of port operations. Combining these systems as a network and creating an exchange energy between them provides both financial and environmental efficiency benefits and increase the reliability of the system (Maroufmashat et al., 2015). In addition, active energy management has been demonstrated to provide substantial efficiency gains, contribute to the development of alternative revenue sources and improve the port competitiveness (Acciaro et al., 2014).

In this perspective, by acting as key promoter and designer of the port energy management through the planning, regulation and monitoring of the energy consumption within the port, port authorities could reduce their energy costs, increase energy efficiency and competitiveness and reach the environmental, economic and financial sustainability. In this function the port authority aims to improve energy efficiency through the evaluation of the energy consumption and the implementation of new policies and changes where necessary. By doing so, as argued by Acciaro et al. (2014) port authorities are expected to positively contribute to the introduction and development of port energy management system with several task aimed at coordinating all aspects of energy management, from energy efficiency and reduction of the GHG emission of the port to waste management as well as sustainable development through: i) the introduction of solutions for carbon management, ii) the promotion of energy conservation practices, iii) and the promotion of the use of renewable energy resources within an organisation or community.

Ports have been argued to represent effective location for energy production, where energy generation facilities operated by third parties, particularly public or private energy companies can be implemented. However, this situation could further evolve when the energy transition path of ports will come to a more mature stage. Relatedly, ports are urged to play a more strategic role within the respective regional energy systems, acting as energy generation and distribution platforms and using their energy hub features to move towards renewable energy communities.

In this perspective, the following Chapter 4 discusses the applicability of the renewable energy community to ports, with a focus on the business model.

CHAPTER 4

INTRODUCTION TO PORT RENEWABLE ENERGY COMMUNITY

4.1. Introduction

According to the European Commission, 2020, by 2050, at least 75% of the energy demand produced in Europe should come from renewable sources, and about 16% of the electricity generation should derive from collective projects. To achieve these ambitious goals Rae and Bradley (2012) propose a structural transformation of the energy sector as an effective solution. This transformation consists of moving away from the centralised energy system towards decentralised systems based on renewable sources, in which citizens are directly and actively involved in the activities of energy consumption, generation, trade and supply. These decentralized energy systems well known as renewable energy communities (RECs) are considered by Koirala et al. (2018) and Lowitzsch et al. (2020), as a cornerstone for achieving the urgent goals dictated by the energy transition process taking place in Europe. Indeed, RECs have the capacity to transform the energy landscape by empowering consumers and contributing to energy and climate targets in terms of demand for renewable energy and emissions reductions.

Furthermore, these new energy models foster a collaborative social transformation engaging local communities to pursue common goals such as energy costs reduction and energy self-sufficiency, also playing a key role in supporting local economy growth and job creation.

The commitment of the local community also includes taking private financing into account. This implies changing the structure of European energy policies from entirely incentive-based programmes to the promotion and use of private finance, without which the objectives of energy transition will be difficult to achieve (Reis et al., 2021).

In this vein, after a long regulatory vacuum, REC has been assessed and regulated in Europe by the Clean Energy for all Europeans Package through the Renewable Energy Directive (RED II 2018/2001), and Internal Energy Market Directive (IEMD 2019/944). The new directive (RED II 2018/2001), in particular, provides a regulatory framework for “renewable energy communities”. This directive defines “renewable energy community”, as non-commercial legal entity, built on the open and voluntary participation of their members (e.g., households, public authorities, and small and medium-sized enterprises), provided that their main activity is not energy-related (European Commission, 2018). Following this definition, community members can be fully or partially involved in day-to-day decision-making and control of operations, and any potential income generated may be used to provide local services. This definition highlights four main characteristics of RECs:

- **The geographical scope**. RECs require participants to be close to place where the renewable energy projects are developed. Thus, the RED II directive promotes the energy community of place model.
- **The activities performed.** REC activities include the engagement of the community members into generation, trading, storage, and supply of energy from renewable sources. Thus, in addition to environmental benefits, socio-economic benefits are one of the main objectives of the RECs, while economic and financial benefits are a secondary.
- **The generation technologies**. RECs intend to use technologies that foster the renewable production, consumption, conversion, and storage. So, these technologies aim to increase the stability and flexibility of the energy system in the REC.
- **The membership rules.** The core business of the members should not be related to energy. The directive promotes the active engagement of the energy community participants.

Indeed, RECs aim to support the deployment of renewable energy resources. Relatedly, various EU Member States have started the institutional and legal pattern aimed at transposing the (RED II 2018/2001), and IEMD 2019/944 into national laws. Each Member State has the task to shape the aforementioned directives according to national realities and to ensure that the key conditions for developing energy communities are met by facing the current regulatory, technical and financial barriers. For example, in Italy, an early and partial transposition of the RED II directive took place in 2020 with the publication of the necessary acts to define the legislation, incentive mechanisms and regulation of tariffs to be applied to RECs and collective self-consumption schemes. This transposition process was completed in 2022 through the conversion into law of the “Milleproroghe” Decree 162/2019, which in the broader discussion on the transposition of the RED II and IEM directives, identifies the objective of RECs which is to provide economic, financial benefits to investors and provide environmental and socio-economic benefits to the local community.

In this perspective, the enabling framework promoted by the RED II is expected to boost the creation of innovative business models and attract private and public investments, giving the opportunity to energy communities to diversify their revenue streams through the supply of new energy services in addition to local energy generation (Reis et al., 2021).

However, the definition of REC provided by the EU Commission in the RED II, seems rather vague, with regards to both the conceptual framework and the concrete implementation tools available for the EU Member States, bringing the risk of missing the sustainable community development and energy democracy goals targeted. Therefore, there is a need of a trade-off solution able to customize the broad definitions of REC provided by RED II to specific contexts (through the definition of the actors, the legal structure, the activities, the scale, etc.) and motivations (by identifying the main beneficiaries of the project and the functioning).

A specific context for REC application is the port domain. Indeed, for carrying out their activities, ports consume a lot of energy, thus generating harmful emissions which negatively impact the environment. To reduce their negative spillovers, ports are urged to start at least partially produce the consumed energy grounding on renewable energy sources and to progressively turn into innovative energy hub. By this way they are expected to put the bases for their transformation into energy community and positioning themselves as pioneers in the energy transition process.

As energy hubs, ports can easily become an effective location for energy production. Therefore, ports are requested to play a strategic role within their respective regional energy systems, acting as energy generation and distribution platforms and finally moving from energy hubs to renewable energy communities.

In this chapter the planning stage and the management of port renewable energy community (PREC) is presented to stress the vision that drives the implementation of PREC, then, the main features of renewable energy communities are analysed for understanding the components provided by the RED II directives. Finally, the different type of renewable energy community models applicable to ports are stressed, as well as the main benefits and challenges of renewable energy community.

4.2. The planning stage and the port renewable energy community management

As humans began to create permanent settlements, planning became essential (Mumford, 1961). As REC represents a form of settlement, planning activities are fundamental. These settlement patterns of REC are driven by several variables, including the physical geography of the area, the related climatic conditions, the construction materials, and especially the general purpose or need that guided the creation of a settlement. As a concept under development, the REC planning stage should consider the long-term goals of the community and if possible, anticipate the changes in external conditions (e.g., climatic conditions).

As ports represent multi-energy systems, where several energy loads including electricity, heating and fuel are consumed, the planning stage of PREC represents a multi objective problem where it is necessary to take into account trade-offs between the different objectives and reach a good overall solution. Tomin et al. (2022) proposed a multi criteria methodology for planning and managing energy communities. This methodology is applied to a network of microgrids of an energy community. Therefore, this methodology can also be extended to ports, given their microgrid quality.

In this vein the planning, and management of PREC is based on 5 steps:

i. The first step consists of describing the current and prospective social and economic conditions for the development of the port and the related supply chain. Based on the results of the analysis, the composition of current and future consumers is defined, then the calculation of electrical load, heat load and fuel load for each consumer is carried out. In addition, for determining the composition of possible energy sources of the PREC, an analysis of renewable energy resources is carried out. Moreover, as the build-up of the PREC is expected to be gradual and it is not possible to achieve a fully based renewable energy system in the blink of an eye, the analysis should include the use of the national grid (electricity and gas) to ensure system stability and tackle the uncertainty that characterises renewable energy resources. The assessment of solutions for reducing the dependence from the national grid such as energy conversion and storage system is always carried out in this step. Finally, a scenario analysis is carried out for the development of the PREC to ensure that the objectives relevant to the key stakeholders are achieved.

ii. The second step in the planning stage is to develop the PREC computer-based configurations. Many software such as HOMER Pro, iHOGA, RETScreen, Hybrid2, INSEL, TRNSYS can be used (Ram et al., 2022). HOMER Pro is the most used software for a single criteria optimization problem. As HOMER Pro performs single-criteria optimization, it does not well fit to PREC, thus it is necessary to adopt multi-criteria software for simulating energy systems that operate under uncertainties such as Fuzzy-AHP, Fuzzy-TOPSIS (Odoi-Yorke et al., 2022; Liu et al., 2022).

iii. In the third step, based on the port key stakeholder preferences (such as terminal operators, port users, shipping companies), a multi-criteria evaluation of PREC configurations can be performed under conditions of uncertainty. This analysis can be carried out using the multi-attribute value theory (MAVT). This method is suitable for PREC as it can be modified to consider for uncertainty of renewable energy resources (Aguayo et al., 2014). Tomin et al., (2022) proposed a new modification of the MAVT method, for using interval estimates for decision makers' answers. They argued that interval estimates are the most convenient for key stakeholders in problems that include a long planning horizon where there is a lack of data for assigning event probabilities. And the multi-criteria interval assessments can be used for determining the PREC configurations that are most appropriate for the scenarios under consideration i.e., the economic scenario which aims to design an energy community with the highest technical and economic efficiency, the environmental scenario which aims to reduce environmental impact while ensuring technical efficiency. And the balanced scenario which combines both the economic and environmental scenarios.

iv. The fourth step aims at evaluating the effectiveness of the scenario that fit well with the object of the PREC. For this purpose, a bi-level "energy community operator" model developed in the Python software environment can be used typically recommended (Tomin et al., 2022). To maximize the social welfare in the PREC, The Monte-Carlo Tree Search (MCTS) can be used to find the optimal strategy for managing PREC in a multi-criteria environment.

v. In the fifth step, the implemented bi-level model of the "energy community operator" for the selected scenario is finalized with the aim to a real implementation.

Globally, for implementing a PREC, it is fundamental to make first a virtual simulation, before performing the real implementation. In addition, theses five steps represent only a guideline and could be modified according to each case.

Ports are different and there is not a global, unified approach to the construction of PRECs. In addition, the architectural and technical configuration of PREC depends on geographical location, climatic factors, the port supply chain, and the type of industries developed around the port. The geographical features are fundamental as they allow to determine the composition of the renewable energy sources and the related technologies suitable (e.g., wind and solar energy produced from wind turbines and photovoltaic panels) to develop the PREC. In addition to the technical perspective of the PREC, it is crucial to address the business perspective underlying the development of the PREC.

4.3. Energy communities along with a business perspective: main features

The business perspective of PREC aims to describe how the PREC operates in term of activities and processes, what is involved in these processes, where the PREC has a presence in term of location, and which actors interact with the PREC activities and with which roles. In this vein, Kubli & Puranik (2023) proposed five critical features of energy communities considering a business perspective which can also be applied to PREC.

Outside-in approach: Based on the RED II and the IEMD directives, the core goal of energy communities is to solve energy-related problems and provide environmental, economic, and social benefits to the community. The focus is not on profit making but on enhancing the prosperity of local communities (Berka & Creamer, 2018). This is in contrast with the classical business model innovation literature, where the aim of companies is constantly innovating their business model for maximising profit for themselves and meeting customer needs (Gassmann et al., 2014).

While traditional business models follow an "inside-out perspective," energy communities follow an "outside-in perspective" for addressing needs that are relevant for society and the planet. This approach typical applies to sustainable businesses (Dyllick & Muff, 2016) and can be easily applied to PREC.

The community: The prosumer approach is applied since the community includes the operator and consumer in the business model together. Meaning that energy consumers play an active role in the energy system due to the combination of energy consumption and production into one entity. Various actors can be part of PREC ranging from port supply chain actors such as shipping companies, terminal operators, port users and concessionaires to local community and societal groups of interests. Therefore, a net positive value proposition should exist in order to obtain the individual willingness to participate port key stakeholders. This is a challenging task due to wide heterogeneity of interests the PREC participants.

Co-benefits exploitation: As an energy hub based on multi energy system, PREC provides a connection and cross-optimization of different energy carriers on the demand and supply sides. Therefore, a successful business model for PREC must focus on exploiting the co-benefits between these services, rather than providing a single service (Lowitzsch et al., 2020).

Multi-sided platforms: PREC functions like multisided platforms due to its ability to create value for the community through direct interaction between PREC participants. Indeed, the prosumer approach that characterises PREC ensures a certain and direct interaction between producers and consumers. Therefore, further functions may be fulfilled by the providers of storage, platforms, or further facilitating features. In multisided platforms the value to customers on one side of a platform is expected to increase with the number of participating customers on another side. As a result, the challenges such as the number of sides to bring on board, the design, the pricing structures, and governance rules must be approached with a maximum precision.

Direct network effects: As a multi-sided platform, PREC creates network effects throughout the community. These network effects also known as network externality or demand-side economies of scale represent a situation where the utility or the value for the user of a product or service depends on the number of other users or complementary products (Katz & Shapiro, 1994). Thus, the benefits for communities' members tend to increase with the size of the community (Hagiu, 2014). In this perspective, a "direct network effect" is expected to have a prominent impact on the business model of PREC. These direct network effects will increase as the size of the PREC increases, leading to a growth in the number of services and access revenue streams.

4.4. Types of renewable energy community business model: the archetypes

According to Amshoff et al., (2015) business model innovation tools, in particular pattern-based approaches, have demonstrated their usefulness "to anticipate the business logics" in emerging markets. In the literature, the most known and commonly implemented business model include the business model canvas, the business model triangle, the key business model attributes, and front and back-end business model innovation (Kubli & Puranik, 2023). Pattern-based approaches are based on the idea that business model patterns can be used as sources for inspiration and can be tailored to the specific context (Johnson, 2010). Since the REC is an emerging market, the development of generic business models can serve as a first source of inspiration. In this sense, the energy sector is gaining more and more attention from business model scholars and specific business models are being proposed. Lüdeke-Freund et al. (2018) as well as Mignon and Bankel (2023) provide business model patterns for a generic sustainability-oriented innovation. Wüstenhagen and Boehnke (2017), instead, propose specific business models for sustainable energy-related activities. Richter (2013) addressed the business model innovation of utility companies by analysing the utilities' business models for renewable energies using two generic business models built on in-depth interviews with German utility managers.

When it comes to ports, conceived as energy hubs, they could adopt a decentralized-energy system approach by locating the energy production facilities close to the ports. This transition is possible thank to the use of renewable energy sources (e.g., solar energy, wind energy) and the related technologies (e.g., solar panel, wind turbine). Therefore, ports are expected to change their business model due to the integration of renewable energy and related technologies in their energy system. This business model may include the diffusion of renewable energy sources (e.g., solar energy, wind energy) and the related technologies (e.g., solar panel, wind turbine), their integration in the energy system, and the local management of these technologies in the form energy hubs, the electrification of port equipment, the introduction of electric mobility and smart charging. PREC should develop an innovative business model that operates as a unique prosumer community and create profit to all PREC's participants. Such business model is expected to combine different decentralized energy technologies, several demand areas, and collective actions.

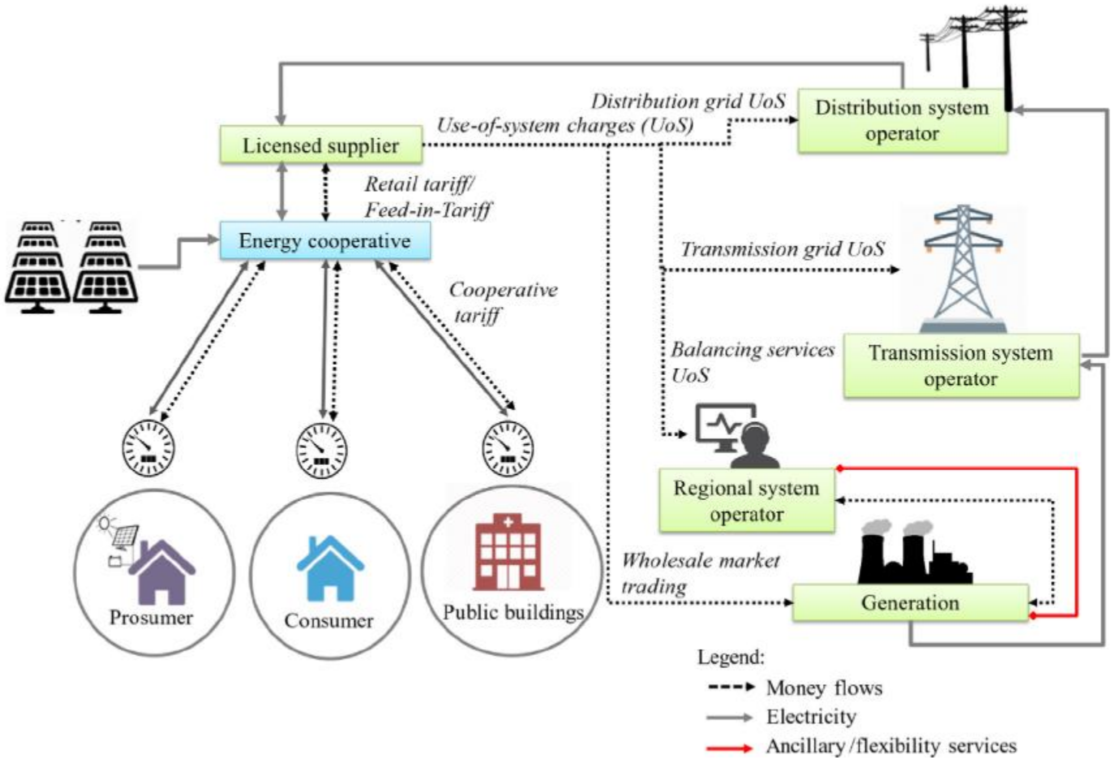
Indeed, no study has developed a business model for PREC; for this reason, this study analysed the literature on business models for energy communities in order to identify the one that may fit well with PREC or at least provide guidance on how to develop business models for PREC. In this vein, the eight business model archetypes proposed by Reis et al. (2021) along with along with the Morphological box for energy community business models presented by Kubli and Puranik (2023) are presented.

The business models proposed by Reis et al. (2021) include energy cooperatives, community prosumerism, local energy markets, community collective generation, third party-sponsored communities, community flexibility aggregation, community energy service companies, and e-Mobility cooperatives. The morphological box represents a tailored business model innovation approach developed by Kubli and Puranik (2023). It provides guidance for REC development and brings flexibility for users to develop an energy community business model that is in line with their needs, opportunities, and the local context.

4.4.1. Energy cooperatives

Energy cooperatives are citizen-driven initiatives where end-users join the community to increase the funding for the ownership of energy generation systems (Bauwens et al., 2016). This energy community model is built on voluntary and open membership rules, democracy-based control with “one participant one vote” principle, and the economic shareholding of member (Wierling et al., 2018). Usually, energy cooperatives are constituted in form of companies for profit-making by shareholders that co-finance the medium and large size photovoltaic or wind power plants to meet the energy need of the communities (Figure 4.1).

Figure 4. 1: Energy cooperative Business model



Source: Reis et al. (2021)

However, energy cooperatives can also be constituted as nonprofit cooperatives, aimed to supply energy for meeting the local community (e.g., region) energy needs. In this configuration, the energy surplus is sold and the financial profits that originate from this market transaction are reinvested in the energy community (Bauwens et al., 2016; Van Der Schoor et al., 2016). Energy cooperatives are assimilated to distribution system operator (DSO) and are responsible for the management and operation of community low-voltage distribution networks. They define the billing conditions, introduce incentives as dynamic pricing schemes in order to increase self-consumption and create some exemptions for cooperative members from paying some user fees related to the system (Brown et al., 2019).

On the one hand, given the potential socio-economic impacts that can derive from the development of REC, large scale energy cooperatives can strongly collaborate with municipalities or regions which can benefit from extra sources of funding and technical knowledge. On the other hand, public entities can also hold the responsibility of managing the energy cooperative on behalf of customers, who benefit from cheaper energy for public services such as street lighting (Ceglia et al., 2020). According to Caramizaru and

Uihlein (2020), energy communities organized as energy cooperatives are by far the most common in Europe.

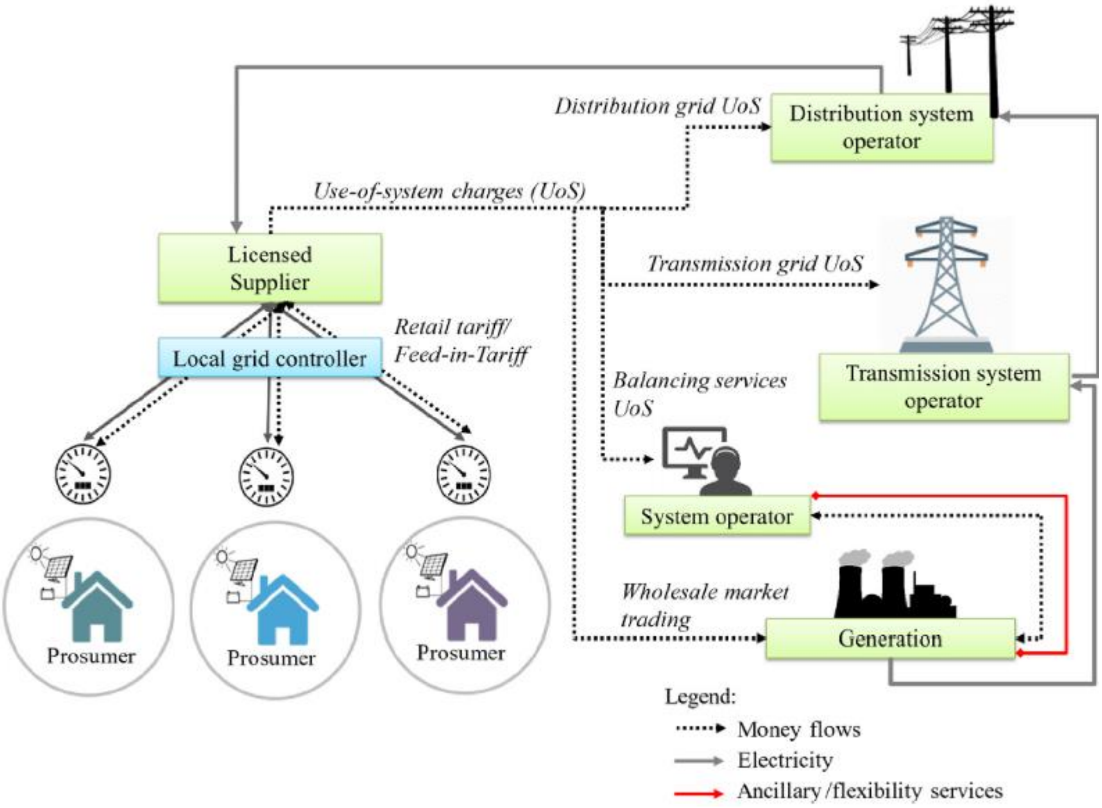
4.4.2. Community Prosumerism

Community prosumerism is a community created by prosumers, who act as decisionmakers, investors and customers at the same time. They joint their effort and resources to benefit from special financing conditions related to the acquisition of assets, to increase their dimension with the aim to participate in flexibility markets, to benefit from joint energy efficiency initiatives or to participate in local energy market (Inês et al., 2020).

In this configuration, collective or individual energy generation and storage systems are purchased by prosumers and long-term public purchase agreement (PPA) are established between energy suppliers and the energy community members. PPA is a process by which public authorities, such as government departments or local authorities, purchase work, goods or services from companies. Thus, in this business model public authorities take the responsibility to buy the surplus generation and supplying the remaining required power. In addition, community members have the capability to buy and sell all their energy within the community confines in local energy market, which provides them specific exemption from paying tariff components for medium and high voltage distribution and transmission networks (Koch & Christ, 2018).

In this business model, transactions with external energy suppliers can be established. In this scenario, use-of-system (UoS) or distribution charges. These charges represent the cost of operating and maintaining a safe and reliable distribution energy network. Finally, the power-related and monetary transactions between community members and non-community energy retailers can be intermediated by local grid controllers (Figure 4.2).

Figure 4. 2: Community prosumerism business model



Source: Reis et al. (2021)

The key benefits of this business model lie in the capacity of the prosumers to aggregate their energy demand and surplus, which will allow them to obtain additional bargaining power when negotiating market conditions with retailers. But this is subject to some constraints such as the obtention of the consensus from all parties, the availability of a physical and technological infrastructures for supporting and constantly tracking of energy, the availability of financial resources and information transactions for billing purposes. Finally, possible income deriving from the sale of surplus energy can be distributed by prosumers to repay their investment or reinvested in the community, to improve social infrastructure and extend installed production or storage capacity.

4.4.3. Local energy markets

Local energy markets are based on the “prosumerism-oriented” community approach and aim to maximize the energy self-sufficiency of the community members and reduce the dependency on energy deriving from external entity suppliers (Council of European Energy Regulators, 2019). In this business model, the contractual conditions and the pricing for energy are directly negotiated between market prosumers and consumers. In such situation, prosumers are free to choose the customers to whom they sell their energy and consumers are free to select the suppliers they buy their energy from, and they know how this energy is generated.

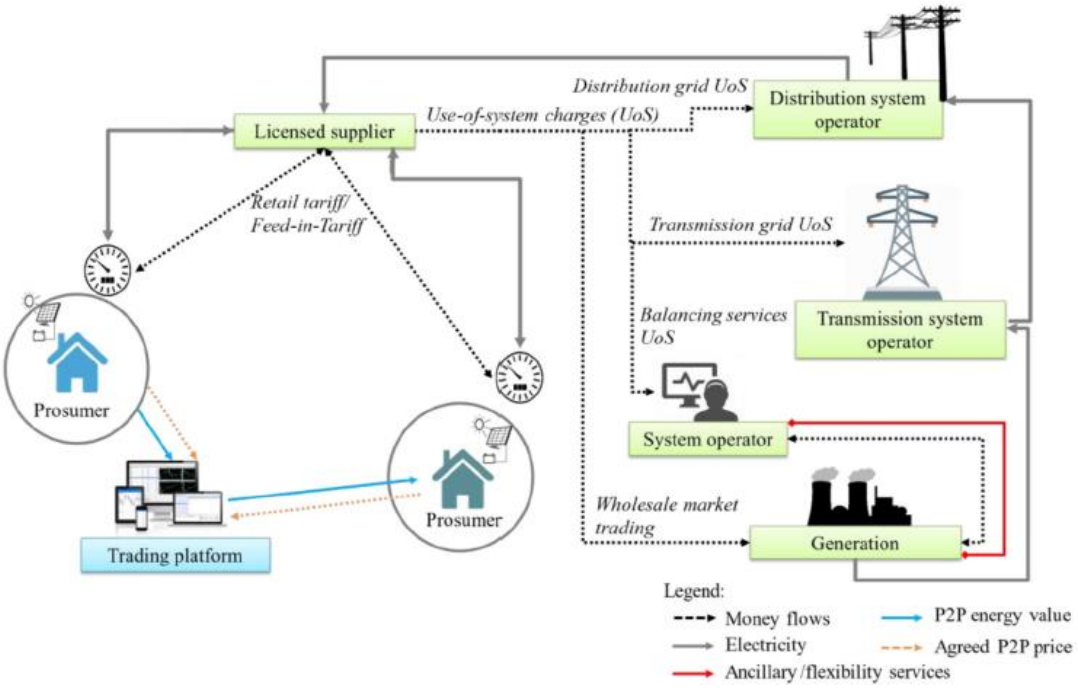
The potential incomes deriving from the sale of energy, are distributed among prosumers and consumers who are jointly responsible for the management of the trading platforms. And to ensure the energy supply and trading system reliability, they can sign specific agreements with energy retailers and the distribution system operator.

The local energy members including consumers and prosumers can be concentrated in the same location in order to reduce the costs related to infrastructure and energy transmission. But they can also be far away from each other and create virtual community power plants even if this configuration is difficult to implement due to the regulation limitations.

Therefore, local energy market where the community members are in the same place is more attractive. It represents the configuration promoted by the IEMD and RED II directives, which exempt energy transactions under the same distribution grid from the payment of the unused upstream distribution and transmission costs (European Commission, 2018).

This business model fosters peer-to-peer (P2P) energy exchanges either in a decentralized configuration or through a centralized configuration. In decentralized configurations, members are free to negotiate with each other while in centralized ones, there are intermediate entities that operate as trading facilitators between the market participants and aim to identify the best matches and find the best negotiations with the energy retailers for solving community imbalances.

Figure 4. 3: Business model of Local energy market community based on P2P trading



Source: Reis et al. (2021)

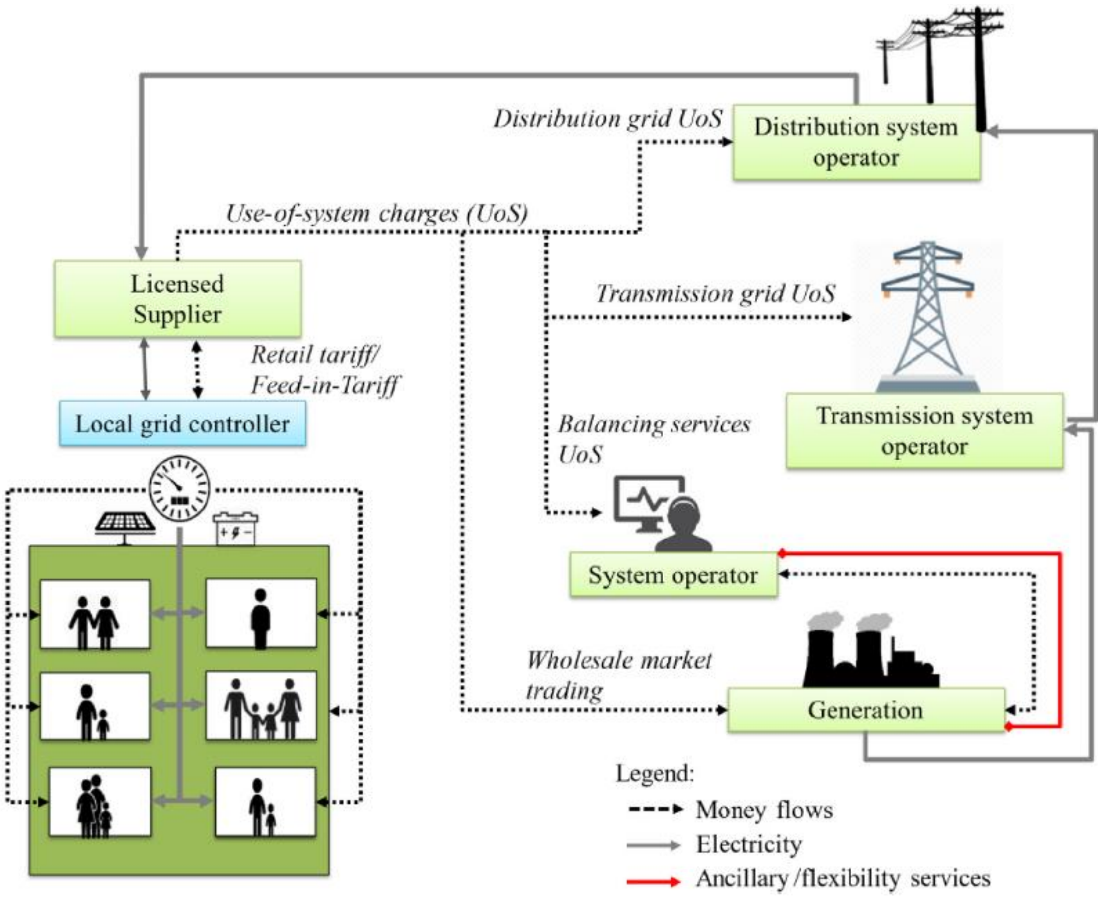
Full decentralized P2P markets are expected several issues, mostly due to the difficulties related to the negotiation processes among peers and the local energy balance control. However, due to their configuration, centralized markets are applicable only to communities of place, in which the community members are in the same place. In such configuration, innovative ICT, net-metering infrastructures, and software-based trading platforms are used for constantly recording all energy, information, and money transactions (Figure 4.3). In this perspective, technologies like blockchain are expected to be powerful recording system to keep track of the transactions in local energy markets: But this technology requires an important computational power and energy consumption given the need to solve problem related to security and cryptocurrencies.

4.4.4. Community collective generation

The community collective generation represents a collective self-consumption business model built on shared energy generation usually from solar PV and storage systems. These technologies are installed on the rooftop of buildings belonging to the community members or close to consumption sites (Figure 4.4).

This business model is a form of communities of place in which the building owners (consumers, decision-makers and investors) make a shared investment for meeting their energy issues, and sophisticated net metering and ICT-based infrastructures are required to reach such objective.

Figure 4.4: Community collective generation business model



Source: Reis et al. (2021)

The distribution of the self-generated energy and potential revenues from the sale of surpluses are voluntarily and collaboratively decided by the community members.

4.4.5. Third party-sponsored communities

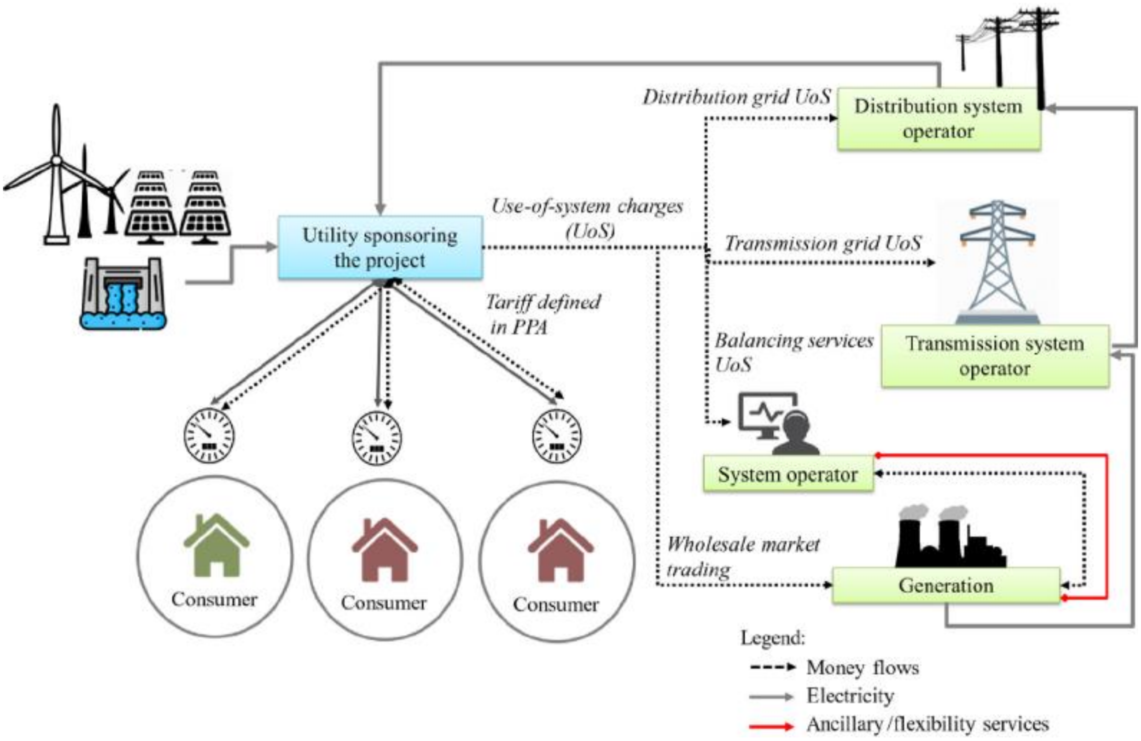
In third party-sponsored communities, companies such as utilities companies or business-related energy companies invest in the energy sector by providing support to the community members in term of technical advice, financial support in the form of grant funding, dedicated investment funds, or energy community projects fully financed. The aim of such strategy can be based on their desire to expand their customers and services portfolios (Hamwi & Lizarraldec, 2019).

However, these companies usually keep the assets ownership, and are responsible for the governance of the project and investment decisions. Therefore, they are the principal decision-makers but strongly collaborate with local communities to develop tailor-made energy supply services through the involvement of community representatives in the decision-making processes.

These companies support all the financial effort and risks, but in counterparts they benefit from the establishment of long-term public purchase agreement with customers. And community users benefit from renewable and low costs and are engaged in local energy-related programs. A company with several of this type of energy investments can use virtual community power plants for implementation.

The third party-sponsored communities are very similar to the so-called sleeving pool business model (Figure 4.5). The distributed generation resources are pooled from a geographical area with the aim to supply a specific number of customers involving using other wholesale market actors (sleeving) (Hall & Roelich, 2015).

Figure 4. 5: Communities sponsored business.



Source: Reis et al. (2021)

This business model can also be used by non-profit local authorities and social entrepreneurs, aiming at supporting local economic development, or at reducing social problems such as poverty, poor housing conditions or boost social change in a community. Therefore, the social entrepreneurs collect the required funding and maintain the infrastructure management near the local consumers and promote their engagement. The profits that can derive from the sale of energy surplus are entirely reinvested in the community.

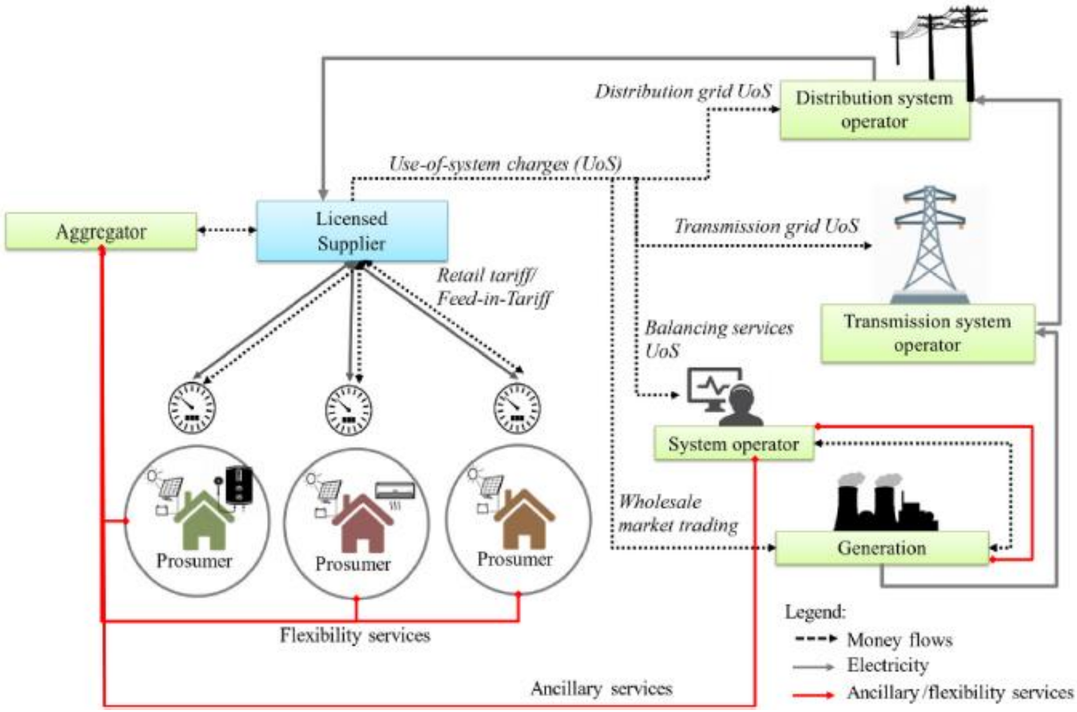
4.4.6. Community based on flexibility aggregation

Flexibility markets represent an instrument that allow energy networks to monitor the energy flows and create market signals for trigger changes in energy supply and demand, through the integration of technologies such as smart meters, smart appliances, renewable energy resources and energy efficient resources (Granado et al., 2023). They play a pivotal role in incentivizing changes in energy supply and demand. Adhering to these markets can result very beneficial for small consumers on the demand side, as they can increase their energy efficiency, reduce energy costs by limiting energy consumption during peak periods when energy is more expensive. In addition, they can also take advantage of the benefits associated with participating to demand response program, such as being notified of grid instability in advance, enabling them to proactively prevent potential outages in the system and therefore ensure the continuity of their operations.

However, small energy consumers on the demand side struggle to participate in energy market to provide flexibility. This is due to the low energy volume they consume, the high engagement costs, and reliability issues. This situation brings a great opportunity for "energy aggregator" to pool these flexibilities and participate in the flexibility markets on behalf of the consumers. Energy aggregators act as intermediary entities that aggregate energy consumption from distinct agents, who are consumers and prosumers, and offer them the service of pooling flexibilities and negotiating better offers for them on the energy market.

By aggregating the available flexibility offered by the community members, community aggregators attain the volumes required to make real offers in energy market, hence enabling the participation of small consumers in such markets. They can operate at a local level and the flexibility collected is pooled by a larger aggregator and can also directly operate at the power system level, if they are able to meet the required conditions (Figure 4.6).

Figure 4.6:Community based on flexibility aggregation



Source: Reis et al. (2021)

In this business model, community aggregators and customers sign binding and explicit bilateral contracts in which customers agree to change their energy consumption patterns by providing a fixed amount of flexibility in exchange for reduced energy bills.

Such operation can be possible through the exploitation of dispatchable and non-dispatchable demand side management programs. In dispatchable programs, customers voluntarily allow external operators to control their appliances during peak periods through direct load control. While in non-dispatchable or price-based programs instead, customers are subjected to dynamic price signals that influence their energy demand profile. In the case of non-compliance with the promised flexibility amounts, penalties may be imposed on the customer to reinforce the commitment.

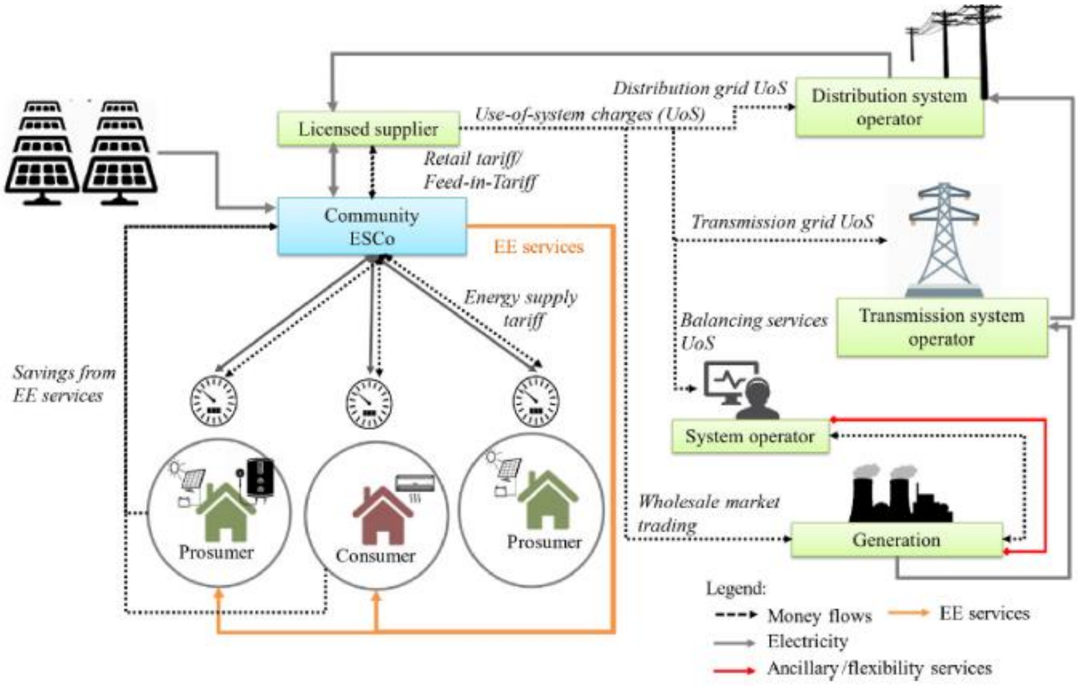
In these configurations, community members have a unique contract with external energy suppliers for buying and selling the required energy.

Technologies such as sensors, smart meters, EMS, monitoring apps, and so on are provided by aggregators to allow customers delivering the contracted flexibility. The financial resources are mostly or fully provided by the aggregator, who are the main decision-makers, but they also involve customers in the decision-making processes through the contractual clauses where their preferences are specified, and the boundaries are expressed. Regulatory frameworks play a key role in the deployment of these BM as they can constrain the aggregators scope of action. Also, technological and ICT infrastructures are key for the success of aggregation activities.

4.4.7. Energy Services Companies (ESCos) communities

In this business model, external companies can work in partnerships with energy communities for jointly creating and operating a community ESCO that aims to provide energy efficiency services for reducing the energy consumption as well as renewable energy supply including electricity and heat. According to Reis et al. (2021), ESCO business model can be defined as "communities of place and interest" (Figure 4.7).

Figure 4. 7: ESCO community business model



Source: Reis et al. (2021)

In this configuration, ESCO can provide the financial resources needed, but their remuneration generally depends on the energy savings achieved by customers. Different business model variants can be used including "solar-as-a-service business model", "heat-as-a-service" business model (Steinberger et al., 2009). In the "solar-as-a-service" business model, end-users are prosumers, and community ESCO finances the PV panels purchasing and is responsible for the installation, the maintenance and upstream supply. While in "heat-as-a-service" business model the ESCO own the infrastructure and offer energy performance contracts to ensure internal temperature comfort. This business model is exploited in district heating and project related to combined heat and power.

In both business models, in addition to energy generation, community ESCO also provide energy efficiency such as building retrofit, electrification, installation of Led lighting etc... By delivering these services, ESCO guarantees customers additional energy savings, at the same time, ensures their remuneration given that their remuneration is driven by the energy savings achieved. So, the greater the energy savings achieved by customers, the higher the ESCO's remuneration.

According to Dreessen (2003), there exist two main ESCO remuneration schemes: i) “guaranteed savings”, when ESCO commits to deliver certain levels of energy savings to end users, and ii) “shared savings”, when the savings achieved are split over a given period in compliance with a previously defined contract between customers and ESCO.

Customer savings can be used to reimburse the investments of the ESCO and for local reinvestments. In these business models, investing companies own the assets, the structures, and the decision-making power.

However, as the projects are tailored and deeply depend on local conditions, the members of the community are also strongly involved in the decision-making processes. Capital intensive investments for providing energy services can constitute a great barrier for implementing this type of business model.

4.4.8. E-mobility cooperatives

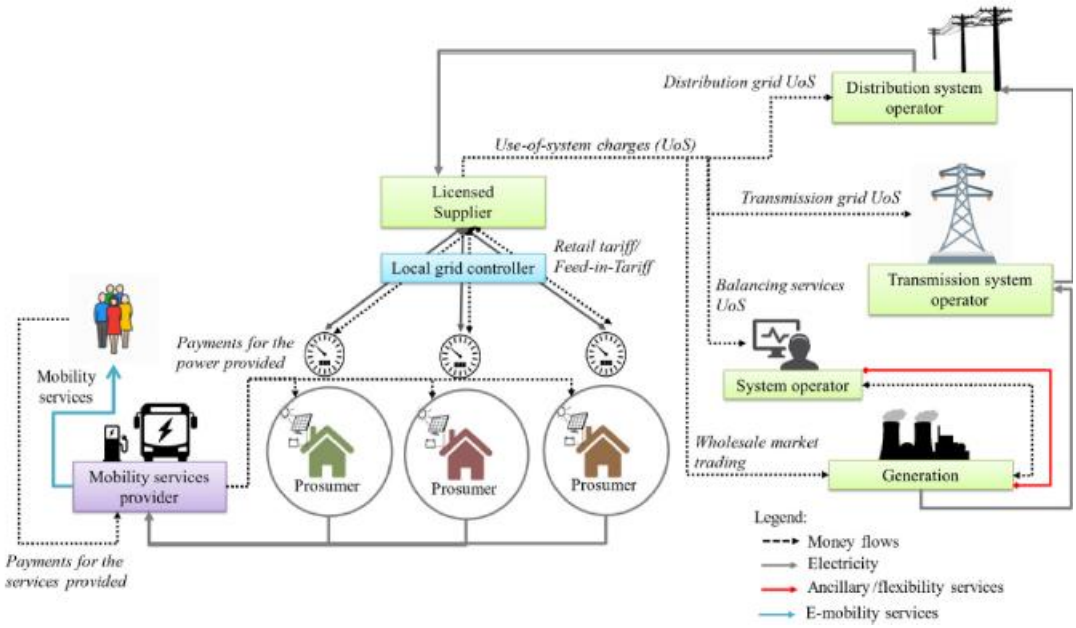
The European Commission encourages electric vehicle as mobility solutions by providing transportation services based on renewable energy in order to tackle the energy transition challenges. The constitution of e-mobility cooperatives results to be a viable solution for reaching such objectives through the development of clean mobility solutions. This business model based on e-mobility is built on the engagement of shareholders including households, SMEs, public entities, social and technical entrepreneurs, utility companies and so on to provide community public transportation, car-sharing or car-pooling services. The cooperatives can also exploit their resources including electric cars, buses, motorbikes, …to increase the resources flexibility in the community. To reduce energy bills EV batteries can be used for energy storage, and vehicle-to-grid and grid-to-vehicle modes can be implemented to reduce energy costs by procuring energy during off-peak periods and increasing flexibility services in the system, which can be pooled by aggregators to supply ancillary services to the grid.

Battery storage can also serve for maximizing local self-consumption and self-sufficiency of the community. Community participants can participate through formal partnerships or not and can be shareholders, decision-makers and mobility customers.

Where the number of EV is high, smart charging schemes can be specifically designed for forecasting purpose. This smart charging can be used for scheduling load operation to off-peak periods or when local energy generation is available, hence, to optimize the local resources use and flattening demand peaks.

However, business model can be combined with flexibility business model forming a hybrid business model (Figure 4.8).

Figure 4.8: E-mobility cooperative business model



Source: Reis et al. (2021)

In this hybrid configuration, the providers of community mobility services can be created with the responsibility to offer e-mobility services with energy generated by community members (Brown et al., 2019). They have the ownership of EV and deliver car-sharing or public passenger transportation services, for making profit, by using the energy deriving from community prosumers. Fees are charged for the services delivered and the energy surplus generated is not sell to an energy supplier, but prosumers make it available to e-mobility services providers, upon payment or reduced service prices. In this setting a partnership between energy communities, distribution system operator, energy suppliers and EV technology providers is needed. These models are technology-driven and require robust physical structures to manage the energy-intensive demand charging processes of e-mobility assets. Regulatory barriers, based on vehicle-to-grid and grid-to-vehicle transactions, and economic barriers due to the capital-intensive nature of this investments may negatively impact the development of these business model.

4.4.9. Morphological box for energy community business models

Kubli & Puranik (2023) proposed a morphological box that is not a complete business model, but it is an instrument for energy communities' implementers. It works as a toolbox to configure an energy community business model based on design option. It consists of five dimensions of energy community business model which includes:

- The value proposition. It represents the reasons behind the development of an energy community. These reasons include reducing energy consumption, reducing energy costs, generating renewable energy, increasing energy self-sufficiency, increasing of the energy system reliability.
- The members of energy community. For the establishment of an energy community, it is fundamental to clearly identify the keys actors including the prosumers, consumers, and service providers as well as their role.
- How energy community capture value. This dimension refers to the ability of energy community member to capture value for profit-making. This value can derive from revenue generated from energy services, from energy cost savings, from revenue related to external services, from community fees and data valorisation. With data valorisation, communities monitor activities related to energy consumption, generation, storage, technology, and behaviour to valorise data acquired. Depending on the reliability of the data, several advantages can be derived from their valorisation.
- The key functions of energy community. This dimension is very important as it shows how the energy community members create and deliver value. These key functions can include P2P trading facilitation, energy aggregation and flexibility for small consumers, energy storage management, shared energy optimization and partner coordination.
- The network effect that can derive from energy community. It represents the value or utility that community members can gain from increasing the number of community members. These effects include the peer effects community feeling creation, economy of scale and scope, learning effects, and co-benefits and amortization of shared investments.

However, these business models are not exhaustive due to the large number of potential hybrid models. The PREC can draw inspiration from one or more of these energy community models to design its own. The next section presents and discusses the benefits and challenges of PREC.

4.5. The main benefits and challenges of port renewable energy communities

PREC represents a step towards a collaborative and sustainable energy management, in which port energy consumers are actively involved and the use of renewable energy sources in ports and the related urban areas is promoted. Port System Authorities are exploring PREC to meet the energy needs of ports. PREC can contribute to ensuring a sustainable energy supply for the entire port cluster, fostering decarbonisation and reducing environmental pollution. Specifically, PREC can bring several benefits that include:

- Local value for the community: PREC can foster the implementation of sustainability-based projects that can lead to the reduction of harmful emissions and energy poverty, the development of the local production chain, the improvement of territorial competitiveness, the creation of new employment opportunities for local community, the reduction of the energy dependence and change in value of land use (Barroco et al., 2021; Vito et al., 2023).
- Energy citizenship and democracy: With the principle of one member one vote, the members of energy community have democratic control on energy investments by becoming co-owners of renewables installations. The participation in renewable ownerships and decision-making can be direct, where members approve decisions in assembly meetings and decide how the energy surplus is distributed, or indirect participation through a board of directors.
- Generating financial returns for the community: profit can be generated from the sale of energy. Energy community members have control over financial resources and profit sharing. Then surpluses can be reinvested in community or in other activities.
- Education and mobilisation of citizens: PREC can also foster the development of joint action for combating climate change in the community.
- Social cohesion: PREC can create a community feeling and trust between the energy community members.

- Contribution to renewable energy expansion: Energy communities increase investments in renewable energy which bring the social acceptance related to energy community projects. These projects give opportunities to the members to finance investments that bring benefits locally including harnessing local renewable resources, increasing employment, and increasing energy security in the community.
- Impact on the energy system: Energy communities lead to the decentralisation of the energy system due to the possibility to install renewable energy resources close to the consumption area. PREC can a enhance the energy optimisation of the system and the reduction in energy losses.
- Impact on system costs: When participating in a PREC, members can participate to demand response programs which can lead to several benefits related to financial gains and energy costs reduction. These can include a reduction energy price as the available renewable energy is cheaper than the retail tariff and can be injected into the grid through feed-in-tariffs. Other benefits may include lower network tariffs due to aggregation effects.

Besides the benefits, PREC also brings several challenges including:

- High investment costs. The establishment of PREC require capital intensive investments and their long-term success will depend on their ability to operate energy networks in a cost-efficient way ensuring benefits for all customers and the whole energy system.
- Capability of aggregate consumption and flexibility. As the benefits of PREC members increase as the members of the community increase, the energy aggregator should be able to attract as many participants as possible.
- The ability of energy communities to share gains amongst their members is key for their long-term sustainability. The viability of a community can be compromised when simple sharing rules fail to fairly distribute benefits to all participants. Consequently, some members may find it more beneficial to abandon these PRECs and look for RECs where benefits are shared more equally.
- Social discrepancy. The use of locally produced energy in the community by PREC participants can lead to the reduction of peak demand in the national energy system and the payment of grid services. This self-energy consumption produced in the community reduces recovery of distribution network costs and policy charges and

levies. As network costs are equally distributed amongst system users, to compensate the income losses incurred, the network operators will increase the tariff to the remaining customers in the system who might not own a renewables installation. This regressive effect creates a social discrepancy between members of the community and non-members. So, for establishing a successful PREC it is fundamental to redesign the network tariffs to avoid negative impacts on the overall cost base.

The preliminary evaluation of the current state of the art and state of the play of PREC in line with the EU legal and institutional framework reported in this chapter. The planning stage and the port renewable energy community management is presented. Then, the main business features of renewable energy communities emerging from the RED II directives are discussed. The development of port renewable energy communities represents a driver for the energy transition and will require the installation of photovoltaics and the maximisation of consumption. In this perspective, this chapter also presented the different types of renewable energy community models applicable to ports are stressed, as well as the main benefits and challenges of PREC.

PART II – EMPIRICAL ANALYSES & PRACTICAL IMPLICATIONS

Introduction

The first part of the present thesis theoretically addressed the concept of green strategy applicable to port, addressed the port as energy hub, analysed the port energy management system and the port renewable energy community. Specifically, the concept of green strategies in the port domain is addressed in the first chapter. The relevant managerial theories related to CSR are developed and a taxonomy of green strategies applicable to port is provided. Then, a green business model applicable to port is introduced and some green finances for implementing this green business model are presented. This chapter also emphasises the energy intensive nature of port activities, making the port a major energy consumer and also producer. In this vein, ports can be considered as EH due to the energy-intensive nature of day-by-day port-related activities. Given the above, the second chapter addressed the port as energy hub in order to analyse the benefits that the energy hub approach could bring to the ports. In this chapter, the different types of energy hub are presented along with the main technical components and the drivers of port renewable energy hub. From the second chapter, it emerged that as multi energy systems, ports integrate different types of energy generation loads and energy transformation technologies that can be used to improve the energy efficiency of port operations. The coexistence of different types of energy supply makes the port a multi-energy system and is seen as promising and economically feasible energy system compared to conventional decoupled energy systems. As such, basing the port energy management systems on the energy hub approach, the port energy system could be smarter and capable to manage energy fluctuations through conversion and storage solutions for meeting volatile port energy demand and specific energy needs. In this perspective, the third chapter addresses the energy management in the port using the energy hub approach. This chapter addressed the policy framework and certification for port energy management. Next to this, the energy demand and supply planning in the port are discussed and the smart energy management system as well as the operational strategies for energy efficiency are analysed. From the analysis of the first three chapters, it emerged that ports represent effective location for energy production, where energy generation facilities can be installed. Therefore, ports could play a more strategic role within the respective regional energy systems, acting as energy generation and distribution platforms and using their energy hub features to move towards renewable energy communities. In this vein, the chapter 4 closed the theoretical part of the thesis by discussing the applicability of the renewable energy community to ports, with a focus on the business model.

However, the second part of the thesis completes the theoretical part by providing four papers related to each chapter of the first part. These papers consist of 4 research objectives:

- ***RO1***. *To identify Green Strategies (GSs) implemented by ports aiming at making port operations more sustainable, especially reducing energy consumptions and increasing energy production from renewable sources.*
- ***RO2***. *To provide a conceptual framework for supporting port decision makers in transforming ports into renewable energy hubs.*
- ***RO3***. *To evaluate the introduction of an ad hoc port energy management approach as a preliminary condition for the energy transition process of ports.*
- ***RO4***. *To propose an innovative (green and smart) business model for the establishment of effective PREC.*

Addressing these research objectives constitutes the main purpose of the second part of this thesis, outlined below. This part also includes the conclusion chapter which presents the concluding remarks and future research agenda.

CHAPTER 5

GREEN STRATEGIES IN PORTS: A STAKEHOLDER MANAGEMENT PERSPECTIVE *

*This paper has been published in the *Maritime Economics and Logistics (MEL) Journal.* DOI: 10.1057/s41278-024-00294-0. A previous version of this paper entitled "Green strategies of port managing bodies: Empirical evidence of stakeholder prioritization in Italian ports" was presented at the 25th EISIC Conference (August 25-26, 2022, Visby) and published in the Proceedings under the following ISBN: 9791221015904.

Abstract

This paper delves into the intricate relationship between green strategies and stakeholder management within the port industry. We employ a robust conceptual framework and a tailored methodology, encompassing all sixteen Italian Port Management Bodies and analysing 344 related green strategies. A unique indirect approach is introduced to identify the primary stakeholders targeted by these strategies. The research identifies three primary categories of green strategies: energy efficiency, electric supply infrastructure development, and renewable energy promotion. These strategies align with increasing environmental expectations and stricter regulations. Terminal operators and local communities emerge as primary stakeholder groups, underscoring their growing influence in port management decisions. This research bridges a substantial gap in the academic literature by shedding light on the benefits of green strategies for the principal port stakeholders and the pivotal role of these strategies for stakeholder management in ports. Port managers can leverage these insights to make informed strategic decisions, strengthen their corporate social responsibility initiatives, and better address environmental concerns while meeting stakeholder expectations. Furthermore, the paper offers valuable guidance to policymakers aiming to stimulate additional investments in environmental sustainability, thereby meeting the expectations of port stakeholders and enhancing port competitiveness.

Keywords: green strategy; CSR; stakeholder management; stakeholder prioritisation; sustainability; port managing bodies; ports; Italian ports.

5.1. Introduction

Over the past decades, there has been a notable shift in societal expectations concerning the role of businesses (Buysse & Verbeke, 2003). Stakeholders increasingly call for a more holistic approach to defining success, emphasising corporate decisions' broader environmental and social implications (Klefsjö et al., 2008). In response to this mounting pressure, numerous organisations have dedicated significant resources to implement comprehensive environmental management practices, to improve their economic, environmental, and social performance (Rodrigues & Ensslin, S 2023). Drawing from stakeholder management theory, as articulated by Freeman et al. (2000), businesses are now encouraged to create value for diverse stakeholders, encompassing employees, investors, customers, and suppliers, all while considering environmental concerns. The interplay between environmentally responsible corporate strategies and effective stakeholder management is paramount (Aragòn-Correa et al., 2020). However, significant gaps persist within the academic literature, necessitating urgent empirical investigation, especially in the transport sector. The port industry has experienced substantial transformation and innovations in recent years (Bergqvist & Monios, 2019). The sector places a high premium on safety and adherence to regulatory standards – for instance when it comes to port-worker training – due to the risks confronting both port workers and port users, as well as because of the environment impacts of port operations (ILO, 1998). This unwavering commitment to safety reinforces the persistence of specific conservative procedures and protocols. Nevertheless, the port sector has recently encountered significant technological innovations and organisational restructuring, reshaping port management and the maritime supply chain (Di Vaio & Varriale, 2018). Environmental sustainability has emerged as a central concern, marked by a growing interest in reducing emissions and other externalities (e.g., noise), and transitioning to cleaner operational practices (Alamoush et al., 2021; Felício et al., 2023). Indeed, this transformation represents a significant departure from historical practices and presents Port Management Bodies (PMBs) with new challenges. PMBs are now tasked with incorporating the environmental concerns of port stakeholders into their decision-making processes. This adjustment is crucial for ensuring compliance with increasingly stringent environmental regulations, and maintaining competitiveness in the industry, with green strategies (GS) serving as the equitable means to achieve these objectives. Despite the increasing significance of GSs, more theoretical and empirical research is needed, to examine how the selection, planning and execution of GSs from PMBs depend upon their stakeholder prioritisation practices. Additionally, there is a need for a taxonomy of GSs to enhance scholars' and practitioners' understanding of the environmental advantages associated with such corporate social responsibility (CSR) interventions, and the Port Stakeholder Groups (PSGs) that benefit from them. Identifying salient beneficiary PSGs of GSs can aid port managers in strategic decision-making and contribute to refining CSR strategies. Considering the existing void in literature, this paper endeavours to address the following two research questions (RQs):

- **RQ1**: What are the primary typologies of GSs implemented by PMBs and their corresponding CSR objectives?
- **RQ2**: Which PSGs emerge as salient beneficiaries of GSs implemented by PMBs?

The paper makes a significant contribution to the academic field of management by presenting a conceptual framework and research methodology for the empirical analysis of GSs from the standpoint of stakeholder management. The research rigorously applies the proposed methodological framework to all sixteen Italian PMBs, offering an extensive case study that yields theoretical insights and practical implications to researchers and port management professionals. Furthermore, it offers insights for policymakers, focused on facilitating additional investments in environmental sustainability objectives, aligning them with the expectations of PSGs and thereby enhancing the competitiveness of ports.

5.2. Theoretical foundations

5.2.1. Green Strategies and CSR-related objectives in the port industry

In the coming years, ports worldwide will encounter various environmental challenges associated with climate change adaptation, mitigation, emission reduction in port activities, and adherence to stricter environmental regulations (Poulsen et al., 2018; Castellano et al., 2020; Alamoush et al., 2021). Consequently, integrating a "green" perspective into port management and development plans allows PMBs to pursue sustainable growth and meet the expectations of multiple stakeholders (Bergqvist & Monios, 2019). PMBs have a pivotal role in the port ecosystem (Van der Lugt et al., 2013; Castellano et al., 2020), taking responsibility for reducing environmental impacts and promoting decarbonisation (Hiranandani, 2014; Bergqvist & Monios, 2019). As regulators, PMBs enforce environmental regulations and policies, ensuring compliance by carriers, terminal operators, and port users (Poulsen et al., 2018). They are also expected to prioritize the adoption of GSs to meet policy targets, address climate change, and gain support from PSGs (Martínez-Moya et al., 2019; Tai & Chang 2022). Several studies argue that PSGs are increasingly pressuring port management for sustainable solutions (Le et al., 2014; Acciaro, 2015; López-Navarro et al., 2015; Chen & Lam, 2018; Parola et al., 2018; Stein & Acciaro, 2020). Consequently, PMBs have integrated CSR aspects into their planning activities (Dooms et al., 2013). Prior research has explored GSs in the port sector from different perspectives, including managerial, operational, technical/technological, and normative ones (Acciaro et al., 2014; Lam & Notteboom, 2014; Di Vaio & Varriale, 2018; Dinwoodie et al., 2012; Puig et al., 2020; Davarzani et al., 2016; Martínez-Moya et al., 2019; Sdoukopoulos et al., 2019; Poulsen et al., 2018; Woo et al., 2018; Zis et al., 2019; Schrobback & Meath, 2020; Alamoush et al., 2021). The literature consistently reveals a strong connection between GSs and the concept and principles of CSR, as the environmental objectives of GSs often extend to other areas of port management, particularly in managing stakeholder groups (Dooms, 2019). GSs play an important role in enabling PMBs to meet the demands of diverse PSGs and fulfil various CSR objectives, encompassing economic, market, governance, regulatory, and social aspects that complement environmental goals (Acciaro, 2015; Ashrafi et al., 2020; Castellano et al., 2020). Table 5.1 summarises the six main CSR-related objectives of GSs grounded on well-established academic contributions.

Table 5. 1: CSR-related objectives of green strategies performed by port managing bodies.

CSR-related objective	***Description***	***Literature***
Environmental	Efforts to lower environmental impact, address climate change adaptation and mitigation, reduce harmful emissions, and abatement of externalities on land and water.	Bailey and Solomon, 2004; Dinwoodie et al., 2012; Acciaro et al., 2014a; Davarzani et al., 2016; Martínez-Moya et al., 2019; Sdoukopoulos et al., 2019; Alamoush et al., 2021.
Economic	Economic and business growth, value creation, competitiveness, enhanced operational efficiency, and cost savings.	Acciaro, 2015; Puente-Rodríguez et al. 2016; Kang and Kim 2017; Woo et al., 2018; Castellano et al., 2020.
Market	Meeting the expectations of maritime cluster firms, effective response to market and competitor pressures, improve the quality and range of services to better meet customer demands.	Acciaro et al. 2014b; Acciaro 2015; Poulsen et al., 2018; Ashrafi et al., 2020; Castellano et al., 2020.
Governance	Ethical leadership, collaboration with port stakeholders, and adoption of sustainable governance models and practices.	Lam and Notteboom 2014; Acciaro 2015; Puente-Rodríguez et al. 2016; Poulsen et al., 2018; Yoshitani 2018;

		Ashrafi et al., 2019; Schrobback and Meath, 2020.
Regulatory	Ensure compliance with regulation at national and international levels and develop stringent policies and measures at the port level.	Acciaro et al., 2014a; Hiranandani 2014; Lam and Notteboom 2014; Le et al. 2014; Puente-Rodríguez et al. 2016; Kang and Kim 2017; Poulsen et al., 2018; Woo et al., 2018.
Social	Legitimacy from local communities, social license to operate, public image enhancement, protection of human health, and development of social initiatives.	Hiranandani 2014; Acciaro 2015; López-Navarro et al., 2015; Notteboom et al. 2015; Puente-Rodríguez et al. 2016; Kang and Kim 2017; Poulsen et al.,2018. Ashrafi et al., 2020; Stein and Acciaro, 2020.

Source: authors' elaboration.

However, the implementation of CSR, particularly in the context of GSs, often encounters various obstacles and barriers (Dooms, 2019). One significant challenge is identifying and prioritising relevant stakeholders from numerous groups and individuals with a vested interest in the business (Mitchell et al., 1997). This issue is particularly prominent in the port industry, where PMBs must align strategic objectives with the demands and interests of diverse PSGs (Acciaro, 2015). Dooms (2019) argues that PMBs should prioritise identifying, classifying, and ranking salient stakeholders before devising specific sustainability strategies to ensure efficient resource allocation and achieve desired outcomes. Due to their unique institutional and governance frameworks, this issue has become increasingly critical for Italian ports. A significant gap persists between the intended and the actual reform trends in key areas of port administration, including financial autonomy, stakeholder representativeness, managerial independence, model hybridisation, and the devolution process (Parola et al., 2017). This disparity adversely affects ports' governance and strategies, particularly regarding sustainability actions, as a cohesive national strategy is absent in this industry, resulting in a fragmented array of locally-driven initiatives.

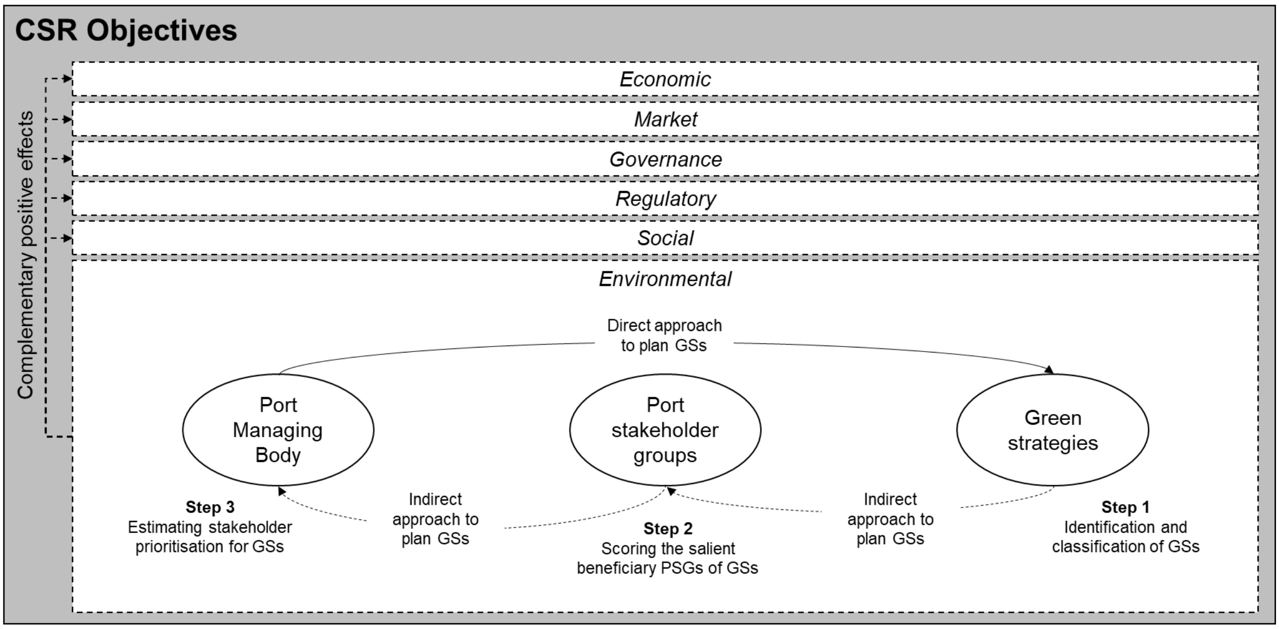
The recognition of stakeholder salience necessitates well-defined criteria for evaluating the influence of each PSG on port processes, operations, and performance. However, this procedure has often limitations stemming from the PMB's potentially politically biased behaviours and assessments (Notteboom et al., 2015), as demonstrated in several concrete and anecdotal recent circumstances both in large and small Italian ports (Haralambides, 2017). Port managers may prioritise certain PSGs (e.g., employees and labour unions, terminal operators, carriers, regulators) due to the predominantly public nature of PMBs, which prioritise strategic objectives for the public good, rather than market competitiveness. While some PMBs are transitioning towards more independent and commercially oriented management structures, as private firms, most ports worldwide are still government-owned or state-owned enterprises prioritising public interest over market competition (Van Der Lugt et al., 2013).

Despite the heterogeneity and complexity of PSG interests (Le et al., 2014; Ashrafi et al., 2020), to our knowledge, prior studies have not adequately explored the stakeholder prioritisation process for GSs from the perspective of PMBs. This process warrants greater attention from scholars, to contribute to the international discourse on CSR in the port domain and support port managers in making complex strategic decisions. Therefore, this paper addresses this gap by presenting a conceptual framework and an empirical approach, to advance understanding.

5.2.2. Conceptual framework

We utilise CSR and stakeholder relationship management principles to establish a conceptual framework for examining GSs in ports and identifying salient beneficiary PSGs, as depicted in Figure 5.1.

Figure 5. 1: Conceptual framework.



Source: authors' elaboration

To address the research questions, the conceptual framework adopted in this study highlights the complementary effects of environmental interventions in achieving economic, market, governance, regulatory, and social objectives. Two direct and indirect approaches are employed to identify salient PSGs of GSs based on stakeholder management theory and the pioneering contribution from Notteboom et al. (2015).

In line with the direct approach, PMBs evaluate PSGs based on their strategic objectives, assess the benefits of potential GSs for each PSG, and select the GSs that offer more significant benefits to the salient PSGs. However, due to the predominantly public nature of PMBs, the direct approach may be subject to limitations and biases and may prioritise certain PSGs based on politically driven considerations that may align differently from the actual strategic goals of the PMBs.

Instead, the indirect approach proposed by Notteboom et al. (2015) can arguably overcome the above limitations. This empirical methodology involves three main steps. First, identifying and classifying GSs inductively performed by selected PMBs. Second, evaluating of the environmental benefits and CSR spillovers of each GS, considering social, economic, market, regulatory, and governance objectives. This allows for scoring the relevance of each GS typology for different PSGs. Third, developing a GSs/PSGs matrix that highlights the beneficiary PSGs for each GS. By combining the outcomes of these empirical phases, indirect estimation of stakeholder prioritisation by PMBs in developing effective GSs can be achieved. The subsequent methodological section presents a detailed explanation of the indirect approach.

5.3. Methodology

5.3.1. The Italian case

The conceptual framework used in this study is rooted in the European regulatory and institutional context, as it specifically applies to Italian ports. Several factors justify this choice, driven by economic, environmental, and regulatory considerations.

From the economic viewpoint, Italian ports hold strategic locations along major transportation routes, handling significant cargo and passenger volumes. In 2022, Italian ports handled 490 million tons of cargo and served 61 million passengers (Assoporti, 2022). Italy is a key player in Mediterranean short-sea shipping, with a 39% market share, and ranks first in Europe for cruise passenger numbers (Brewer, 2020). From an environmental perspective, the port industry contributes significantly to Italy's air pollution and greenhouse gas (GHG) emissions. Italy has consistently exceeded the EU average for PM2.5 levels, as reported by Brewer (2020).

Furthermore, the transportation sector was responsible for over 24% of Italy's total GHG emissions in 2019 (European Commission, 2020). Italy's extensive coastline of 7,600 km, with approximately one-third of the population residing within 5 km of the coast, magnifies the environmental impact of the maritime industry. As an EU member state, Italy must align with the European Commission's pollution reduction targets (e.g., strategy 2018/773/EC). This necessitates the adoption of GSs by PMBs, requiring comprehensive insights into the green initiatives of Italian ports. Additionally, Italy's legal and institutional framework underwent significant changes following the 2016 reform of the Italian port system. The reform introduced substantial alterations in administrative procedures and port management practices. The Port System Environmental and Energy Plan (DEASP) became mandatory for Italian PMBs, assessing energy demands and outlining crucial GSs to reduce the environmental impact of ports. Despite the strides made by Italian PMBs in enhancing sustainability, considerable variation exists in the types of GS initiatives and their geographical coverage, warranting further examination, in order to understand the primary drivers, which shape both the type and the magnitude of GS actions and interventions implemented by the Italian PMBs.

This study encompasses all sixteen Italian PMBs as the research domain, ensuring a comprehensive understanding of the Italian context. We map, analyse, report and discuss 344 GS actions. Including all PMBs allows for a robust analysis of green strategies and stakeholder prioritisation practices in the Italian port industry. This approach facilitates the identification of common trends, patterns, and variations across different PMBs, offering valuable insights and a holistic understanding of the Italian context. The extensive coverage enhances the reliability and validity of the findings, contributing to the academic literature on stakeholder prioritisation and green strategies in port management.

5.3.2. Taxonomy of Green Strategies

The first step of the proposed indirect methodological approach involves identifying and classifying GSs. Desk research thoroughly examined vital documents such as the Port System Environmental and Energy Plan (DEASP), Strategic Planning Document of Port Systems (DPSS), and other strategic planning documents and reports on environmental and energy management released by the sixteen Italian PMBs. Furthermore, we conducted comprehensive interviews with managers from 7 Italian PMBs, which represent approximately 50% of the sample. The interviews aimed to gather more in-depth information about the environmental advantages of GSs and their associated objectives2. The in-depth interviews consisted of two parts: the first focused on the PMB's CSR strategy and the related GSs to meet stakeholders' expectations, while the second aimed to gain deeper insights into each GS's achieved or anticipated environmental benefits.

After conducting a thorough analysis and reviewing relevant documents obtained from desk research and interviews with expert personnel from the PMBs, a database comprising 344 GSs was created. These GSs serve as our unit of analysis and are categorised based on their project title and timeframe. The breakdown of GSs per sample PMBs is presented in Table 5.2. By this approach, the study aims to gain comprehensive knowledge about the GSs implemented by the sixteen Italian PMBs, their alignment with stakeholders' expectations, and the environmental outcomes they have generated or are expected to generate.

Table 5. 2: Sample green strategies.

PMB	No. of green strategies	% of the sample
North Tyrrhenian Sea (Ports of Livorno, Capraia, Piombino, Rio Marina, Portoferraio, and Cavo)	44	13%
Northern Adriatic Sea (Ports of Venice and Chioggia)	35	10%
Sardenian Sea (Ports of Cagliari, Olbia, Golfo Aranci, Porto Torres, Oristano, Portovesme, Santa Teresa Gallura)	33	10%
Western Ligurian Sea (Ports of Genoa, Prà, Savona and Vado)	32	9%
Eastern Ligurian Sea (Ports of La Spezia and Marina di Carrara)	31	9%
Northern Central Tyrrhenian Sea (Ports of Civitavecchia, Fiumicino and Gaeta)	30	9%
Eastern Adriatic Sea (Port of Trieste and Monfalcone)	22	6%
Western Sicily Sea (Ports of Palermo, Termini Imerese, Porto Empedocle and Trapani)	20	6%
Southern Adriatic Sea (Ports of Bari, Brindisi, Manfredonia, Barletta and Monopoli)	20	6%
Ionian Sea Port (Ports of Taranto)	19	6%
Eastern Sicily Sea (Ports of Augusta and Catania)	15	4%
Central Adriatic Sea (Ports of Ancona, Falconara, Pescara, Pesaro, San Benedetto del Tronto and Ortona)	12	3%

[2] We scheduled several meetings with key figures of these PMBs. These included meetings with the directors of the Technical and Environmental Management Department of the Western and Ligurian Sea Port Network Authority, the head of Special Projects, Innovation, and Institutional Relations of the Eastern Ligurian Sea Port Network Authority, a manager from the board of the Major Projects Office of the Central Tyrrhenian Sea Port Network Authority, and a manager from the Planning and Development Department of the Ionian Sea Port Network Authority. We also conducted three online meetings with a manager from the Planning and Development Department of the Sardinian Sea Port Network Authority, a manager from the Development and Innovation Department of the North Tyrrhenian Sea Port Network Authority, and a manager from the Southern Tyrrhenian Ionian Sea Port Network Authority.

Central Tyrrhenian Sea (Ports of Naples, Castellammare di Stabia and Salerno)	8	2%
Northern Central Adriatic Sea (Port of Ravenna)	8	2%
Southern Tyrrhenian and Ionian Sea (Ports of Gioia Tauro, Corigliano, Crotone, and Palmi)	8	2%
Messina Strait (Ports of Messina and Milazzo)	7	2%
Overall	**344**	

Source: authors' elaboration

A systematic approach was taken to organise and classify the GSs using two classification schemes: GS typology and GS objective. The typologies of GSs were developed through an inductive process based on the analysis of the examined documents. This involved iteratively constructing, testing, and revising categories while continuously comparing data and information. The outcome of this process gave a set of 8 comprehensive and internally coherent types, which can be seen in Table 5.3. To ensure the accuracy and reliability of the categorisation, all the GS actions included in the analysis have been reviewed and evaluated at least three times before the final labelling, involving different researchers and assessing inter-coder reliability. This collaborative review confirmed that the categories accurately represented the characteristics of the GSs and were consistent with the research findings.

Table 5. 3: Green strategies typology.

Green strategies typology	Description
Digitalisation and ICT platforms	Digital innovations (e.g., IoT[3], digital platforms for data exchange, smartphone applications, etc.) are being used to mitigate the environmental concerns of maritime logistics operations within the port domain. The focus is on improving operational efficiency by using ICT platforms, smart sensors, and other technological tools to monitor emissions and environmental externalities stemming from port activities.
Energy efficiency	Strategies for enhancing the energy efficiency of maritime logistics activities in the port. These strategies encompass substituting 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 include installing solar panels, wind turbines 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.

[3] The Internet of Things (IoT) denotes the transformative technology facilitating the seamless integration of interconnected devices, sensors, and systems within the maritime sector. This interconnected network collects and transmits real-time data, revolutionizing fleet management, enhancing cargo tracking, and refining supply chain processes. By harmonizing these elements, this integration endeavours to elevate efficiency, safety, and sustainability standards in maritime operations.

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 shore power (i.e., cold ironing) and electric vehicles charging facilities.
Land-use conversion	Strategies to convert specific port areas into new neighbourhoods, parks, museums, and edutainment centres related to the maritime logistics industry and touristic attractions.
Research and Development	Research initiatives and investigations to improve port sustainability, undertaken by the port authority/port management body (individually or in collaboration with scientific/industrial partners).

Source: authors' elaboration.

In addition, a brief survey was administered to academic colleagues and to the port managers who were previously interviewed to validate the identified categories. This step was undertaken to obtain feedback and insights from experts in the field, ensuring the reliability and suitability of the classification scheme.

The second classification scheme is based on five categories of CSR-related objectives: economic, market, governance, regulatory, and social. These categories, encompassing environmental and non-environmental objectives, were derived deductively from the existing CSR literature on port management, as presented in the conceptual framework.

5.3.3. Evaluation of the salient beneficiary port stakeholder groups of green strategies

According to Freeman's (1984) stakeholder definition, port stakeholders can be described as individuals or groups with a legitimate interest in or impacted by the actions or inactions of the port (Notteboom & Winkelmans, 2003). This broad definition allows for various interpretations and classifications of significant stakeholders, both those who can contribute to achieving port objectives and those who can be affected by port operations. Building upon significant scholarly contributions (e.g., Notteboom and Winkelmans, 2003; Notteboom et al., 2015; Ashrafi et al., 2020), this study identifies ten distinct groups of port stakeholders, which are presented in summarised form in Table 5.4.

Table 5. 4: Port stakeholder groups (PSGs).

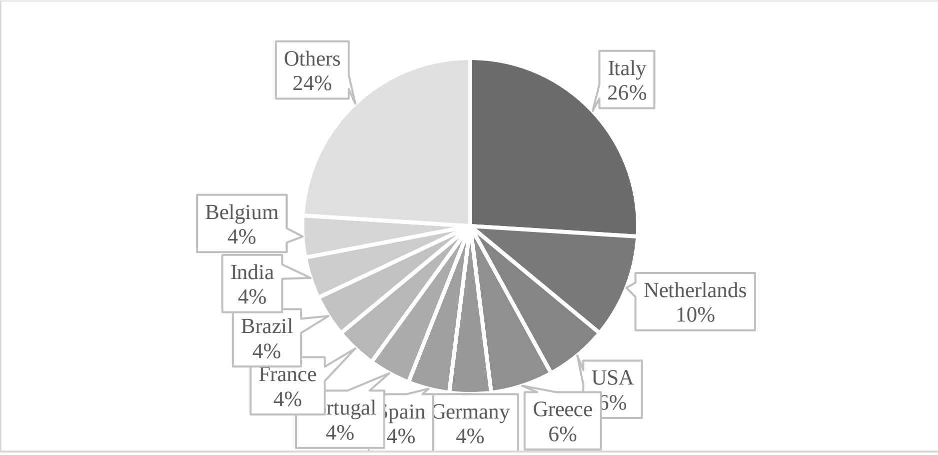
Group	Description
Shareholders /owners	Public entities or private organisations/firms which hold the ownership or at least a stake in the Port Authority (PA) or Port Managing Body (PMB), empowered to appoint the PA/PMB board of directors or executive directors (e.g., central government, regional governments, municipalities, and other public entities).
Financial community	Credit and financial institutions that provide funding to support PA/PMB investment decisions and port development.

Employees and labour unions	Labour unions, executive and operational employees in the port domain.
Terminal operators	Companies owning or operating a terminal under concession.
Other concessionaires	Firms operating at least a concession related to warehouses, industrial sites, logistics platforms, malls, or commercial areas in the port area.
Carriers	Shipping lines (container, ro-ro, cruise companies, etc.) and tramp operators (liquid bulk, dry bulk, etc.).
Port users	Freight forwarders, ship agents, brokers, road hauliers, railway companies, logistics providers, etc.
Passengers	Ferry or cruise ship travellers who pass through the port for embarking/disembarking.
Local community and societal groups of interests	People and organisations located close to the port areas and directly or indirectly impacted by port operations and business.
Regulatory agencies	Policymakers and public institutions that set the institutional framework and governance mechanisms.

Source: Authors' elaboration.

A structured questionnaire was administered to a panel of international experts with extensive expertise in ports to evaluate the prioritisation of crucial beneficiary PSGs about GSs (i.e., the second step of the indirect approach). The questionnaire was distributed online using Survey Monkey and it was sent to 75 experts. The survey was open for response from October 18, 2021, to December 18, 2021. Out of the 65 received responses, 50 were deemed complete and suitable for analysis, resulting in a response rate of 67%. The final panel's composition demonstrated consistency in dimension, heterogeneity, and respondents' experience. Notably, 70% of the participants had over ten years of experience in the maritime industry, with 36% having more than 20 years of experience. The responses were obtained from experts residing in 23 different countries (Figure 5.2.), ensuring a comprehensive evaluation of salient beneficiary PSGs.

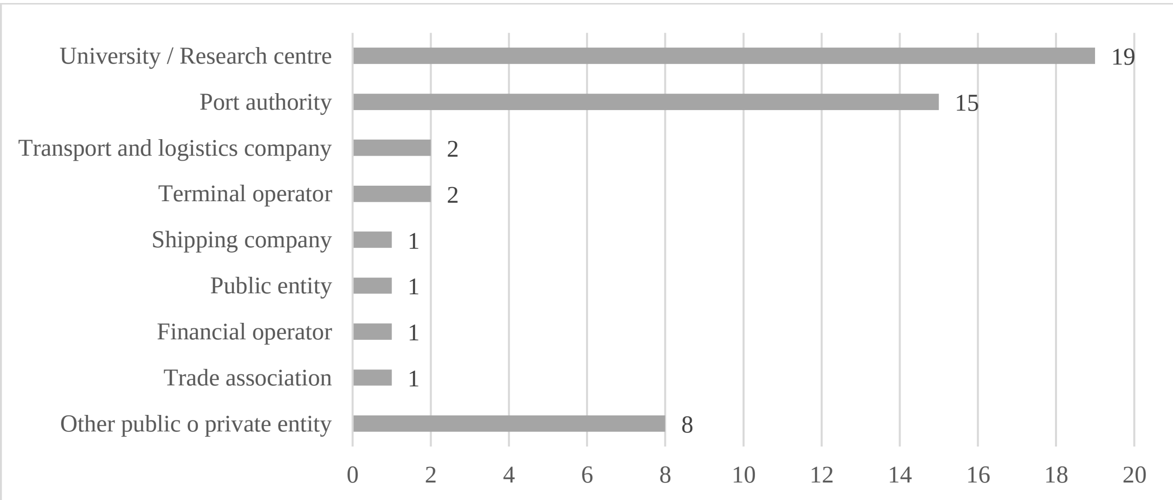
Figure 5. 2: Descriptive statistics of the survey respondents: country of employment.



Source: authors' elaboration

Furthermore, among the respondents, 38% were affiliated with universities or research centres, while 30% were associated with PMBs (Figure 5.3). The remaining panel members held positions in private companies such as shipping companies, transport and logistics firms, terminal operators, and financial operators. Additionally, some respondents held key positions within public entities, including municipalities, regions, transport-related ministries, national or international regulatory agencies, and other organisations involved in the port industry. This diverse representation within the panel ensured a comprehensive perspective from various sectors and institutions relevant to the field.

Figure 5. 3: Descriptive statistics of the survey respondents: type of company or public entity



Source: authors' elaboration

The questionnaire, administered to the international experts, requested them to assess the expected benefits for each PSG resulting from the implementation of GSs, using a 7-point Likert scale. The scale ranged from 1, indicating "no benefits," to 7, representing "maximum benefits." The responses were used to populate the "salient beneficiary stakeholders' matrix" in Table 5.5. This matrix captures the perspectives and experiences of the experts, mapping the 8 identified typologies of GSs in the rows and the 10 PSGs in the columns. The average scores assigned to each of the 80 combinations within the matrix were utilised as coefficients to estimate PMBs' prioritisation of stakeholders for GSs. The estimation follows the procedure outlined in Table 5.5: the average scores were used as coefficients (c_i where $i = 1, 2, \ldots 80$), multiplied by the number of GSs of each typology performed by the Italian PMBs of the sample (n_j where $j = 1,2, \ldots 8$). The sum of the results of each column ($\sum c_i * n_j$) constitutes the total score achieved by each PSG. The relative scores (i.e., $\sum c_i * n_j / \sum\sum c_i * n_j$) represent the estimation of stakeholder prioritisation for GSs performed by the Italian PMBs of the sample.

Finally, the matrix was tested on the Italian case, to carry out the last step of the indirect approach. The theoretical and empirical findings are reported and discussed in Section 5.4. The salient beneficiary stakeholders' matrix scores were normalised to understand the results better.

Table 5. 5: The salient beneficiary stakeholders' matrix.

Green strategy	*Shareholders/ owners*	*Financial community*	*Employees and labour unions*	*Terminal operators*	*Other concessionaires*	*Carriers*	*Port users*	*Passengers*	*Local community and societal groups of interests*	*Regulatory agencies*	*Total score*
Digitalisation and ICT platforms	c_1 x n_1	c_2 x n_1	…	…	…	…	…	…	…	c_{10} x n_1	$\sum$ c_i x n_1
Energy efficiency	…	…	…	…	…	…	…	…	…	…	…
Renewable energy production	…	…	…	…	…	…	…	…	…	…	…
Policies and measures	c_i x n_4	c_i x n_4	…	…	…	…	…	…	…	c_i x n_4	$\sum$ c_i x n_4
Bunkering and storage facilities for alternative fuels	…	…	…	…	…	…	…	…	…	…	…
Facilities and infrastructure for electric energy supply	…	…	…	…	…	…	…	…	…	…	…
Land-use conversion	…	…	…	…	…	…	…	…	…	…	…
Research and Development	C_{71} x n_8	c_{72} x n_8	…	…	…	…	…	…	…	C_{80} x n_8	$\sum$ c_i x n_8
Total score	$\sum$ c_i x n_j	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	$\sum$ c_i x n_j	$\sum\sum$ c_i x n_j
Relative score	$\sum$ c_i x n_j / $\sum\sum$ c_i x n_j	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	$\sum$ c_i x n_j / $\sum\sum$ c_i x n_j	**1**

Source: authors' elaboration

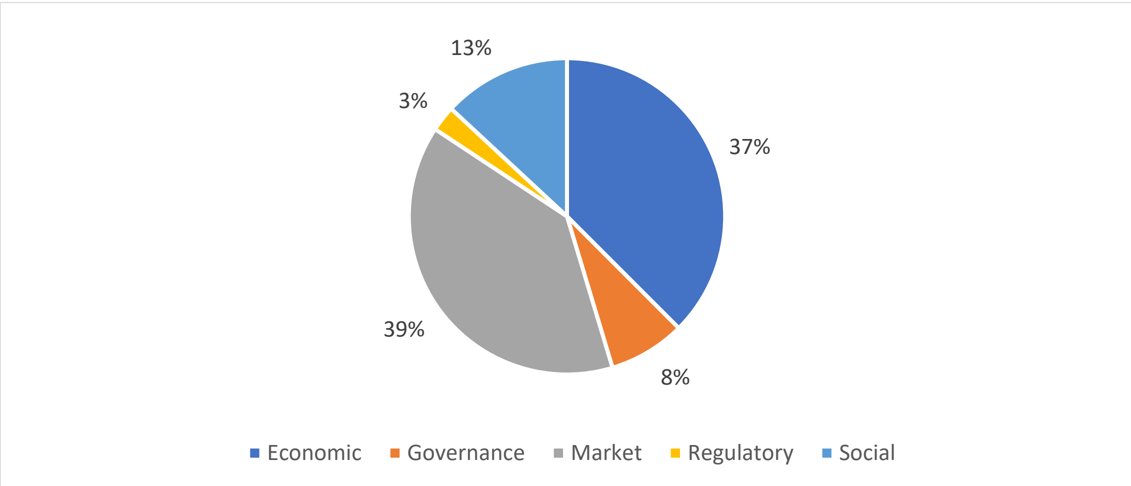
5.4. Findings

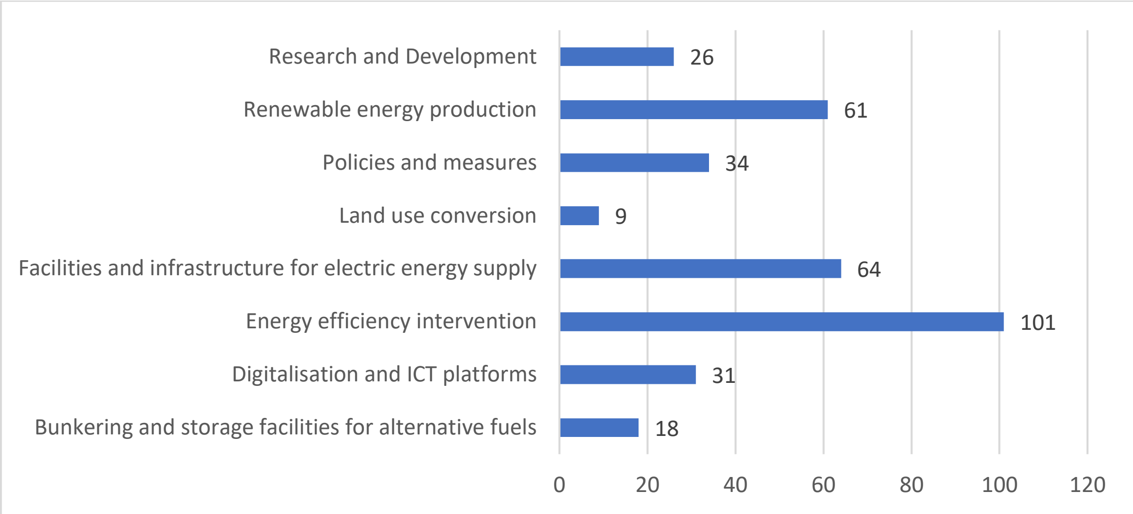
5.4.1. The main typologies of green strategies and related CSR objectives

Figure 5.4 reports the main typologies of GSs implemented by the Italian PMBs and related CSR objectives. As to be expected, the majority of GSs consist of actions and interventions for improving port energy efficiency (29% of the sample), followed by facilities and infrastructure for shore energy supply (19%) and renewable energy production (18%). Then, 10% of the sample concerns "policies and measure" interventions and 9% refer to "digitalisation and ICT platforms" (e.g., the integration of IoT systems to streamline port operations and monitor environmental impact; the establishment of a digital port community platform for seamless management of import and export processes; the deployment of unmanned robots for monitoring carrier activities and port infrastructure; and the implementation of a smart traffic tool and mobile application to enhance gate management efficiency and access). Research and development" accounts for 8%, "bunkering and storage facilities for alternative fuels" for 5% and only 3% of interventions concern "land use conversion".

Regarding CSR-related objectives, "market" and "economic" objectives (see Table 5.1 for details) emerge as the most diffused ones within the sample GSs (39% and 37% of the sample, respectively). Social objectives rank third (13%), followed by governance (8%) and regulatory objectives (3%).

Figure 5. 4: Green strategies typologies and related CSR objectives: The Italian port case.





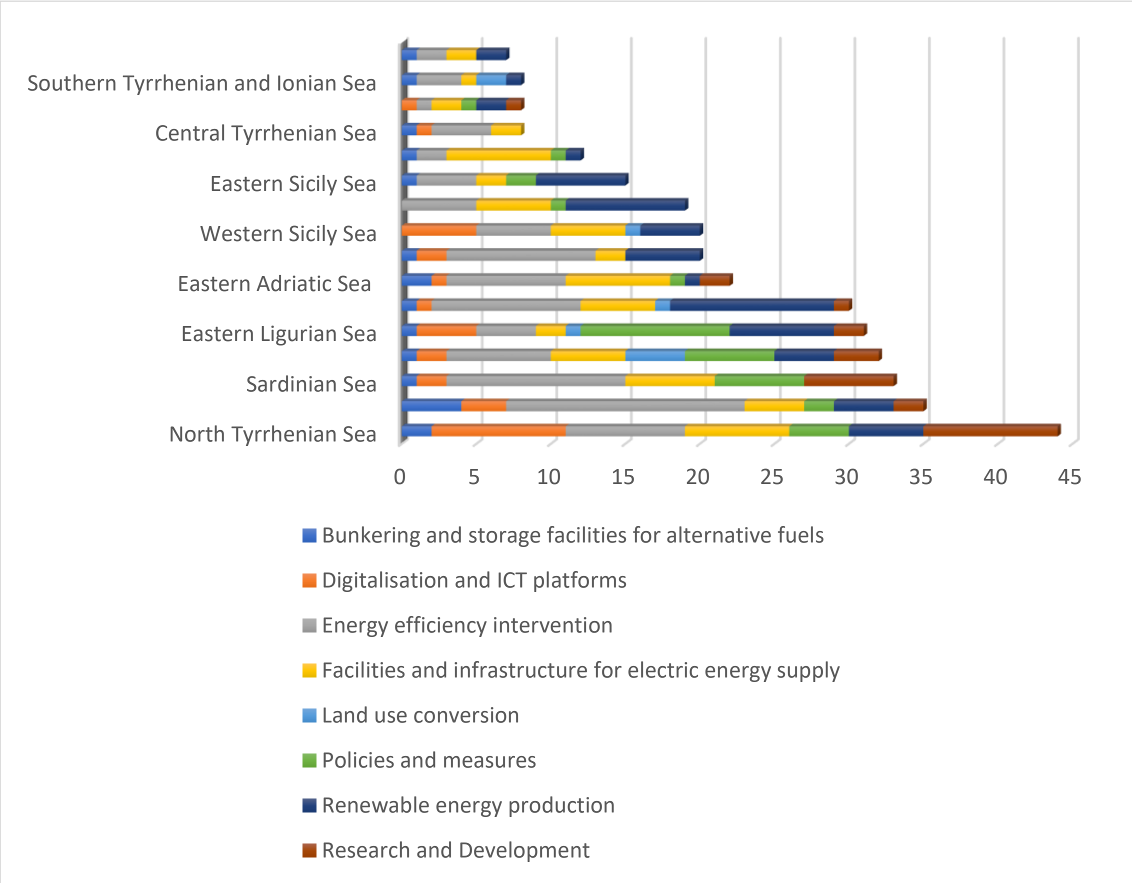
Source: authors' elaboration

The findings per single PMB are reported in figures 5.5 and 5.6. The North Tyrrhenian Sea Port Network Authority, consisting of the ports of Livorno, Piombino, Capraia, Portoferraio and Rio Marina, exhibits the most significant number of interventions (44), representing the lead Italian PMB for GSs regarding digitalisation and ICT platforms (9), and research and development (9).

Regarding energy efficiency and alternative fuels bunkering and storage facilities, the Northern Adriatic Sea Port Network Authority is the leader, with 16 and 4 GSs respectively. As energy hubs, ports consume different types of energy in substantial volumes. Thus, energy efficiency measures are crucial in making port activities more sustainable. The most prevalent interventions implemented by sample PMBs revolve primarily around three core areas: replacing conventional lighting fixtures with LED lighting systems, retrofitting the fleet of handling equipment (e.g., forklifts, reach stackers, straddle carriers), and enhancing port buildings' energy efficiency.

Conversely, bunkering and storage facilities for alternative fuels are almost neglected by Italian PMBs, except for the Eastern Adriatic Sea (Ports of Trieste and Monfalcone) and North Tyrrhenian Sea Port Network Authorities (Ports of Livorno, Piombino, Capraia, Portoferraio and Rio Marina) that have carried out two interventions primarily focused on LNG.

Figure 5. 5: The main findings from the Italian case: the most diffused green strategies



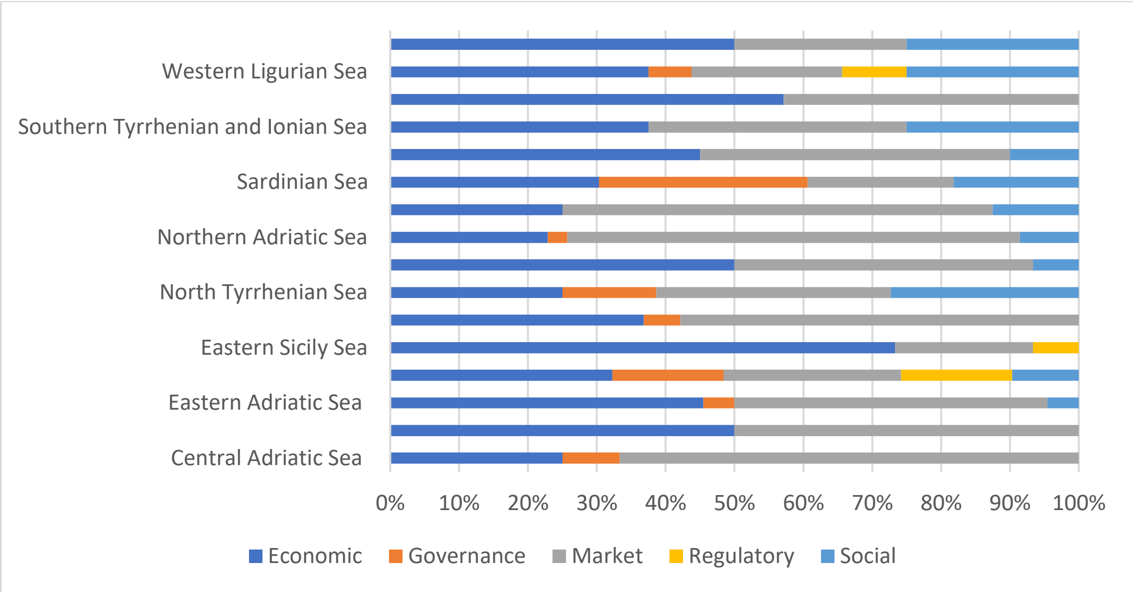
Source: authors' elaboration

The Western Ligurian Sea Port Network Authority (Ports of Genoa, Prà, Savona and Vado) shows the most comprehensive and diversified array of GSs. It is by far the Italian PMB with the most interventions regarding land use conversion (44% of the sample). Two specific projects named "Dune di Prà" have been initiated in this respect. The projects aim to establish a "green zone" between the operational area of the port of Genoa Prà and the adjacent urban regions to mitigate the acoustic impact of port operations and provide citizens with a new open-air space near the sea. Despite being a marginal investment, only the Southern Tyrrhenian and Ionian Sea (2) (Ports of Gioia Tauro, Corigliano, Crotone, and Palmi), Eastern Ligurian Sea (1) (Ports of La Spezia and Marina di Carrara), Northern Central Tyrrhenian Sea (1) (Ports of Civitavecchia, Fiumicino and Gaeta), and Western Sicily Sea (1) (Ports of Palermo, Termini Imerese, Porto Empedocle and Trapani) Port Network Authorities have shown participation in this particular category of interventions.

The Eastern Ligurian Sea Port Network Authority (ports of La Spezia and Marina di Carrara) is the most active in GSs related to policies and measures (29% of the sample).

It has devised a range of incentives aimed at facilitating the adoption of renewable energy sources by shipowners and terminal operators. The measures also include tariff changes, offering different prices to port stakeholders; market-based measures aiming at creating funds to promote the adoption of greener technologies, improve port management and offset greenhouse gas emissions; and voluntary agreements, which rely on the CSR behaviour of port stakeholders.

Figure 5. 6: The main findings from the Italian case: primary objectives of Italian PMBs



Regarding renewable energy production, the first-ranked Italian PMB is the Northen Central Tyrrhenian Sea Port Network Authority (accounting for 18% of the sample interventions). Most interventions primarily focus on installing photovoltaic plants due to their high technology readiness level (TRL), affordability, operating and maintenance costs. Unlike bunkering facilities, installing solar panels on building roofs eliminates the space constraint issue, making their implementation feasible. Consequently, it is unsurprising that photovoltaic plants rank as the third most frequently implemented green solution in Italian ports.

Concerning the “facilities and infrastructure for electric energy supply" category, the North Tyrrhenian, the Central Adriatic and the Eastern Adriatic Sea Port Network Authorities are the leaders in implementing these GSs (10% of the sample each). The main interventions are cold ironing and electricity recharge columns for vehicles. Supported by the National Recovery and Resilience Plan fund, all the Italian Sea Port

Network Authorities will install at least one cold ironing plant for supplying electricity to ships; this justifies its position as the second most implemented GS in Italian ports.

5.4.2. Stakeholder prioritisation for green strategies

The results from the questionnaire, administered to the panel of international experts, are presented in Table 5.6. The average scores highlight the salient beneficiary PSGs for each typology of GSs

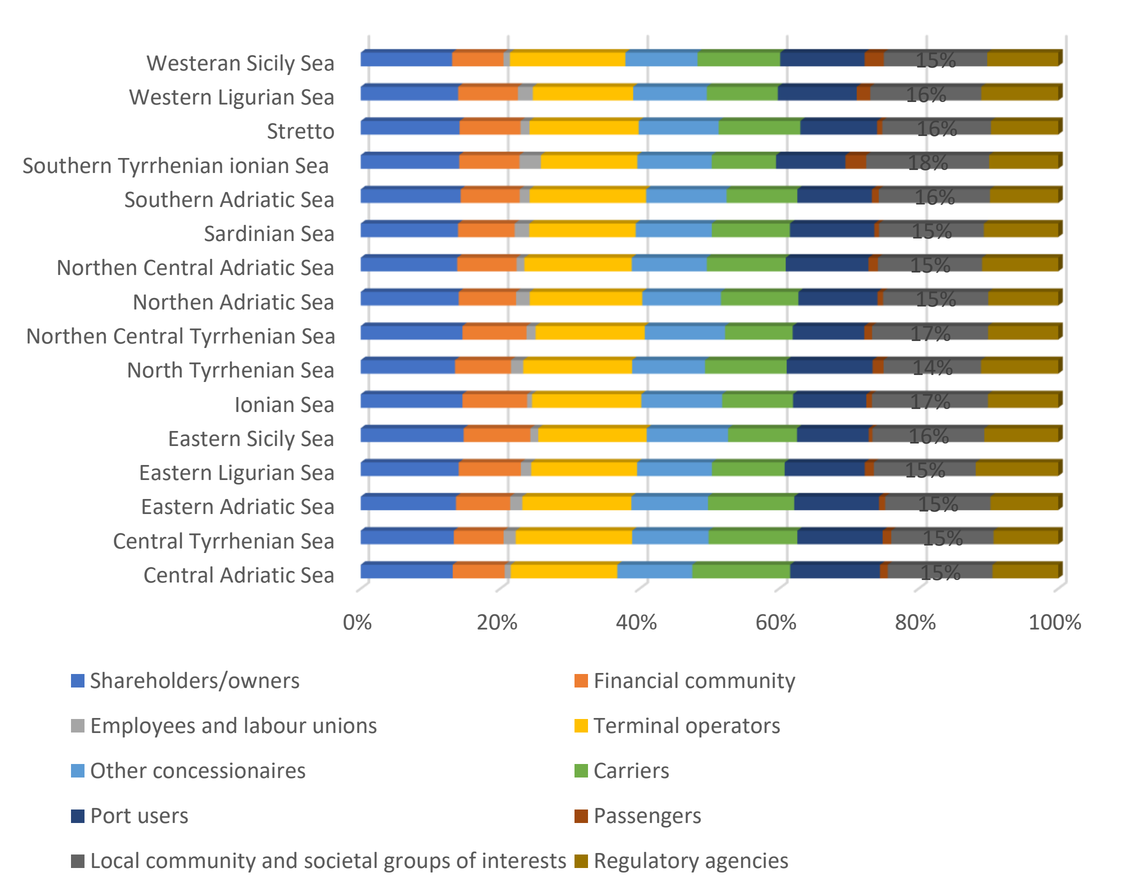
Table 5. 6: The salient beneficiary stakeholders' matrix: coefficients.

Green strategy	***Shareholders/ owners***	***Financial community***	***Employees and labour unions***	***Terminal operators***	***Other concessionaires***	***Carriers***	***Port users***	***Passengers***	***Local community and societal groups of interests***	***Regulatory agencies***
Digitalisation and ICT platforms	5.1	4.7	4.4	5.8	4.9	5.5	5.5	4.9	4.9	5.3
Energy efficiency	5.4	4.9	4.4	5.6	5.2	4.9	5.0	4.3	5.6	4.9
Renewable energy production	5.4	5.1	4.1	5.3	5.1	4.6	4.7	4.1	5.5	5.0
Policies and measures	5.4	5.0	4.4	5.4	5.1	5.1	5.2	4.2	5.3	5.3
Bunkering and storage facilities for alternative fuels	5.2	4.7	4.2	5.3	4.9	5.6	5.0	3.7	4.7	4.8
Facilities and infrastructure for electric energy supply	5.2	4.8	4.3	5.5	5.1	5.6	5.4	4.4	5.5	5.0
Land-use conversion	4.8	4.4	4.4	3.9	4.1	3.5	4.1	5.0	6.1	4.7
Research and Development	5.4	5.1	4.7	5.2	5.1	5.0	5.2	4.3	5.4	5.3

Source: authors' elaboration

Table 5.6 presents the normalised relative scores of the salient beneficiary stakeholders' matrix for each PMB in Italy. The rows in the table represent the hierarchy of PSGs for the Italian PMBs. Each cell value indicates the percentage level of prioritisation for each PSG.

Figure 5. 7: Stakeholder prioritisation for green strategies by Italian port managing bodies



Source. Authors' elaboration

Figure 5.7 presents the most important stakeholders target by Italian PMBs when implementing GSs. As expected, terminal operators represent the primary beneficiaries of GSs, with an average prioritisation of 15.6%. The results align with expectations. Given that terminal operators cater to the primary clients of PMBs, it is essential for the latter to strategically align with their expectations to achieve optimal outcomes. The focus on meeting the needs and goals of terminal operators reflects the significance of catering to their requirements for fostering productive and mutually beneficial relationships. The local community and societal interest groups are prominent beneficiaries at 15.5%, with shareholders/owners following closely in the third position at 14.0%. Interestingly, passengers, employees, and labour unions receive lower rankings in prioritisation, suggesting comparatively less focus on their concerns and needs.

While there are no substantial variations among the scores achieved by each PSG, essential distinctions emerge among the PMBs included in the sample. The Southern Tyrrhenian Ionian Sea (ports of Gioia Tauro, Corigliano, Crotone, and Palmi), Northern Central Tyrrhenian Sea (ports of Civitavecchia, Fiumicino and Gaeta), and Ionian Sea

(Port of Taranto) Port Network Authorities demonstrate a higher priority for the local community and societal interest groups, with respective scores of 17.6%, 16.6%, and 16.6%. In contrast, terminal operators take precedence in the Central Tyrrhenian Sea (ports of Naples, Castellammare di Stabia and Salerno), Southern Adriatic Sea (ports of Bari, Brindisi, Manfredonia, Barletta and Monopoli), and Western Sicily Sea (ports of Palermo, Termini Imerese, Porto Empedocle and Trapani) Port Network Authorities, that reported scores of 16.7%, 16.7%, and 16.6%, respectively. Compared to other PMBs in the sample, the Central Adriatic Sea Port Network Authority (ports of Ancona, Falconara, Pescara, Pesaro, San Benedetto del Tronto and Ortona) pays significant attention to carriers and port users, evidenced by 14.0% and 12.9%, respectively. The Port Network Authorities of the Ligurian Sea, i.e. Western Ligurian Sea (ports of Genoa, Prà, Savona and Vado) and Eastern Ligurian Sea (ports of La Spezia and Marina di Carrara), while prioritising terminal operators and local communities as the most relevant stakeholders, also assign notable significance to shareholders/owners, with scores of 14.1% for the Eastern Ligurian Sea and 14.0% for the Western Ligurian Sea. These variations reflect the contexts and dynamics within each PMB, underscoring the diverse stakeholder priorities across different regions.

5.5. Discussion

In response to RQ1, which focuses on identifying the primary typologies of GSs adopted by PMBs and their corresponding CSR objectives, our findings reveal three main typologies of GSs. These include energy efficiency, accounting for 29% of the sample; facilities and infrastructure for shore supply (19%); and renewable energy production, representing 18% of the sample. The findings are unsurprising and validate the observation that Italian ports are actively implementing GSs that align with the core objectives of the European Green Deal, which are geared toward advancing the industry's transition to environmentally sustainable energy practices. To date, the Environmental and Energy Plans of the Italian Port System (DEASP) show that investments in green strategies amount to more than €200 million in the 2022-2023 period, considering only of completed projects with reported figures. Green investments in the Italian port industry are expected to increase significantly in the next years. In this vein, for example, the first round of the “Green Ports” project, i.e., the recent national bidding procedure (deadline expired in November 2021), which provided public incentives for both PMBs and private operators investing in green port projects located in the Northern and Central Italy, has guaranteed over 270 million euros for green projects (not included in the previously reported figures) planned in the next years (to be accomplished by December 2027). In addition, a similar amount of financial resources will be earmarked for ports located in Southern Italy in the next two years. Furthermore, these findings align with the principal goals outlined in the Italian National Recovery and Resilience Plan which foresees funding for port modernisation and efficiency measures of more than EUR 2.8 billion for the years 2021 to 2026, including the ambitious plan to electrify the quays of 34 Italian ports4 before 2026. Finally, our analysis reveals that only 3% of the interventions are related to land use conversion. This finding emphasises the need for increased efforts in transforming port areas by altering their usage to generate value for the local community. This perspective is also supported by authors such as Felício et al. (2023), who have demonstrated how sustainable port practices can influence the perception of ports by local communities. This implies that more attention and action are required to convert and repurpose port areas, ensuring they align with sustainable development goals and positively impact the surrounding communities.

Our results show that market and economic objectives take precedence within the sampled Italian PMBs, represented 39% and 37% of the total CRS-related objectives. Economic objectives revolve around creating value within the port system, enhancing competitiveness, and optimising operational efficiency (e.g., construction of a new branch line to supply power to towers T18 and T19, as well as lighting systems with LED lights in the Port of Olbia). On the other hand, market objectives focus on meeting the expectations of firms within the maritime cluster, effectively responding to market pressures and competition (e.g. implementation of cold ironing in the Port of La Spezia). These findings underscore the paramount importance of GSs in not only reducing the environmental impact of port activities but also in bolstering the overall competitiveness of the Italian port system. Social objectives constitute 13% of the identified GSs, reflecting the increasing interest of Italian PMBs in obtaining the social license to operate

[4] Port of La Spezia, Port of Leghorn, Port of Piombino, Port of Portoferraio, Port of Civitavecchia, Port of Naples, Port of Salerno, Port of Goia Tauro, Port of Cagliari, Port of Olbia, Port of Golfo Aranci, Port of Torres, Port of S. Teresa di Gallura, Port of Portovesme, Port of Palermo, Port of Trapani, Port of Termini Imerese, Port of Empedocle, Port of Catania, Port of Augusta, Port of Taranto, Port of Ancona, Port of Pesaro, Port of San Benedetto di Tronto, Port of Ortona, Port of Pescara, Port of Ravenna, Port of Venezia, Port of Trieste, Port of Porto di Monfalcone, Port of Rovigo, Port of Nogaro, Port of Siracusa, Port of Gela.

and enhancing their public image. The recognition of social objectives signifies a shift in the mindset of port managers towards assuming greater social responsibility and engaging meaningfully with local communities. Though rooted in the nuances of the Italian context, our study's methodology holds potential for broader generalisation. Our survey questions transcend specific national boundaries by employing an indirect approach facilitated by input from a panel of international experts. Consequently, the resultant matrix offers a versatile tool for investigating ports in various countries. Furthermore, our ongoing research aims to provide valuable benchmarks for assessing the evolving prioritisation strategies of PMBs concerning emerging stakeholder categories.

Regarding RQ2, which focuses on identifying the key beneficiaries of GSs implemented by PMBs, we have utilised an indirect empirical approach to estimate stakeholder prioritisation. The findings unveil three prominent PSGs for PMBs: terminal operators (15.6%), the local community and societal interest groups (15.5%), and shareholders/owners (14.0%). These findings align with the resulting CSR-related objectives. Terminal operators and shareholders prioritise economic and market objectives, while the local community and social interest groups focus on social objectives. Notably, the local community and social interest groups rank second, ahead of shareholders, and nearly on par with terminal operators. This underscores the importance of GSs in achieving social approval and emphasises the necessity of considering the perspectives of local communities in port decision-making processes. This is a consequence of the growing recognition of the substantial impact of port activities on air quality, especially in coastal regions, as substantiated by studies like that of Gilbert et al. (2018). This research reveals that approximately 70% of ship emissions occur within 400 km off the coast, with severe implications for local communities. Given the well-known high emissions associated with port operations, an ongoing dialogue with the surrounding community is crucial.

This emerging inclusive approach of PMBs aims to jointly address the challenges of maintaining business continuity while effectively managing both short-term and long-term environmental concerns. Through proactive collaboration, port managers can foster shared responsibility and pursue sustainable solutions that balance economic and ecological considerations. For example, the Blueconnect project, conducted by the Eastern Ligurian Sea Port Network Authority aims to establish a collaborative network among companies, institutions, and industry operators to implement initiatives and policies for supporting the transition of the port of La Spezia into a smarter and more environmentally sustainable port. Another noteworthy initiative is the Aer Nostrum project, which not only engages terminal operators and shipping companies but also fosters collaboration among various Italian Port Managing Bodies (PMBs) to enhance air quality in ports and surrounding areas. This project engages Port Network Authorities of the North Tyrrhenian Sea (ports of Livorno, Capraia, Piombino, Rio Marina, Portoferraio, and Cavo), the Sardinian Sea (ports of Cagliari, Olbia, Golfo Aranci, Porto Torres, Oristano, Portovesme, and Santa Teresa Gallura), and the Western Ligurian Sea (ports of Genoa, Prà, Savona, and Vado) that have collaborated to implement an innovative model for monitoring and forecasting emissions within ports. This model not only facilitates the collection of crucial data but also empowers them to strategically plan and share sustainable actions, taking into account both environmental and economic factors. The literature on green business typically distinguishes between firms that adhere to compliance-driven approaches, which focus primarily on meeting legal mandates, and those that embrace proactive environmental strategies, considering a range of factors beyond government regulation (Aragòn-Correa et al., 2020). Specifically, incorporating environmental considerations into corporate strategy beyond what is mandated by government regulations can be seen as a means of enhancing a company's alignment with the increasing environmental concerns and expectations of its stakeholders. The findings of this study show that the GSs implemented by PMBs reflect an endeavour to meet the expectations of emerging PSGs (i.e., local community and societal interest groups) that go beyond what is required by the regulations. These PSGs are, therefore, recognised as crucial participants in the development of port corporate strategies, signifying a noteworthy transformation in the management of the conservative port industry.

Interestingly, our findings underscore that employees and labour unions hold a lower position in the PSG hierarchy. Despite Italian PMBs' high sensitivity to social issues concerning port labour, as reflected in the DPSS and related initiatives, GSs do not substantially benefit port workers. Workplace safety and labour rights are prominent concerns within the port domain but have limited connection with GSs. As discussed in the literature, organisations with a track record of inadequate quality management concerning environmental and social concerns related to their employees may encounter difficulties in attracting or retaining highly skilled personnel. These employees are often strongly inclined toward organisations with proactive environmental management practices (Buysse & Verbeke, 2003; Klefsjö et al., 2008). In this context, the effectiveness of PMBs can be significantly enhanced through the cultivation of green competencies, a process heavily reliant on the participation and engagement of their employees.

This discussion underscores that Italian ports primarily embrace environmental sustainability initiatives in alignment with the objectives set forth in the European Green Deal. This is in line with previous literature that suggests that policies aimed at further investments in these areas could significantly contribute to improving port competitiveness (Woo et al., 2028). Moreover, such policies can align with the expectations of PSGs, ultimately enhancing the competitiveness of ports. The findings also indicate that Italian PMBs prioritise economic and market objectives. Consequently, it is imperative for policies to seek a delicate equilibrium between these objectives and environmental aspirations. By doing so, policies can encourage businesses to adopt sustainable practices while safeguarding their competitiveness. Continuing to prioritise and actively promote the engagement of local communities in port decision-making processes through communication about upcoming port authority meetings, newly proposed infrastructure projects, notices of environmental impact documents, port commission meeting minutes and monitoring of environmental performance remains of paramount importance (Rodrigues & Ensslin, 2023). For example, in 2021, the Western Ligurian Sea Port Network Authority organised the first Italian public debate regarding the construction of the new outer breakwater for the Port of Genoa. Activating this procedure was pivotal in planning a significant port infrastructure project of national importance, aimed at facilitating the development of the port area and enhancing economic traffic. Given the potential environmental and social impact, the project underwent community evaluation through four meetings to gather feedback and proposals to enrich the design, as well as to address any potential disagreements and achieve a consensus-approved project. This demonstrates local communities are gaining ever more influence in shaping the trajectory and success of port businesses, especially in urban areas closely tied to port infrastructure where the environmental impact is felt more. Therefore, policies should persist in fostering strong community involvement. However, it is noteworthy that employees and labour unions appear to hold a comparatively lower position within PMBs' stakeholder hierarchy. To rectify this, policies could be instrumental in encouraging port businesses to establish and implement GSs with a focus on encouraging green behaviours (e.g., reducing resource consumption, waste generation, and overall environmental impacts), improving workplace safety, thereby enhancing the well-being of employees of the port business.

5.6. Conclusion

The study delves into the emerging and significant domain of green strategies within the conservative port industry, employing a strategic management lens. It introduces a robust conceptual framework integrating the foundational principles of stakeholder management and, more specifically, of CSR to comprehensively unveil and categorise the primary types of GS activities carried out by PMBs. To validate empirically the effectiveness of the conceptual framework, the study conducts an extensive investigation of all sixteen Italian PMBs to answer two distinct and compelling research questions.

This paper contributes substantially to the academic debate regarding the interplay between environmental initiatives and stakeholder management in the port sector, by introducing an indirect empirical approach for stakeholder prioritisation. It also offers valuable insights to aid port managers in enhancing their decision-making processes regarding GSs. This approach allows managers to effectively assess and prioritise the diverse PSGs based on their specific needs and preferences. Consequently, ports can optimise their portfolio of GSs, tailoring strategies to maximise the benefits for targeted PSGs. Additionally, the findings provide policymakers with valuable insights that can serve as a cornerstone for nurturing the ongoing development of GSs in ports. These insights can potentially advance the environmental sustainability efforts of ports, striking a harmonious balance between economic, market and environmental objectives, fostering the involvement of local communities and diverse stakeholders in decision-making processes, and encouraging employee engagement in sustainability initiatives.

Nevertheless, it is crucial to recognise specific limitations in this paper, which provide opportunities for future research. Firstly, since many of the GSs discussed in this study are yet to be implemented, assessing their impact becomes challenging. The analysis primarily relies on projections and expert opinions, which may introduce uncertainty in evaluating benefits. Secondly, the assessment of the benefits of PSGs is based on the perspective of international experts who participated in the survey panel. This may introduce a certain degree of bias to the empirical analysis. To enhance the robustness of the coefficients associated with the GSs-PSGs matrix, future studies could incorporate the perspectives of the PSGs themselves. A more comprehensive and balanced understanding can be obtained by directly evaluating their own perceptions of the benefits derived from each typology of GSs. Addressing these limitations will strengthen the empirical analysis and provide a more nuanced understanding of the potential impact and benefits of GSs for different PSGs. It is recommended that future research endeavours consider PSG perspectives as an integral part of the evaluation process, ensuring a more holistic assessment of the benefits arising from various GSs.

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Appendices

Appendix 5.1. Green Strategies database

Port Authority	Project	Description	GS Typology	Objectives
Central Adriatic Sea	Ancona Blue Agreement	The agreement reduces the sulphur content of the fuels used to 0.1% for main and auxiliary engines from the end of the mooring manoeuvre in port until departure and exit from the port, compared to the 1.5% required by law.	Policies and measures	Governance
Central Adriatic Sea	Cogeneration plant and storage system	Installation of a cogeneration plant and a storage system for energy production and storage in the port	Energy efficiency intervention	Economic
Central Adriatic Sea	Cold ironing - Ferries terminal at Port of Ancona	Cold ironing system for ferries moored in the historic port of Ancona	Facilities and infrastructure for electric energy supply	Market
Central Adriatic Sea	Cold ironing - Molo Martello	Electrification of the Molo Martello quay to supply power to small passenger or service vessels	Facilities and infrastructure for electric energy supply	Market
Central Adriatic Sea	Cold ironing - Port of Ancona	Columns for low-voltage power supply of small boats for Harbour Master's Office, Navy, Guardia di Finanza, and towing service (Corima)	Facilities and infrastructure for electric energy supply	Market
Central Adriatic Sea	Cold ironing - Port of Ortona	Electrification of mooring docks to supply power to self-propelled cranes in the port of Ortona	Facilities and infrastructure for electric energy supply	Market
Central Adriatic Sea	Cold ironing - Port of Pesaro	Electrification of the docks in the Port of Pesaro	Facilities and infrastructure for electric energy supply	Market
Central Adriatic Sea	Cold ironing - Port of Pescara	Electrification of the commercial dock to supply power to passenger or service vessels of limited size	Facilities and infrastructure for electric energy supply	Market
Central Adriatic Sea	Cold ironing - Port of San Benedetto del Tronto	Electrification of the docks in the Port of San Benedetto del Tronto	Facilities and infrastructure for electric energy supply	Market
Central Adriatic Sea	District heating	Construction of a district heating loop network using waste heat from the power plant.	Energy efficiency intervention	Economic
Central Adriatic Sea	LNG storage terminal	construction of an LNG storage terminal	Bunkering and storage facilities for alternative fuels	Market
Central Adriatic Sea	Photovoltaic plant - Port of Ancona	The fully integrated Photovoltaic plant was built on the roofs of the former Tubimar industrial plant (warehouses) in the Port of Ancona, owned by the Port Authority.	Renewable energy production	Economic
Central Tyrrhenian Sea	Cold ironing - Port of Naples	Installation of a Cold ironing plant to supply electricity to the ship in port	Facilities and infrastructure for electric energy supply	Market
Central Tyrrhenian Sea	Cold ironing - Port of Salerno	Electrification of two quays, one of which belongs to the Molo Trapezio and the other to the Molo di Ponente where Containers and RO-RO ships berth respectively.	Facilities and infrastructure for electric energy supply	Market

Central Tyrrhenian Sea	Energy efficiency intervention - Port of Naples	Installation of Photovoltaic plants on the roofing surfaces of some state-owned buildings in the port area	Energy efficiency intervention	Economic
Central Tyrrhenian Sea	Energy infrastructures - monumental area of the Port of Naples	Upgrading and redevelopment of infrastructures in the monumental area of the Port of Naples for passenger traffic, port activities and connection with the city.	Energy efficiency intervention	Economic
Central Tyrrhenian Sea	Lastmile rail link	The project conists of reorganising of last-mile rail links and port road network in the Port of Naples	Digitalisation and ICT platforms	Market
Central Tyrrhenian Sea	LED Lighting system replacements - Port of Naples	Replacement of conventional luminaires with LED technology	Energy efficiency intervention	Economic
Central Tyrrhenian Sea	LNG storage facilities	Construction of LNG coastal storage facilities in the Port of Naples	Bunkering and storage facilities for alternative fuels	Market
Central Tyrrhenian Sea	SUSPORT – Sustainable Ports	Reduce the emission from ships during the stop in port and installation of LED lighting system	Energy efficiency intervention	Economic
Eastern Adriatic Sea	ACCESS2NAPA	Design of infrastructure projects including enhancement of railway tracks and Cold ironing.	Research and Development	Economic
Eastern Adriatic Sea	Clean Berth Project	Retrofit of the car fleet of the Port Authority	Energy efficiency intervention	Economic
Eastern Adriatic Sea	Cold ironing - Port of Monfalcone	Electrification of the docks at the port of Monfalcone	Facilities and infrastructure for electric energy supply	Market
Eastern Adriatic Sea	Cold ironing - Port of Trieste at Bersaglieri Pier docks	Electrification of the Bersaglieri Pier docks	Facilities and infrastructure for electric energy supply	Market
Eastern Adriatic Sea	Cold ironing - Port of Trieste at Pier V and Riva Traiana	Electrification of the quays at Pier V and Riva Traiana	Facilities and infrastructure for electric energy supply	Market
Eastern Adriatic Sea	Cold ironing - Port of Trieste at Pier VII	Electrification of the quays at Pier VII	Facilities and infrastructure for electric energy supply	Market
Eastern Adriatic Sea	Cold ironing - Port of Trieste at Timber yard	Electrification of docks Timber yard, Logistics platform.	Facilities and infrastructure for electric energy supply	Market
Eastern Adriatic Sea	EALING	Electrification of the port's quays including the Ro-Ro terminal between Pier V and Pier VI	Facilities and infrastructure for electric energy supply	Market

Eastern Adriatic Sea	High-efficiency LED lamps	Replacement of existing lamps (high-pressure sodium) with high-efficiency LED lamps, i.e. above 150 lumens/W.	Energy efficiency intervention	Economic
Eastern Adriatic Sea	Insulating materials at Torre Lloyd	Improve energy savings by choosing windows and doors with insulating materials for the Torre del Lloyd	Energy efficiency intervention	Economic
Eastern Adriatic Sea	Insulation materials at the building Addossato 53	Improve energy savings by choosing windows and doors with insulating materials forthe building "Addossato 53"	Energy efficiency intervention	Economic
Eastern Adriatic Sea	METRO	METRO studies physical interface between the hybrid ship and the port infrastructure on Trieste area. It provides several analysis to find a future solution to create a charging station in the port.	Facilities and infrastructure for electric energy supply	Market
Eastern Adriatic Sea	New heat pump	Replacing the old oil-fired heat generator with a heat pump	Energy efficiency intervention	Economic
Eastern Adriatic Sea	Photovoltaic plant - Torre Lloyd	Photovoltaic plant installation on Torre Lloyd	Renewable energy production	Economic
Eastern Adriatic Sea	PIXEL project	PIXEL is a smart, flexible and scalable solution for reducing environmental impacts while enabling the optimization of operations in port ecosystems through IoT.	Digitalisation and ICT platforms	Market
Eastern Adriatic Sea	POSEIDON MED	Its ultimate objective is to prepare in detail a global solution of infrastructure development in the Mediterranean area so that LNG can be embraced as the marine fuel of the future making thus shipping more efficient and sustainable	Bunkering and storage facilities for alternative fuels	Market
Eastern Adriatic Sea	Railway Terminal and LNG Facility	Study and design of LNG bunkering facility in the port of Trieste	Bunkering and storage facilities for alternative fuels	Market
Eastern Adriatic Sea	REMEMBE R	Enhancement of the historical, monumental and intangible heritage of the ports in terms of tourism and generation of new economy and new employment.	Policies and measures	Social
Eastern Adriatic Sea	Retrofit of heating system of Torre Lloyd	Retrofit of heating system with fuel change from oil to natural gas on the Torre del Lloyd	Energy efficiency intervention	Economic
Eastern Adriatic Sea	SUSPORT – Sustainable Ports	Replace the lighting systems of public areas of the port with LED systems and purchase electric car	Energy efficiency intervention	Economic
Eastern Adriatic Sea	Sustainable Ports in the Adriatic-Ionian Region	Within SUPAIR project the Port Authority of Trieste will elaborate a Low Carbon Port Action Plan outlining the initiatives to be taken in view of an increasingly attention paid to environmental protection through the decarbonisation of the port's activities.	Research and Development	Governance
Eastern Adriatic Sea	Thermal insulation of building Addossato 53	Thermal insulation of building "Addossato 53"	Energy efficiency intervention	Economic
Eastern Ligurian Sea	Blueconnect	The project wants to create a network of companies, institutions, operators of the sector and the territory, to the realization of a greener and smarter port of the future.	Policies and measures	Governance
Eastern Ligurian Sea	Blueconnect	The project wants to create a network of companies, institutions, operators of the sector and	Policies and measures	Governance

		the territory, to the realization of a greener and smarter port of the future.		
Eastern Ligurian Sea	Cold ironing - Gulf Terminal	Realization of Cold ironing infrastructure and network through one connection of 6 MW and one of 4 MW which will supply two ships simultaneously.	Facilities and infrastructure for electric energy supply	Market
Eastern Ligurian Sea	Cold ironing - La Spezia port	Realization of Cold ironing infrastructure in the port of La Spezia powered through an independent system of 10MW.	Facilities and infrastructure for electric energy supply	Market
Eastern Ligurian Sea	COMODAL CE	The project will improve the multimodal freight transport in Central Europe through the use of ICT systems that optimize the coordination and interoperability between the systems currently adopted by the actors of the logistics chain (ports - transport operators - freight villages).	Digitalisation and ICT platforms	Market
Eastern Ligurian Sea	Energy efficiency intervention at the La Spezia Container Terminal	Replacement of the current SAP lights on RTG and STACKING cranes with a new LED lighting system that will achieve significant energy savings.	Energy efficiency intervention	Market
Eastern Ligurian Sea	Energy efficiency intervention of buildings and outdoor areas	Planning and implementation of measures to reduce the energy consumption of different energy vectors, including concessionaires and port operators.	Energy efficiency intervention	Economic
Eastern Ligurian Sea	Fenix	Digitalisation of the multimodal logistics chain in the Core TEN-T port of La Spezia.	Digitalisation and ICT platforms	Market
Eastern Ligurian Sea	GEREMIA	The objective is to provide innovative tools and solutions for managing port waters.	Policies and measures	Governance
Eastern Ligurian Sea	Green electricity supply measure	Purchase of electricity on the market with a certificate of guarantee of the origin that would allow more accurate quantification of CO_2eq emissions without using national conversion factors.	Policies and measures	Governance
Eastern Ligurian Sea	IMPATTI-NO	Improvement of the managerial practices for port-waste through the development of a circular economy model.	Research and Development	Social
Eastern Ligurian Sea	Incentives for Cold ironing	Realization of some new mooring quays equipped with Cold ironing in the port of La Spezia.	Policies and measures	Regulatory
Eastern Ligurian Sea	Incentives for Energy efficiency intervention	Reduction of concession fees according to the reduction of CO_2eq emissions through the implementation of Energy efficiency intervention measures on buildings or processes as well as the expense of the concessionaires.	Policies and measures	Regulatory
Eastern Ligurian Sea	Incentives for reducing environmenta l impact	The AdSP could incentivize the mooring of vessels characterized by a good ESI score (related to pollutant emissions) through a reduction in the value of mooring fees.	Policies and measures	Regulatory
Eastern Ligurian Sea	Incentives for Renewable Energy Sources	Incentives related to the construction and adoption of RES by concessionaires.	Policies and measures	Regulatory
Eastern Ligurian Sea	Intermodel	The project aims to develop an integrated platform to support the multimodal transport system with	Policies and measures	Governance

		the use of key performance indicators (KPI) and risk indicators (KRI).		
Eastern Ligurian Sea	LED lighting towers - Port of La Spezia	Conversion of the approximately 1 kW high-pressure sodium (SAP) floodlights currently installed in 7 Lighthouse Towers to new high efficiency LED technology floodlights of approximately 300 W.	Energy efficiency intervention	Economic
Eastern Ligurian Sea	Lighting system replacement at the port of Marina di Carrara	Increasing efficiency of the lighting system together with the lighthouse (today SAP type).	Energy efficiency intervention	Economic
Eastern Ligurian Sea	LNG infrastructure supply	Development of a series of scenarios and projects to implement a strategic road map for the LNG supply chain in the Port of La Spezia.	Bunkering and storage facilities for alternative fuels	Market
Eastern Ligurian Sea	Mon Acumen	The project aims to reduce the acoustic impact generated by ports.	Research and Development	Social
Eastern Ligurian Sea	Photovoltaic plant - Cantieri Apuania	Installation of a 100 kWp Photovoltaic plant on the roof of an existing shed: 9 strings are polycrystalline Sunerg XP 60/156-250, 250 Wp each.	Renewable energy production	Economic
Eastern Ligurian Sea	Photovoltaic plant - Ferretti	Installation of a 244.8 kWp Photovoltaic plant on the roof of two warehouses in the port of La Spezia.	Renewable energy production	Economic
Eastern Ligurian Sea	Photovoltaic plant - Port of La Spezia 1	Feasibility analysis to produce electricity from photovoltaics through an approach based on a GIS (Geographic Information System), which has allowed to realize a mapping of solar radiation and potential production of energy.	Renewable energy production	Economic
Eastern Ligurian Sea	Photovoltaic plant - Port of La Spezia 2	Realization of a Photovoltaic plant to be installed on the road sound barriers near the road underpass with the adoption of photovoltaic modules of size 1000x1560mm with a peak power of 327 Wp.	Renewable energy production	Economic
Eastern Ligurian Sea	Photovoltaic Plant - Warehouses	Installation of two Photovoltaic plants of 100 kWp each on the roof of two new warehouses.	Renewable energy production	Economic
Eastern Ligurian Sea	Protocol for reducing the Impact of vessel emissions within port docks	This protocol aims to improve the laws currently in force that require fuel changes within a maximum of two hours after the end of mooring operations with specific reference to switching to a fuel with a sulphur content of less than 0.1% by mass.	Policies and measures	Regulatory
Eastern Ligurian Sea	Transport infrastructures system for CO_2 reduction	Upgrading and optimisation of the Varco Stagnoni to reduce bottlenecks and emissions from trucks.	Digitalisation and ICT platforms	Market
Eastern Ligurian Sea	Ursa Major Neo	Development of ITS (Intelligent Transportation System) services to improve freight traffic on the TEN-T road network and reduce congestion.	Digitalisation and ICT platforms	Market
Eastern Ligurian Sea	Waterfront Marina of Carrara	The project aims to create a new seafront promenade in the Tuscan town, consisting of walking, jogging, relaxation, and leisure by the sea.	Land use conversion	Social
Eastern Ligurian Sea	Wave energy production	A preliminary analysis for the installation of wave power systems in the Gulf of La Spezia and Marina di Carrara.	Renewable energy production	Economic

Eastern Ligurian Sea	Wind power generation	Installation of wind power generation systems in the Gulf of La Spezia and Marina di Carrara, analysing the data collected by the anemometer stations.	Renewable energy production	Economic
Eastern Sicily Sea	Cold ironing - Augusta port	Construction of an electrification plant for the port quays to achieve economic and environmental sustainability.	Facilities and infrastructure for electric energy supply	Market
Eastern Sicily Sea	Cold ironing - Catania port	Construction of an electrification plant for the port quays to achieve economic and environmental sustainability.	Facilities and infrastructure for electric energy supply	Market
Eastern Sicily Sea	Electric vehicles	The AdSP plans over the next three years to replace the most obsolete vehicles with green electrically driven green cars. The administration will finance the construction of electric fast-charging stations in areas of state property that are not under concession.	Policies and measures	Economic
Eastern Sicily Sea	Energy efficiency intervention and use of renewable sources	The AdSP wants to promote agreements/conventions with ship owners/port operators/concessionaires in order to incentivise them to carry out, Energy efficiency intervention measures in ports. In particular, these agreements/conventions may include incentive measures or tax reliefs to be promoted for port operators.	Policies and measures	Regulatory
Eastern Sicily Sea	Energy efficiency intervention in the Port of Augustus	In the buildings covered by the intervention, work will be carried out to install thermal insulation and soundproofing 'coat' cladding on all opaque vertical surfaces; while the existing window and door frames will be replaced with aluminium alloy, thermal break and double-glazed frames.	Energy efficiency intervention	Economic
Eastern Sicily Sea	Lighting system replacement	Reducing energy consumption from lighting inside buildings through the use of LED lamps	Energy efficiency intervention	Economic
Eastern Sicily Sea	Lighting system replacement - public roads	Reduction of energy consumption from lighting of roads and yards through the use of LED lamps	Energy efficiency intervention	Economic
Eastern Sicily Sea	Lighting system replacement-yards	Reduction of energy consumption from lighting of roads and yards through the use of LED lamps	Energy efficiency intervention	Economic
Eastern Sicily Sea	LNG infrastructure supply	Construction of an LNG plant in the Port of Catania, also evaluating the possibility of building a HUB in the Port of Augusta	Bunkering and storage facilities for alternative fuels	Market
Eastern Sicily Sea	Photovoltaic plant - Port of Augusta	Installation of Photovoltaic plants on shading shelters for the production of electricity from renewable sources in the parking areas at the Ports of Augusta and Catania.	Renewable energy production	Economic
Eastern Sicily Sea	Photovoltaic plant - Port of Catania	Installation of Photovoltaic plants on shading shelters for the production of electricity from renewable sources in the parking areas at the Ports of Augusta and Catania.	Renewable energy production	Economic
Eastern Sicily Sea	Photovoltaic plant - Port System Authority	Construction of Photovoltaic plants for the production of electricity from renewable sources in the buildings of the Port System Authority of the Sea of Eastern Sicily located at the Commercial Port of Augusta	Renewable energy production	Economic
Eastern Sicily Sea	Wave energy production - Port of Augusta	On-shore oscillating water column systems are considered to be the most suitable technology. The application of such an energy system could be	Renewable energy production	Economic

		implemented with the replacement of part of the breakwater structures of the two ports.		
Eastern Sicily Sea	Wave energy production - Port of Catania	On-shore oscillating water column systems are considered to be the most suitable technology. The application of such an energy system could be implemented with the replacement of part of the breakwater structures of the two ports.	Renewable energy production	Economic
Eastern Sicily Sea	Wind power generation - Port of Augusta	A wind farm with 5 GAMESA G80 2 MW turbines with a 78 m tower and a nominal power of 2,000 kW was chosen. Wind farm with a total output of 10 MW.	Renewable energy production	Economic
Ionian Sea Port	Beleolico	"Beleolico": Wind Power Plant/Wind Turbine	Renewable energy production	Economic
Ionian Sea Port	Cold ironing - Molo Polisettoriale	Construction of a Cold ironing plant at the Molo Polisettoriale of the port of Taranto	Facilities and infrastructure for electric energy supply	Market
Ionian Sea Port	Cold ironing - Port of Taranto	Construction of a Cold ironing plant at the oil wharf in the port of Taranto	Facilities and infrastructure for electric energy supply	Market
Ionian Sea Port	Cold ironing - Public dock	Construction of a Cold ironing plant at the public docks of the port of Taranto.	Facilities and infrastructure for electric energy supply	Market
Ionian Sea Port	ECOWAVE S	The project aims to prevent the growing tide of plastic and other waste from entering the seas by supporting the development of fundamental long-term transnational sustainable and well-coordinated waste management systems	Policies and measures	Governance
Ionian Sea Port	Electric charging columns - Taranto port	Charging Column	Facilities and infrastructure for electric energy supply	Market

Ionian Sea Port	Electric vehicles	conversion of existing vehicles to electric vehicles.	Energy efficiency intervention	Economic
Ionian Sea Port	Floating PV system	Installation of a floating wind farm in the port of Taranto	Renewable energy production	Market
Ionian Sea Port	Hydrogen plants	Constrcution of hydrogen plant in the port of Taranto	Renewable energy production	Market
Ionian Sea Port	Indoor Lighting system replacements of AdSP buildings	Relamping the indoor lighting of AdSP buildings	Energy efficiency intervention	Economic
Ionian Sea Port	LED Lighting system replacementes - Port of Taranto	Replacement of the port's obsolete outdoor lighting with LED lighting systems (concessionaires)	Energy efficiency intervention	Market
Ionian Sea Port	LED Lighting system replacements	Replacement of the port's obsolete indoor lighting with LED lighting systems (concessionaires)	Energy efficiency intervention	Market
Ionian Sea Port	LNG Plants	Construction of a liquefied natural gas plant in the port of taranto	Facilities and infrastructure for electric energy supply	Market
Ionian Sea Port	Outdoor Lighting system replacements	Relamping of AdSP outdoor lighting	Energy efficiency intervention	Economic
Ionian Sea Port	Photovoltaic plant - Concessionaires' Buildings	Development of Photovoltaic plants at Concessionaires' Buildings	Renewable energy production	Market
Ionian Sea Port	Photovoltaic plant - Ionian Sea AdSP Offices	Development of Photovoltaic Installations at the Ionian Sea AdSP Offices	Renewable energy production	Economic
Ionian Sea Port	Photovoltaic plant - Molo Polisettoriale	Development of a Photovoltaic Plant for the Molo Polisettoriale.	Renewable energy production	Economic
Ionian Sea Port	Photovoltaic plant - Port of Taranto	Photovoltaic plants	Renewable energy production	Economic
Ionian Sea Port	Wave energy production	Wave motion plant for electricity generation	Renewable energy production	Market
North Tyrrhenian Sea	Aer Nostrum	The project aims to contribute to preserving and improving the air quality in the areas facing the ports of the cooperation area while promoting the sustainable growth of port activities.	Policies and measures	Social
North Tyrrhenian Sea	Blueconnect	The project wants to create a network of companies, institutions, operators of the sector and the territory, to the realization of a greener and smarter port of the future.	Policies and measures	Governance
North Tyrrhenian Sea	Cold ironing - cruise and Roro Pax	Electricity supply from quayside for cruise and Roro Pax type ships at berth	Facilities and infrastructure for electric energy supply	Market
North Tyrrhenian Sea	Cold ironing - Port of Leghorn at cruise and Roro Pax ships	Quayside electricity supply for cruise and Roro Pax ships at the berth.	Facilities and infrastructure for electric energy supply	Market

North Tyrrhenian Sea	Cold ironing - Port of Leghorn at the Darsena Toscana Europa	Quayside electricity supply for container ships at the Darsena Toscana/Darsena Europa.	Facilities and infrastructure for electric energy supply	Market
North Tyrrhenian Sea	Cold ironing - Port of Portoferraio at cruise and Roro Pax	Electricity supply from quayside for cruise and Roro Pax type ships at berth	Facilities and infrastructure for electric energy supply	Market
North Tyrrhenian Sea	COREALIS	COREALIS proposes a strategic, innovative framework, supported by disruptive technologies to increase efficiency, and optimize land use, respecting circular economy principles.	Digitalisation and ICT platforms	Social
North Tyrrhenian Sea	Easylog	Development of an innovative system for the optimisation of cargo flows. Establish a common intelligent cross-border traffic management system that can improve the logistics chain and maritime transport.	Digitalisation and ICT platforms	Market
North Tyrrhenian Sea	Electric charging columns - Port of Leghorn	Construction of infrastructure for the use of electricity in the ports of Livorno (2 columns), Piombino (2 columns) e Portoferraio (1 columns)	Facilities and infrastructure for electric energy supply	Social
North Tyrrhenian Sea	Electric charging columns - Port of Piombino	Construction of infrastructure for the use of electricity in the ports of Livorno (2 columns), Piombino (2 columns) e Portoferraio (1 columns)	Facilities and infrastructure for electric energy supply	Social
North Tyrrhenian Sea	Electric charging columns - Portoferraio port	Construction of infrastructure for the use of electricity in the ports of Livorno (2 columns), Piombino (2 columns) e Portoferraio (1 columns)	Facilities and infrastructure for electric energy supply	Social
North Tyrrhenian Sea	Electricity distribution system	For the ports of Livorno and Piombino, a feasibility study was carried out regarding the establishment of a closed electricity distribution system, as referred to in Directive 2009/72/EC.	Research and Development	Economic
North Tyrrhenian Sea	Energy efficiency intervention at the Maritime Station Port of Piombino	The intervention consists in the Energy efficiency intervention and upgrading of the building housing the current AdSP's headquarters and Maritime Station of the port of Piombino.	Energy efficiency intervention	Economic
North Tyrrhenian Sea	Energy efficiency intervention of Palazzo Rosciano Leghorn	The intervention consists in the Energy efficiency intervention and upgrading of the Palazzo Rosciano	Energy efficiency intervention	Economic
North Tyrrhenian Sea	Energy efficiency intervention of port rail infrastructure	It consists of the basic connection of the Livorno Calambrone-Livorno Darsena railway district, a railway infrastructure serving the port of Livorno.	Energy efficiency intervention	Market

North Tyrrhenian Sea	Fuel gas treatment	Flue gas treatment, through the installation at the quayside of plants for the treatment of exhaust gases emitted by stationary ships, which involves capturing and fixing SOx and PM emitted by ships' engines	Energy efficiency intervention	Social
North Tyrrhenian Sea	GNL FACILE	Encourage a progressive reduction in the use of the most polluting fuels and dependence on oil and promoting the deployment of LNG for maritime propulsion.	Bunkering and storage facilities for alternative fuels	Market
North Tyrrhenian Sea	GRAMAS	Bathymetry survey campaigns in the harbour water mirror.	Research and Development	Governance
North Tyrrhenian Sea	GREENCRA NES	Green technologies and eco-efficient alternatives for cranes and operations at port container terminals	Energy efficiency intervention	Economic
North Tyrrhenian Sea	Hydrogen boat	The project consists in the provision by the AdSP of a hydrogen-powered vessel capable of carrying out environmental monitoring activities, bathymetric campaigns, in-situ port infrastructure inspections, security activities, port visits, as well as rescue operations in areas accessible from the sea.	Renewable energy production	Social
North Tyrrhenian Sea	Hydrogen Port Rail Shunting	The aim of the project is to reduce emissions into the environment through a modernization of the fleet of the railway system in the port of Livorno and, subsequently, also in the port of Piombino.	Renewable energy production	Market
North Tyrrhenian Sea	IMPATTI-NO	Improvement of the managerial practices for port-waste through the development of a circular economy model.	Research and Development	Social
North Tyrrhenian Sea	iNGENIOUS	The project aims to develop newly designed Internet of Things elements and ICT platforms for maritime logistics.	Digitalisation and ICT platforms	Market
North Tyrrhenian Sea	ISIDE	The project aims to implement a ICT communication infrastructure essential for the safety of navigation, also capable of facilitating the action of the Port Authorities in the prevention and management of risk situations at sea.	Digitalisation and ICT platforms	Governance
North Tyrrhenian Sea	Lighting system replacements - Port of Leghorn	Replacement of traditional lamps (sodium vapour, metal halide or fluorescent) with LED type luminaires.	Energy efficiency intervention	Economic
North Tyrrhenian Sea	Lighting system replacements - Port of Piombino	Replacement of traditional lamps (sodium vapour, metal halide or fluorescent) with LED type luminaires.	Energy efficiency intervention	Economic
North Tyrrhenian Sea	MED NEW JOB	The project aims to enhance the existing opportunities in the blue economy with the participation of the main actors of the industry for the creation of sustainable employment in the nautical sector and in the sea economy.	Policies and measures	Social
North Tyrrhenian Sea	Mon Acumen	The project aims to reduce the acoustic impact generated by ports.	Research and Development	Social
North Tyrrhenian Sea	Moni.C.A.	Development of new application modules related to the Moni.C.A. system for the monitoring of environmental impacts and carbon footprint.	Digitalisation and ICT platforms	Market
North Tyrrhenian Sea	OMD	Improvement of safety at sea during the transport of dangerous goods through a shared and collaborative method.	Policies and measures	Governance

North Tyrrhenian Sea	Photovoltaic plant - Port of Leghorn	The project involves the construction of a Photovoltaic plant with a total power of approximately 2,000 kW to be installed both on carports and on the slopes of a shed located in an area owned by the AdSP MTS located in the Municipality of Collesalvetti (LI).	Renewable energy production	Economic
North Tyrrhenian Sea	Photovoltaic plant - Port of Piombino	The intervention consists of the construction, in state-owned areas, of Photovoltaic plants with a power of 685 kWp on carports to be installed on parking spaces.	Renewable energy production	Economic
North Tyrrhenian Sea	Port energy infrastructure - light towers	The Intervention consists of the sensitization of the port's light towers	Energy efficiency intervention	Economic
North Tyrrhenian Sea	PortForward	The project aims to provide innovative solutions to make the ports of the future smarter, greener, and more interconnected.	Research and Development	Governance
North Tyrrhenian Sea	PROMO GNL	The objective of the project is to achieve a coordinated framework of joint feasibility studies that will foster enlightened choices for promoting the optimal uses of LNG as a less polluting fuel in ports of commerce in the cooperation area.	Research and Development	Governance
North Tyrrhenian Sea	ROBORDER	The project aims to develop and demonstrate an autonomous system of surveillance of perimeter areas through the use of unmanned mobile robots.	Digitalisation and ICT platforms	Economic
North Tyrrhenian Sea	RUMBLE	Supporting sustainability practices in the port domain for reducing noise pollution.	Research and Development	Social
North Tyrrhenian Sea	SEATERMI NALS	Technical assessment on LNG logistics development in Port of Livorno	Bunkering and storage facilities for alternative fuels	Market
North Tyrrhenian Sea	Smooth Ports	Reduce the environmental impact associated with cargo inspections at ports by developing best practices among the ports involved.	Research and Development	Market
North Tyrrhenian Sea	TPCS	Implementation of a Port Community platform for the paperless management of processes relating to the import and export of goods.	Digitalisation and ICT platforms	Market
North Tyrrhenian Sea	TPCS-VBS	Development of a module for the management of reservations for the release collection of goods in the port.	Digitalisation and ICT platforms	Market
North Tyrrhenian Sea	TRIPLO	Improvement of noise management practices in the most populated surrounding port areas.	Research and Development	Social
North Tyrrhenian Sea	Ursa Major Neo	Development of ITS (Intelligent Transportation System) services to improve freight traffic on the TEN-T road network and reduce congestion.	Digitalisation and ICT platforms	Market
North Tyrrhenian Sea	Wind farm - Port of Leghorn	The project involves the construction of a system of wind turbines with a total capacity of about 200 kW to be installed in a port area exposed to prevailing winds and not obstructed by buildings and cranes.	Renewable energy production	Economic
Northen Central Tyrrhenian Sea	Cold ironing - Civitavecchia	Electrifying quays in concession to cruise ships, from RES. The connections will be made in accordance with the IEC/ISO/IEEE 80005:2019 standard	Facilities and infrastructure for electric energy supply	Market

Northen Central Tyrrhenian Sea	Cold ironing - Marina Yachting' quayside	a plant has been built at the Marina Yachting quay capable of supplying electricity to the pleasure boats (up to 140 metres long) that this port area is intended to host	Facilities and infrastructure for electric energy supply	Market
Northen Central Tyrrhenian Sea	Cold ironing - Tug mooring	At the Sant'Eufanio wharf and the Sardinia wharf there are two electrical connections to meet the needs of the tugboats at berth	Facilities and infrastructure for electric energy supply	Economic
Northen Central Tyrrhenian Sea	Container terminal Lighting system replacement upgrade	Replacing high-pressure sodium floodlights with LED floodlights	Energy efficiency intervention	Market
Northen Central Tyrrhenian Sea	Cruise terminal Lighting system replacement upgrade	Replacing high-pressure sodium floodlights with LED floodlights	Energy efficiency intervention	Market
Northen Central Tyrrhenian Sea	Cryogenic fuel logistics chain	Using the port of Civitavecchia as a 'ship-to-ship' bunkering hub for ships using LNG as fuel, as well as 'ship-to-truck' transfer operations of this fuel to shore-based users, and the possibility of implementing the use of bio-LNG.	Bunkering and storage facilities for alternative fuels	Market
Northen Central Tyrrhenian Sea	Electric charging columns - Port of Civitavecchia	The intervention consists in the realisation of the first public charging infrastructure for electric vehicles within the port of Civitavecchia.	Facilities and infrastructure for electric energy supply	Market
Northen Central Tyrrhenian Sea	Energy efficiency intervention at AdSP headquarters 1	Replacement of the winter heating and summer cooling systems that consist of 3 gas boilers of 97.6 kW and 3 electric chillers of 156 kW with a reversible heat pump that can operate in both winter and summer and powered exclusively by electrical energy	Energy efficiency intervention	Economic
Northen Central Tyrrhenian Sea	Energy efficiency intervention at AdSP headquarters 2	Replacement of approximately 700 traditional luminaires of various types with LED luminaires	Energy efficiency intervention	Economic
Northen Central Tyrrhenian Sea	Energy efficiency intervention at AdSP headquarters 3	Interventions for the implementation of the thermal insulation system and the replacement of some glazing.	Energy efficiency intervention	Economic

Northen Central Tyrrhenian Sea	Energy efficiency intervention of Autostrade del Mare terminal 1	replacement of the heat pumps in the Autostrade del Mare passenger terminal building with new generation heat pumps, which have a higher COP value of 3.24, for a total capacity of 376 kW in cooling and 358 kW in heating.	Energy efficiency intervention	Economic
Northen Central Tyrrhenian Sea	Energy efficiency intervention of Autostrade del Mare terminal 2	replacement of old, inefficient components with LED equipment of an equivalent type.	Energy efficiency intervention	Economic
Northen Central Tyrrhenian Sea	Energy efficiency intervention of Harbour Master's Offices 1	replacement of old, inefficient components with LED equipment of an equivalent type.	Energy efficiency intervention	Economic
Northen Central Tyrrhenian Sea	Energy efficiency intervention of Harbour Master's Offices 2	installation of an 8-cm thick external thermal insulation coat made of rock wool to insulate the building and replacement of single-glazed windows with double-glazed pvc windows with argon-filled 4-6-4 thick double glazing.	Energy efficiency intervention	Economic
Northen Central Tyrrhenian Sea	Green areas to mitigate "heat islands"	In the port of Civitavecchia the areas dedicated to vegetation occupy a total area of over 35,000 m2, and in the next decade it is expected to increase the surface area of fine green areas to 50,000 m2	Land use conversion	Social
Northen Central Tyrrhenian Sea	Photovoltaic plant - Civitavecchia Darsena Romana	Installation of a Photovoltaic plant on a multifunctional building located in Darsena Romana, in the port of Civitavecchia.	renewable energy production	Market
Northen Central Tyrrhenian Sea	Photovoltaic plant - Civitavecchia Forest Fruit Terminal	Installation of a Photovoltaic plant at Civitavecchia Forest Fruit Terminal S.p.A.	renewable energy production	Market
Northen Central Tyrrhenian Sea	Photovoltaic plant - Harbour Master's Offices	The project involves the installation of five Photovoltaic plants on as many roofs of Harbour Master's buildings, with a total capacity of 130.6 kWp.	Renewable energy production	Economic
Northen Central Tyrrhenian Sea	Photovoltaic plant - Il Saraceno multipurpose building	It was assumed that 600 panels of 300 W each would be installed on the part of the building that houses the warehouses below, The total installable power is 180 kW	Renewable energy production	Economic
Northen Central Tyrrhenian Sea	Photovoltaic plant - Konig	Installation of a Photovoltaic plant on the roof of the Konig S.r.l. dealership's halls.	renewable energy production	Market
Northen Central Tyrrhenian Sea	Photovoltaic plant - Meeting Village	Installation of a Photovoltaic plant at meeting village	renewable energy production	Market
Northen Central Tyrrhenian Sea	Photovoltaic plant - retroport areas	installation of PV system in retroport areas to achieve decarbonisation	Renewable energy production	Economic
Northen Central Tyrrhenian Sea	Photovoltaic plant - Roma Cruise Terminal	Installation of a Photovoltaic plant at Roma Cruise Terminal S.r.l.	renewable energy production	Market

Northen Central Tyrrhenian Sea	Photovoltaic plant - the Autostrade del Mare terminal	use of Fly Solartech srl panels model F-MWT325M60S for commercial and residential applications, as they should have characteristics of greater mechanical strength and durability over time	Renewable energy production	Economic
Northen Central Tyrrhenian Sea	Port electricity grid digitisation	The proposed initiative envisages a multiplicity of interventions aimed at improving and upgrading the port electricity network to make it more efficient and responsive to the needs of port users, with the aim of creating the first neural network for the management of a national port electricity system.	Digitalisation and ICT platforms	Market
Northen Central Tyrrhenian Sea	Primary energy storage system from renewable energy sources	Installation of primary energy storage system combined with renewable energy sources	Renewable energy production	Economic
Northen Central Tyrrhenian Sea	Public lighting system replacement	Replace all lighting fixtures in outdoor areas with an LED lighting system in order to achieve a drastic reduction in electricity consumption for port users.	Energy efficiency intervention	Economic
Northen Central Tyrrhenian Sea	REWEC3 Project	The main objective of the project is to produce a feasibility study for the reduction of the CO2 emissions associated with the mobility within the Port of Civitavecchia.	Research and Development	Social
Northen Central Tyrrhenian Sea	Wave energy production	Wave energy production through by converting wave motion into electricity with WaveSax technology	Renewable energy production	Economic
Northen Central Tyrrhenian Sea	Zero Emission Port Programme - Grimaldi Group Spa	The two Grimaldi Group ships that connect Civitavecchia with Barcelona on a daily basis while dockside use lithium batteries charged during navigation through Shaft-Generators to meet their electricity needs (within the limit of 5MWh, 1C charging, 3C delivery).	Facilities and infrastructure for electric energy supply	Market
Northern Adriatic Sea	ACCESS2NAPA	Design of infrastructure projects including enhancement of railway tracks and Cold ironing.	Research and Development	Economic
Northern Adriatic Sea	Clean Berth Project	The project aims to define a cross-border model for environmental sustainability and port Energy efficiency intervention, to be implemented in each port through a specific plan, which will result in the implementation of pilot actions capable of producing tangible results in terms enhanced environmental protection and energy performance	Policies and measures	Governance
Northern Adriatic Sea	Cold ironing - Marghera Dock	installation of Cold ironing systems to supply electricity to ships at the port	Facilities and infrastructure for electric energy supply	Market
Northern Adriatic Sea	Cold ironing - Reefer TIV	Replacement of the diesel generators in the existing port equipment with equivalent electric power supplies.	Facilities and infrastructure for electric energy supply	Market
Northern Adriatic Sea	Cold ironing - VECO	Replacement of diesel generators in existing port equipment with equivalent power supplies, particularly for Reefer - TIV and VECO outlets	Energy efficiency intervention	Market
Northern Adriatic Sea	Cold ironing - Venice Dock	installation of Cold ironing systems to supply electricity to ships at the port	Facilities and infrastructure for electric energy supply	Market

Northern Adriatic Sea	EALING	The project aims to investigate the studies needed to accelerate the implementation of OPS in the ports.	Bunkering and storage facilities for alternative fuels	Market
Northern Adriatic Sea	Electric cars	Transfer services, with green vehicles, to connect the macro island of Marghera and the city	Energy efficiency intervention	Social
Northern Adriatic Sea	Electric charging columns - Port of Marghera	Installation of electric car supply systems: 2 fast-charging columns in Venice (two fast-charging sockets for each column) and one column in Marghera (two fast-charging sockets for each column)	Facilities and infrastructure for electric energy supply	Market
Northern Adriatic Sea	Electric cranes	Replacement of diesel cranes with electric cranes	Energy efficiency intervention	Market
Northern Adriatic Sea	Electric cranes	Replacement of reach stacker with electric cranes	Energy efficiency intervention	Market
Northern Adriatic Sea	Electrification of cranes	Replacement of diesel cranes with electric cranes	Energy efficiency intervention	Market
Northern Adriatic Sea	GAINN4SEA	Construction of new infrastructure for LNG logistics, in particular a coastal depot and a transport vehicle for distribution and bunkering.	Bunkering and storage facilities for alternative fuels	Market
Northern Adriatic Sea	GREEN C Ports	The GREEN C Ports Action will pilot the use of sensors, big data platforms, business intelligence tools and artificial intelligence modelling at the ports of Valencia, Venice, Piraeus, Wilhelmshaven and Bremerhaven, contributing this way to the future roll out of these technologies in the market.	Digitalisation and ICT platforms	Market
Northern Adriatic Sea	GreenerSites Project	Carrying out studies and research into new environmental and economic solutions for brownfield redevelopment, development of a new air quality monitoring system, and testing of a soil remediation methodology.	Research and Development	Market
Northern Adriatic Sea	LED Lighting system replacements - Port of Venice	Installation of LED lighting systems (garage).	Energy efficiency intervention	Economic
Northern Adriatic Sea	LED Lighting system replacements - Port of Venice (quayside)	Installation of LED lighting systems (quayside and yards in concession).	Energy efficiency intervention	Market
Northern Adriatic Sea	Night Lighting system replacements	Optimisation of lighting on/off in the port area	Energy efficiency intervention	Market
Northern Adriatic Sea	Outdoor Lighting system replacement	Dimming Light Towers of the port	Energy efficiency intervention	Economic
Northern Adriatic Sea	Outdoor Lighting system replacement	Light Tower Lamps Replacement with LED	Energy efficiency intervention	Market
Northern Adriatic Sea	Photovoltaic plant - Building 117	Implementation of Photovoltaic plant on the roof of Building 117 (concessionary)	Renewable energy production	Market

Northern Adriatic Sea	Photovoltaic plant - Building TRV	Realisation of 700 kWp photovoltaic plant - TRV.	Renewable energy production	Market
Northern Adriatic Sea	Photovoltaic plant - Port of Venice 1	Installation of photovoltaic plant	Renewable energy production	Economic
Northern Adriatic Sea	Photovoltaic plant - Port of Venice 2	Installation of a Photovoltaic plant for the use of renewable energy in the port	Renewable energy production	Economic
Northern Adriatic Sea	POSEIDON MED II	POSEIDON MED II envisages actions and initiatives to promote the adoption of LNG as a fuel for maritime transport in Eastern Mediterranean ports	Bunkering and storage facilities for alternative fuels	Market
Northern Adriatic Sea	REEFER Area	REEFER area connection in Medium Voltage	Energy efficiency intervention	Market
Northern Adriatic Sea	REMEMBE R	Enhancement of the historical, monumental and intangible heritage of the ports in terms of tourism and generation of new economy and new employment.	Policies and measures	Social
Northern Adriatic Sea	Replacing reefer sockets	Replacing reefer sockets for electric use.	Energy efficiency intervention	Market
Northern Adriatic Sea	Requalificati on of buildings	Diagnosis of the energy performance of buildings for their requalification and energy certification.	Energy efficiency intervention	Economic
Northern Adriatic Sea	SUPAIR	The Port System Authority of the Northern Adriatic Sea aims to reduce emissions from road traffic congestion to and from the Port of Venice-Marghera through two pilot actions: 1. Design and implementation of a Smart Traffic Management Tool to reduce the waiting time of trucks at the entry gates; 2. Drafting of an operational plan (Masterplan) to reduce emissions and make better use of the resources available in the port area.	Digitalisation and ICT platforms	Market
Northern Adriatic Sea	SUSPORT – Sustainable Ports	Replacement of existing damaged lighting and installation of new LED luminaires equipped with lighting management devices.	Energy efficiency intervention	Economic
Northern Adriatic Sea	Upgrading of the Port's electricity distribution network	Efficiency enhancement of the Port's electricity distribution network and adaptation of electricity supply lines	Energy efficiency intervention	Economic
Northern Adriatic Sea	Ursa Major Neo	development of an ITS (Intelligent Transport Services for the road) platform for improving road traffic management along European multi-modal corridors	Digitalisation and ICT platforms	Market
Northern Adriatic Sea	Use of Hybrid Buses	Transfer services, with green vehicles, to connect the macro island of Marghera and the city	Energy efficiency intervention	Social
Northern Adriatic Sea	VENICE LNG FACILITY	Construction of new infrastructure for LNG logistics, in particular a coastal depot and a transport vehicle for distribution and bunkering.	Bunkering and storage facilities for alternative fuels	Market
Northern Central Adriatic Sea	ACCESS2N APA	Design of infrastructure projects including enhancement of railway tracks and Cold ironing.	Research and Development	Economic
Northern Central Adriatic Sea	Cold ironing - Port of Ravenna at Corsini cruise terminal	Construction of a Cold ironing station at Porto Corsini to serve the Cruise Terminal the port of Ravenna	Facilities and infrastructure for electric energy supply	Market

Northern Central Adriatic Sea	GNL retrofit of tugs and marine port service naval units	Gnl retrofit for tugs and marine anti-pollution port service operators.	Energy efficiency intervention	Market
Northern Central Adriatic Sea	Photovoltaic plant - Port companies	Photovoltaic plant for port companies	Renewable energy production	Market
Northern Central Adriatic Sea	Photovoltaic plant - Port system authority headquarter	Photovoltaic plant for port system authority headquarter	Renewable energy production	Economic
Northern Central Adriatic Sea	REMEMBE R	Enhancement of the historical, monumental and intangible heritage of the ports in terms of tourism and generation of new economy and new employment.	Policies and measures	Social
Northern Central Adriatic Sea	Revamping of the quayside electricity network	The revamping of the quayside electricity network	Facilities and infrastructure for electric energy supply	Market
Northern Central Adriatic Sea	Ursa Major Neo	Development of ITS (Intelligent Transportation System) services to improve freight traffic on the TEN-T road network and reduce congestion.	Digitalisation and ICT platforms	Market
Sardinian Sea	Aer Nostrum	The project aims to contribute to preserving and improving the air quality in the areas facing the ports of the cooperation area while promoting the sustainable growth of port activities.	Policies and measures	Social
Sardinian Sea	Cold ironing - Port of Cagliari	Installation of a power supply system for ships docked in the port of Cagliari.	Facilities and infrastructure for electric energy supply	Market
Sardinian Sea	Cold ironing - Port of Golfo Aranci	Installation of a power supply system for ships docked in the port of Golfo Aranci.	Facilities and infrastructure for electric energy supply	Market
Sardinian Sea	Cold ironing - Port of Olbia	Installation of a power supply system for ships docked in the port of Olbia.	Facilities and infrastructure for electric energy supply	Market
Sardinian Sea	Cold ironing - Port of Porto Torres	Installation of a power supply system for ships docked in the port of Porto Torres.	Facilities and infrastructure for electric energy supply	Market
Sardinian Sea	Cold ironing - Port of Portovesme	Installation of a power supply system for ships docked in the port of Portovesme.	Facilities and infrastructure for electric energy supply	Market
Sardinian Sea	Cold ironing - Port of S. Teresa di Gallura	Installation of a power supply system for ships docked in the port of S. Teresa di Gallurai.	Facilities and infrastructure for electric energy supply	Market
Sardinian Sea	DECIBEL	Monitoring noise pollution and development of new practices to mitigate the externalities.	Research and Development	Social
Sardinian Sea	Electric energy maintenance in the port of Portovesme	The intervention involves the replacement of the current lighting fixtures with new LED technology projectors along with the removal and rebuilding of electrical connections from the main power backbone to the individual lighting fixtures.	Energy efficiency intervention	Economic

Sardinian Sea	Energy efficiency intervention in the Port Authority of Olbia and Golfo Aranci	Installation of air conditioning systems with high Energy efficiency intervention performance in all offices as well as electrical and lighting systems.	Energy efficiency intervention	Economic
Sardinian Sea	Energy requalification of Lighting system replacements at the port of Portovesme	Replacement of lighting fixtures and the modernization of some parts of the energy system to ensure compliance with the requirements of UNI EN 12464-2.	Energy efficiency intervention	Economic
Sardinian Sea	Facility management services	The agreement provides multiple services, including maintenance services of plants, networks, minor maintenance of buildings, based on green practices.	Policies and measures	Governance
Sardinian Sea	GEREMIA	The objective is to provide innovative tools and solutions for managing port waters.	Policies and measures	Governance
Sardinian Sea	GESTA	Upgrading and Energy efficiency intervention of the lighting systems as well as the management and supply of energy carriers.	Energy efficiency intervention	Economic
Sardinian Sea	GNL FACILE	Encourage a progressive reduction in the use of the most polluting fuels and dependence on oil and promoting the deployment of LNG for maritime propulsion.	Bunkering and storage facilities for alternative fuels	Market
Sardinian Sea	IMPATTI-NO	Improvement of the managerial practices for port-waste through the development of a circular economy model.	Research and Development	Social
Sardinian Sea	ISIDE	The project aims to implement a ICT communication infrastructure essential for the safety of navigation, also capable of facilitating the action of the Port Authorities in the prevention and management of risk situations at sea.	Digitalisation and ICT platforms	Governance
Sardinian Sea	Lighting system replacements - Port of Olbia Isola Bianca	Construction of a new branch line to supply power to towers T18 and T19 as well as lighting systems with LED lights in the following areas.	Energy efficiency intervention	Economic
Sardinian Sea	Lighting system replacements - Port of Porto Torres	Maintenance of the lighting system of the selected areas in the port of Porto Torres to reduce the energy requirements and consumption.	Energy efficiency intervention	Economic
Sardinian Sea	Listport	Development of a shared approach to mitigate noise pollution generated by port activities.	Policies and measures	Social
Sardinian Sea	LUCE - Port of Cagliari	The project aims to develop a Management Plan for the energy system in the port of Cagliari.	Energy efficiency intervention	Governance
Sardinian Sea	LUCE - Port of Oristano	Installation of LED lamps as well as the unification of power supply systems and the definition of a Management Plan that allows rationalizing energy requirements.	Energy efficiency intervention	Governance
Sardinian Sea	Mon Acumen	The project aims to reduce the acoustic impact generated by ports.	Research and Development	Social

Sardinian Sea	New headquarter of the Port Authority of Olbia and Golfo Aranci	Construction of the new energy efficient headquarter of the Port Authority of Olbia and Golfo Aranci	Energy efficiency intervention	Governance
Sardinian Sea	OMD	Improvement of safety at sea during the transport of dangerous goods through a shared and collaborative method.	Policies and measures	Governance
Sardinian Sea	Port lighting service - Port of Golfo Aranci Cocciani	Definition of a service for the management and ordinary and extraordinary maintenance of port lighting systems to improve Energy efficiency intervention and reduce the volume of atmospheric emissions in the port context.	Energy efficiency intervention	Economic
Sardinian Sea	Port lighting service - Port of Olbia	Definition of a service for the management and ordinary and extraordinary maintenance of port lighting systems to improve Energy efficiency intervention and reduce the volume of atmospheric emissions in the port context.	Energy efficiency intervention	Economic
Sardinian Sea	Port lighting service - Port of Porto Torres	Definition of a service for the management and ordinary and extraordinary maintenance of port lighting systems to improve Energy efficiency intervention and reduce the volume of atmospheric emissions in the port context.	Energy efficiency intervention	Economic
Sardinian Sea	Public Lighting system replacements	Establishment of a partnership aimed at the concession of multiple services, including the management of lighting and maintenance of the energy system.	Policies and measures	Governance
Sardinian Sea	Qualiporti	Identification of the type of water pollutants and their origin.	Research and Development	Governance
Sardinian Sea	RUMBLE	Supporting sustainability practices in the port domain for reducing noise pollution.	Research and Development	Social
Sardinian Sea	Se.Dri.Port	Development of an advanced system for monitoring the phenomenon of accumulation of sediments.	Digitalisation and ICT platforms	Governance
Sardinian Sea	SEDITERRA	Study of opportunities for treatment and reuse of dredging waste on land	Research and Development	Economic
Southern adriatic sea	Cold ironing - Port of Bari	Cold ironing system in port to supply electricity to ships at the quay	Facilities and infrastructure for electric energy supply	Market
Southern Adriatic Sea	Energy efficiency in the Massi Quay	Energy efficiency intervention intervention in the Massi Quay	Energy efficiency intervention	Market
Southern Adriatic Sea	Energy efficiency intervention in the Border Inspection Post	Energy efficiency intervention intervention in the Border Inspection Post	Energy efficiency intervention	Economic
Southern Adriatic Sea	Energy efficiency intervention in the Casa del Portuale	Energy efficiency intervention intervention in the Casa del Portuale	Energy efficiency intervention	Economic
Southern Adriatic Sea	Energy efficiency intervention	Energy efficiency intervention intervention in the Cruise Station	Energy efficiency intervention	Market

	in the Cruise Station			
Southern Adriatic Sea	Energy efficiency intervention in the Extra-Schengen Station	Energy efficiency intervention intervention in the Extra-Schengen Station	Energy efficiency intervention	Market
Southern Adriatic Sea	Energy efficiency intervention in the Ferry Station	Energy efficiency intervention intervention in the Ferry Station	Energy efficiency intervention	Market
Southern Adriatic Sea	Energy efficiency intervention in the former Maritime Station	Energy efficiency intervention intervention in the former Maritime Station	Energy efficiency intervention	Economic
Southern Adriatic Sea	Energy efficiency intervention in the Maritime Station	Energy efficiency intervention intervention in the Maritime Station	Energy efficiency intervention	Market
Southern Adriatic Sea	Energy efficiency intervention in the Palazzina PIF	Energy efficiency intervention intervention in the Palazzina PIF	Energy efficiency intervention	Economic
Southern Adriatic Sea	Energy efficiency intervention in the Terminal Levante	Energy efficiency intervention intervention in the Terminal Levante	Energy efficiency intervention	Market
Southern Adriatic Sea	Geothermal plant	Geothermal plant installation in the port	Renewable energy production	Economic
Southern Adriatic Sea	GUTTA	The GUTTA project aims to set up a pilot system in order to plan ferry routes capable of minimising CO2 emissions, to support the EU-MRV 757/2015 Regulation on CO2 maritime emissions and to facilitate the establishment of a new Italy-Croatia cross-border route.	Digitalisation and ICT platforms	Social
Southern Adriatic Sea	Photovoltaic plant - Port of Bari	Installation of thermal solar panels in the port	Renewable energy production	Economic
Southern adriatic sea	Photovoltaic plant - Port of Bari	Photovoltaic plant installation in the ports of Bari	Renewable energy production	Economic
Southern adriatic sea	Photovoltaic plant - Port of Brindisi	Photovoltaic plant installation in the ports of Brindisi	Renewable energy production	Economic
Southern adriatic sea	SUPER-LNG - Port of Bari	Construction of coastal LNG storage facilities in the ports of Bari	Bunkering and storage facilities for alternative fuels	Market
Southern adriatic sea	SUPER-LNG - Port of Brindisi	Construction of coastal LNG storage facilities in the ports of Brindisi	Facilities and infrastructure for electric energy supply	Market

Southern Adriatic Sea	SUSPORT – Sustainable Ports	Thanks to the SUSPORT project, the Port Authority has strengthened its environmental protection action in through the acquisition and installation of sensors and stations to monitor noise, air (concentrations of PM, pollutant gases) and water quality (turbidity produced by excavations and ship traffic, solid and hydrodynamic transport to the port mouths), connected to the VEGA system.	Digitalisation and ICT platforms	Social
Southern adriatic sea	Wind farm - Port of Brindisi	Installation of a Wind farm in the port of Brindisi	Renewable energy production	Economic
Southern Tyrrhenian and Ionian Sea	Cold ironing - Port of Gioia Tauro	Electrification of Ro-Ro docks	Facilities and infrastructure for electric energy supply	Market
Southern Tyrrhenian and Ionian Sea	Eco-sustainability accomodations	The project envisages the construction of a new low-energy building to house 10 new staff accommodation units. A structure built with materials that guarantee complete insulation and equipped with photovoltaic roofs with energy storage systems.	Land use conversion	Social
Southern Tyrrhenian and Ionian Sea	Electrification of rail tracks	The intervention concerns the electrification of the second track between San Ferdinando station (Porto) and Rosarno station (connection to the RFI national network).	Energy efficiency intervention	Market
Southern Tyrrhenian and Ionian Sea	Energy efficiency intervention at the AdSP headquarter	Replacement of existing windows and doors with newer, higher-performance products, together with replacement of all lighting fixtures and implementation of thermal insulation	Energy efficiency intervention	Economic
Southern Tyrrhenian and Ionian Sea	LED Lighting system replacement at the AdSP headquarter	Replacement of energy installations with the implementation of LED technology	Energy efficiency intervention	Economic
Southern Tyrrhenian and Ionian Sea	LNG bunkering and refuelling facilities	Development of LNG bunkering and refuelling facilities within the framework of the European Parliament Directive 2014/94/EU on the establishment of an infrastructure for alternative fuels.	Bunkering and storage facilities for alternative fuels	Market
Southern Tyrrhenian and Ionian Sea	Photvoltaic plant - AdSP headquarters	A 66.5 kilowatt Photovoltaic plant will be placed on the roof of the building by installing 266 solar panels.	Renewable energy production	Economic
Southern Tyrrhenian and Ionian Sea	Redevelopment of the back harbour area	Construction of a new road system with safety, green, and entertainment areas.	Land use conversion	Social
Stretto	Cold ironing - Messina port	Construction and commissioning of On-Shore Power Supply (Cold ironing) plants for the power supply of various types of ships in the ports of the Port System Authority of the Strait of Messina.	Facilities and infrastructure for electric energy supply	Market
Stretto	Electric charging columns - Port of Messina	Installation of an electric vehicle charging station within the port	Facilities and infrastructure for electric energy supply	Market
Stretto	Energy efficiency intervention	Revamping of a building to be used for its offices in the port of Reggio Calabria. The building, will be subject to Energy efficiency intervention interventions of the envelope and of the summer and winter air conditioning systems.	Energy efficiency intervention	Economic

Stretto	Experimentation of wave energy production	The construction, installation and commissioning of three GEMSTAR plants, each with a nominal capacity of 300 kW, for a total installed capacity of 900 kW.	Renewable energy production	Economic
Stretto	LNG infrastructure supply	The objective is to install of a plant consisting of 10 full integrity pressure tanks, with a total useful storage volume of 9,000 m3, equipped with structures and equipment for refuelling of tankers and loading of tank trucks.	Bunkering and storage facilities for alternative fuels	Market
Stretto	Photovoltaic plant - Port of Messina	Installation of Photovoltaic plants on roofs within the Adsp boundaries for renewable energy production	Renewable energy production	Economic
Stretto	Public Lighting system replacement	Upgrading and replacement of the current 384 luminaires with LED bulbs.	Energy efficiency intervention	Economic
Western Ligurian Sea	Aer Nostrum	The project aims to contribute to preserving and improving the air quality in the areas facing the ports of the cooperation area while promoting the sustainable growth of port activities.	Policies and measures	Social
Western Ligurian Sea	Cogeneration plant in the Sampierdarena Area-Port of Genoa	Reduction of energy consumption through the development of a new cogeneration system in the current thermal power plant by gradually replacing boilers with congenators.	Energy efficiency intervention	Economic
Western Ligurian Sea	Cold ironing - Genoa Cruises and Ferries terminal	Realization of Cold ironing infrastructure in the Genoa Cruises and Ferries terminal.	Facilities and infrastructure for electric energy supply	Market
Western Ligurian Sea	Cold ironing - Terminal Container Genova Pra’	Realization of Cold ironing infrastructure in the Genoa Prà terminal.	Facilities and infrastructure for electric energy supply	Market
Western Ligurian Sea	Dune di Prà-1	Creation of a "green zone" between the operational areas of the port and the urban context both to reduce the acoustic impact of port works and to offer citizens a new space to live in the open air by the sea.	Land use conversion	Social
Western Ligurian Sea	Dune di Prà-2	Creation of a "green zone" between the operational areas of the port and the urban context both to reduce the acoustic impact of port works and to offer citizens a new space to live in the open air by the sea.	Land use conversion	Social
Western Ligurian Sea	E-BRIDGE	The EU project E-Bridge integrates with the activities developed by the Port in the field of vehicular flow optimization, the automation of gates, the design of a buffer area system at the service of traffic.	Digitalisation and ICT platforms	Market
Western Ligurian Sea	Electric charging columns - Port of Genoa	Installation of electric vehicle charging stations and interventions for the gradual replacement of service cars and commercial vehicles with new electric traction vehicles.	Facilities and infrastructure for electric energy supply	Market
Western Ligurian Sea	Electric charging columns - Port of Savona	Installation of electric vehicle charging stations and interventions for the gradual replacement of service cars and commercial vehicles with new electric traction vehicles.	Facilities and infrastructure for electric energy supply	Market

Western Ligurian Sea	Energy efficiency intervention on "Officina Bruzzo" plants-Port of Genoa	The intervention of Energy efficiency intervention for the decommissioning of the current central heating and related auxiliary systems and the installation of a hydronic heat pump sized to air-condition only the volumes used.	Energy efficiency intervention	Economic
Western Ligurian Sea	Establishment of the DEASP Committee	Establishment of a special Technical Committee called the "DEASP Committee", which will be entrusted to implement the program of interventions provided by the DEASP.	Policies and measures	Governance
Western Ligurian Sea	GNL FACILE	Encourage a progressive reduction in the use of the most polluting fuels and dependence on oil and promoting the deployment of LNG for maritime propulsion.	Bunkering and storage facilities for alternative fuels	Market
Western Ligurian Sea	GRAMAS	Bathymetry survey campaigns in the harbour water mirror.	Research and Development	Governance
Western Ligurian Sea	Hennebique building	The project envisages the conversion of the building and surrounding areas into a cruise, tourist-recreational and residential hub.	Land use conversion	Social
Western Ligurian Sea	IMPATTI-NO	Improvement of the managerial practices for port-waste through the development of a circular economy model.	Research and Development	Social
Western Ligurian Sea	Incentives for green energy	Incentives for concessionaires to purchase electricity produced exclusively or largely from renewable sources.	Policies and measures	Regulatory
Western Ligurian Sea	INES	Electrification of the docks of the port terminal of Genova Prà to achieve a significant reduction of polluting and acoustic emissions produced by ships at berth.	Facilities and infrastructure for electric energy supply	Market
Western Ligurian Sea	Information campaign on sustainability issues	Increasing awareness of civil society on the efforts of AdSP on sustainability issues.	Policies and measures	Social
Western Ligurian Sea	Led Lighting system replacement - Port of Genoa	Replacement of sodium vapour lamps with LED lamps in cargo and passenger terminals within the port of Genoa.	Energy efficiency intervention	Economic
Western Ligurian Sea	LED Lighting system replacementes - Port of Genoa	Replacement of sodium vapour lamps with LED lamps in the outdoor areas of the port of Genoa.	Energy efficiency intervention	Economic
Western Ligurian Sea	LED Lighting system replacementes - Port of Savona/Vado Ligure	Replacement of sodium vapour lamps with LED lamps in the outdoor areas of the port of Savona/Vado Ligure	Energy efficiency intervention	Economic
Western Ligurian Sea	Measure for Energy efficiency intervention and renewable sources	Incentives for concessionaires to carry out interventions aimed at improving their energy-environmental performance.	Policies and measures	Regulatory
Western Ligurian Sea	Measure for green energy	Purchase of green electricity from renewable sources for all users of the ports of AdSP of Mar Ligure Occidentale.	Policies and measures	Regulatory

Western Ligurian Sea	Monitoring and optimization system for energy-environmental performance	Implementation of an integrated ICT system for managing and optimising energy and environmental performance using an Energy Control Unit (ECU), interconnected, and integrated with a Web-GIS system.	Digitalisation and ICT platforms	Economic
Western Ligurian Sea	Photovoltaic plant - Port of Genoa	Realization of Photovoltaic plants on the roof surfaces of buildings located within the state property boundaries in the port of Genoa. Total exploitable surface 123.880 sqm.	Renewable energy production	Economic
Western Ligurian Sea	Photovoltaic plant - Port of Savona/Vado Ligure	Realization of Photovoltaic plants on the roof surfaces of buildings located within the state-owned boundaries in the port of Savona-Vado Ligure. Total exploitable surface 54.720 sqm.	Renewable energy production	Economic
Western Ligurian Sea	Photovoltaic plant - Stazioni Marittime Terminal	Installation of a Photovoltaic plant on the buildings of Stazione Marittima and replacement of natural gas boiler with air/water heat pump.	Renewable energy production	Economic
Western Ligurian Sea	RUMBLE	Supporting sustainability practices in the port domain for reducing noise pollution.	Research and Development	Social
Western Ligurian Sea	Smart Grid in the Port of Savona	Realization of a "Smart Grid", i.e., an innovative electricity distribution network in the port of Savona-Vado Ligure.	Energy efficiency intervention	Economic
Western Ligurian Sea	Trigeneration plant in the Prà Area- Port of Genoa	Reduction of energy consumption through the construction of a new trigeneration plant in the Port of Genoa	Energy efficiency intervention	Economic
Western Ligurian Sea	Waterfront of Levante	Redevelopment of the eastern port area, fairground and ship repair area to create a new living space, with a strong nautical and sustainable vocation, available to citizens and tourists.	Land use conversion	Social
Western Ligurian Sea	Wave energy production - Port of Genoa	Realization of a 1:1 scale prototype of the OWCM (Oscillating Water Column Motor) system.	Renewable energy production	Economic
Western Sicily Sea	Cold ironing - Port of Palermo	It is planned to electrify seven berths, five of which will be used for Ro-Ro traffic, for a total installed MegaWatt development of 32.	Facilities and infrastructure for electric energy supply	Market
Western Sicily Sea	Cold ironing - Port of Porto Empedecole	The project aims to electrify 1 berth for Ro-Ro traffic for a total installed MegaWatt development of 3	Facilities and infrastructure for electric energy supply	Market
Western Sicily Sea	Cold ironing - Port of Termini Imerese	The project consists of the electrification of 2 berths for Ro-Ro traffic for a total installed MegaWatt development of 6	Facilities and infrastructure for electric energy supply	Market
Western Sicily Sea	Cold ironing - Port of Trapani	This project aims to electrify two berths for Ro-Ro traffic for a total of 6 MegaWatts installed.	Facilities and infrastructure for electric energy supply	Market
Western Sicily Sea	Digital platform at the Port Empedocle	Creation at the ports of Palermo, Trapani, Termini Imerese and Porto Empedocle of a complete digital wayfinding and digital signage platform that, by means of a mobile APP available for iOS and Android systems, and special interactive touch-screen totems placed on the exit route from the	Digitalisation and ICT platforms	Social

		port towards the city, proposes itineraries and events organised in the area to visitors.		
Western Sicily Sea	Digital platform at the Port of Palermo	Creation at the ports of Palermo, Trapani, Termini Imerese and Porto Empedocle of a complete digital wayfinding and digital signage platform that, by means of a mobile APP available for iOS and Android systems, and special interactive touch-screen totems placed on the exit route from the port towards the city, proposes itineraries and events organised in the area to visitors.	Digitalisation and ICT platforms	Social
Western Sicily Sea	Digital platform at the Port of Termini Imerese	Creation at the ports of Palermo, Trapani, Termini Imerese and Porto Empedocle of a complete digital wayfinding and digital signage platform that, by means of a mobile APP available for iOS and Android systems, and special interactive touch-screen totems placed on the exit route from the port towards the city, proposes itineraries and events organised in the area to visitors.	Digitalisation and ICT platforms	Social
Western Sicily Sea	Digital platform at the Port of Trapani	Creation at the ports of Palermo, Trapani, Termini Imerese and Porto Empedocle of a complete digital wayfinding and digital signage platform that, by means of a mobile APP available for iOS and Android systems, and special interactive touch-screen totems placed on the exit route from the port towards the city, proposes itineraries and events organised in the area to visitors.	Digitalisation and ICT platforms	Social
Western Sicily Sea	Electric charging columns - Port of Palermo	Installation, at the Port of Palermo, of an electric charging infrastructure and simultaneous supply of two electric cars.	Facilities and infrastructure for electric energy supply	Economic
Western Sicily Sea	Electrical port area lighting at the Port of Palermo	It is planned to electrify seven berths, five of which will be used for Ro-Ro traffic, for a total installed MegaWatt development of 32.	Energy efficiency intervention	Economic
Western Sicily Sea	Electrical port area lighting at the Port of Porto Empedecle	The project aims to electrify 1 berth for Ro-Ro traffic for a total installed MegaWatt development of 3	Energy efficiency intervention	Economic
Western Sicily Sea	Electrical port area lighting at the Port of Termini Imerese	The project consists of the electrification of 2 berths for Ro-Ro traffic for a total installed MegaWatt development of 6	Energy efficiency intervention	Economic
Western Sicily Sea	Integrated Management System	Provision, at the Port of Palermo, of an Integrated Management System that, by means of customized algorithms and specific information dashboards, guarantees maximum simplicity of interaction with all the technologies and devices envisaged in the project;	Digitalisation and ICT platforms	Market
Western Sicily Sea	Led Lighting system replacement	The realization at the ports of Palermo, Trapani, Termini Imerese, and Porto Empedocle of LED relamping of the currently existing lighting points and the simultaneous expansion of the ports' public lighting infrastructure.	Energy efficiency intervention	Economic

Western Sicily Sea	Photovoltaic plant - Port of Palermo	A Photovoltaic plant to be installed both on the roofs of buildings with pitched/shed/flat roofs at the Grantor's disposal for a total of approximately 1,450 kWp, and on the carports of the newly constructed car park for a total of approximately 504 kWp.	Renewable energy production	Economic
Western Sicily Sea	Photovoltaic plant - Port of Porto Empedocle	A Photovoltaic plant to be installed both on the roofs of buildings with pitched/shed/flat roofs at the Grantor's disposal for a total of approximately 1,450 kWp, and on the carports of the newly constructed car park for a total of approximately 504 kWp.	Renewable energy production	Economic
Western Sicily Sea	Photovoltaic plant - Port of Termini Imerese	A Photovoltaic plant to be installed both on the roofs of buildings with pitched/shed/flat roofs at the Grantor's disposal for a total of approximately 1,450 kWp, and on the carports of the newly constructed car park for a total of approximately 504 kWp.	Renewable energy production	Economic
Western Sicily Sea	Photovoltaic plant - Port of Trapani	A Photovoltaic plant to be installed both on the roofs of buildings with pitched/shed/flat roofs at the Grantor's disposal for a total of approximately 1,450 kWp, and on the carports of the newly constructed car park for a total of approximately 504 kWp.	Renewable energy production	Economic
Western Sicily Sea	Restyling of the Maritime Station on Molo Vittorio Veneto	The project is part of the broader redesign of the waterfront, in a desirable and increasingly modern and mature relationship between the city and its port, capable of making the cruise terminal not only more efficient but also livable and pleasant for citizens.	Land use conversion	Social
Western Sicily Sea	Trigeneration plant	A trigeneration plant consisting of a power station with a generator set fuelled by mains methane gas, operating in grid tracking mode, with an electrical output of 260 kWe and operating for at least 5,840 hours per year;	Energy efficiency intervention	Economic

Source: Author’s elaboration

CHAPTER 6

PORT AS RENEWABLE ENERGY HUBS: INSIGHTS FROM THE ITALIAN CASE*

*An extended abstract of this paper has been presented at the IAME conference (September 5-8, 2023, Long Beach, California). The full version of the paper has been submitted at the Impresa Progetto – Electronic Journal of Management for publication.

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 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, energy storage, energy conversion

6.1. 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. And 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 6.2 provides the conceptual framework and the theoretical foundation of the study consisting of literature review on the energy hub concept. In section 6.3, the methodology is presented. Section 6.4 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 6.5 through the presentation of the PREH configuration. Finally, the section 6.6 presents the conclusions.

6.2. Theoretical foundations

6.2.1. 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.

6.2.1.1. 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.

6.2.1.2. 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.

6.2.1.3. 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.

6.2.1.4. 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.

6.2.1.5. 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.

6.2.1.6. 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.

6.2.1.7. 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).

6.2.2. 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).

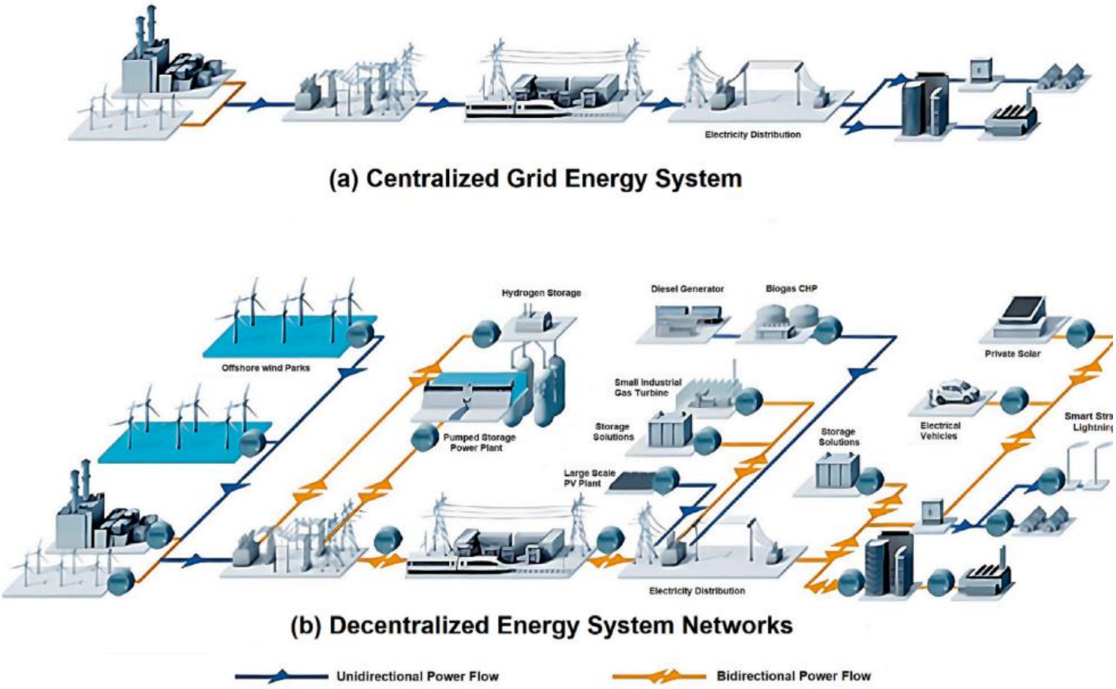
Traditionally, even if ports do not belong to the energy sector, they have equipment, tools, instruments, know-how and experience to carry out operations related to energy activities due to the high energy demand arising from the port activities. Over time ports are trying to better manage their energy 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 6.1).

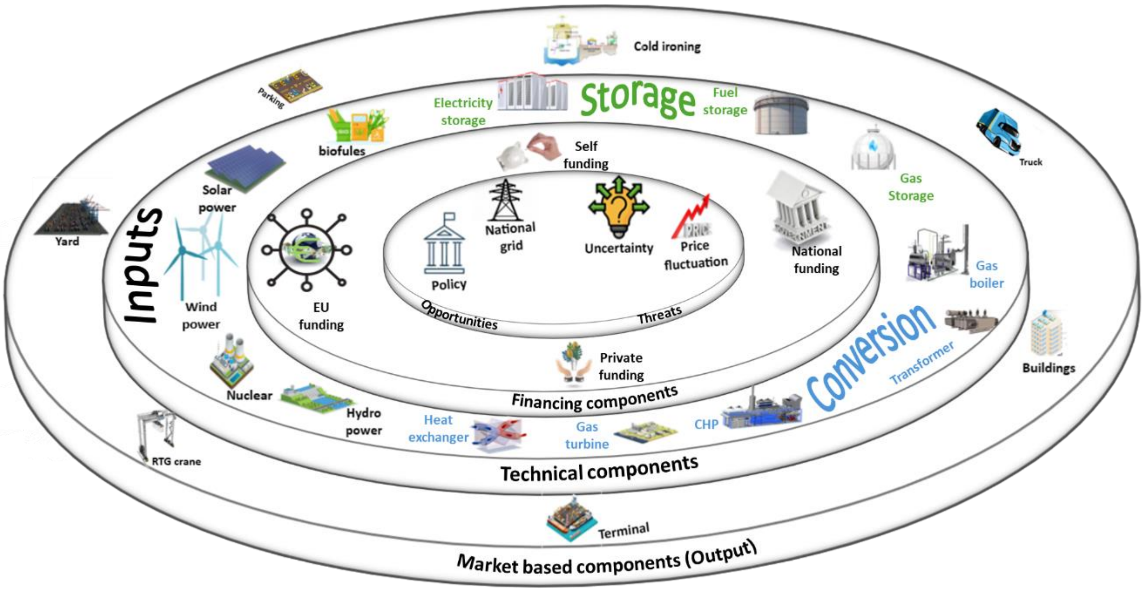
Figure 6. 1: Centralized grid energy system Vs decentralized energy system.



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 6.2). 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 6. 2: The conceptual framework for developing a port renewable energy hub configuration.



Source: Author's 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.

6.2.2.1. 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.

6.2.2.2. 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.

6.2.2.3. 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[5], OpEx[6] 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.

[5] CapEx: capital expenditure
[6] OpEx: operating expenditure

6.2.2.4. 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.

6.3. 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. (2022). 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 6.1).

Table 6. 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.

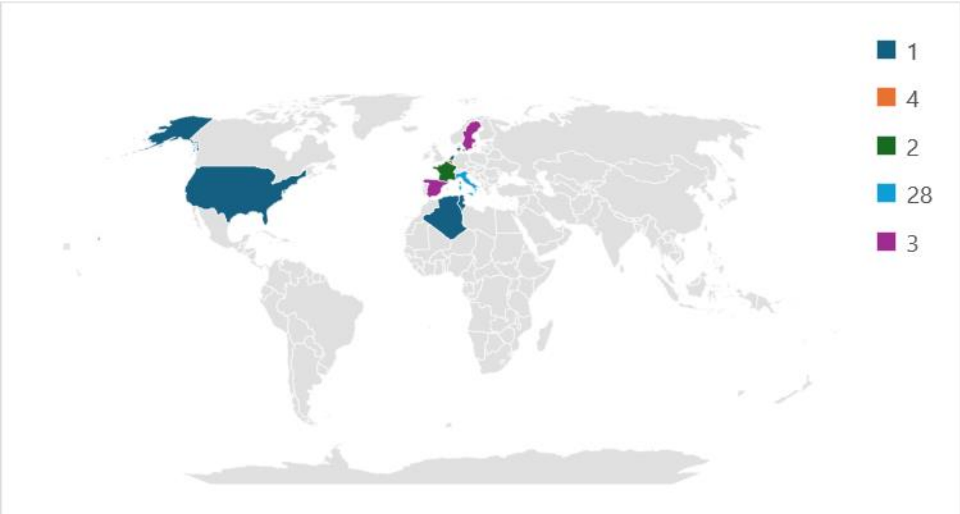
Source: Satta et al. (2022)

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 6.3). Most of the respondents were in Europe, specifically in Italy (28), Belgium (4), Sweden (3), Spain (3) and France (2).

Figure 6. 3: Country of employment of the respondents.

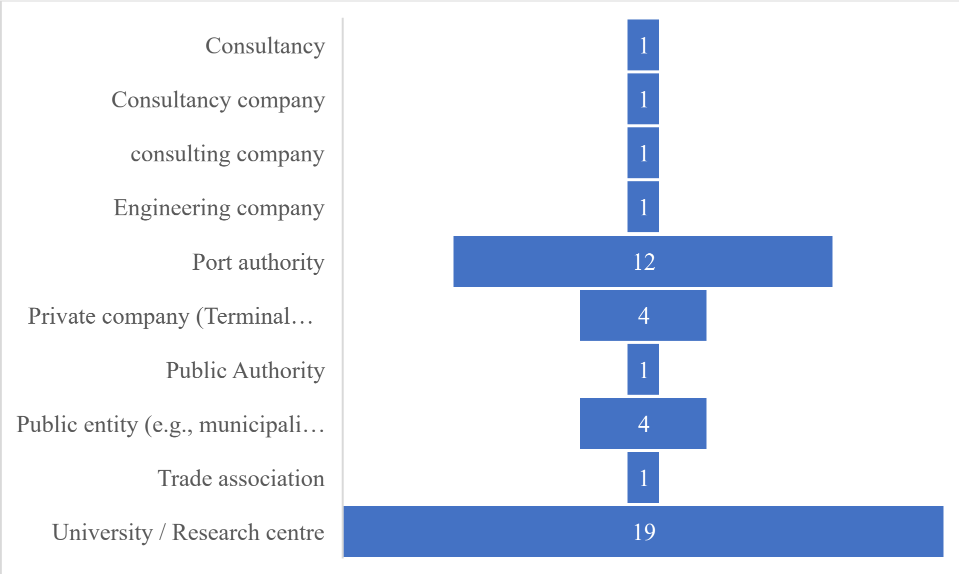


Source: Author's elaboration

Furthermore, among the respondents, 42% are affiliated with universities or research centres, while 27% are associated with port authorities (Figure 6.4). 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 6. 4: Type of companies of respondents.



Source: Author's 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.

6.4. Results/Findings

6.4.1. 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)

6.4.2. The port energy hub main components

The inputs and the selection criteria

Figure 6.5 presents the most important inputs and Figure 6.7 presents the selection criteria of the inputs resulting from the average scores given by the port experts.

Following the Moscow (Figure 6.6), 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) represents 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 6. 5: Port renewable energy hub inputs

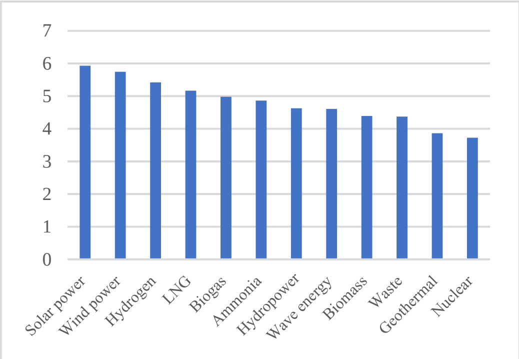
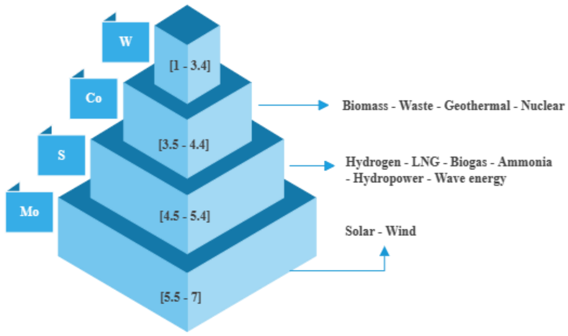


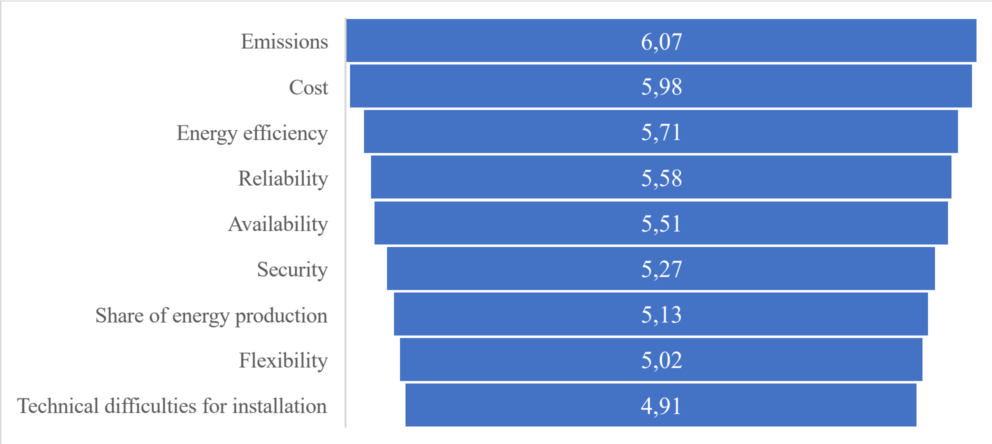
Figure 6. 6: MoSCoW classification of PREH inputs.



Source: Author’s elaboration

The implementation of these inputs is based on several selection criteria (Figure 6.7). 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 6. 7: Inputs selection criteria.



Source: Author's elaboration

The Outputs and the selection criteria

The outputs and selection criteria are shown in Figures 6.8 and 6.10. Following the MosCoW method (Figure 6.9) 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 6. 8: Port renewable energy hub outputs

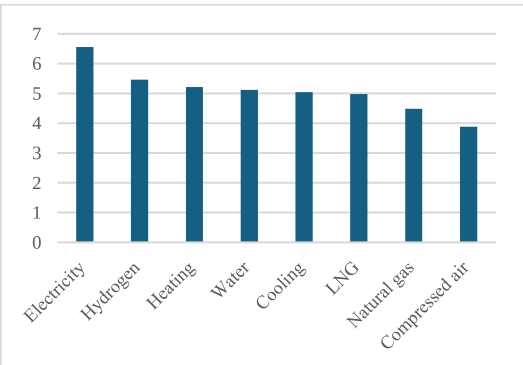
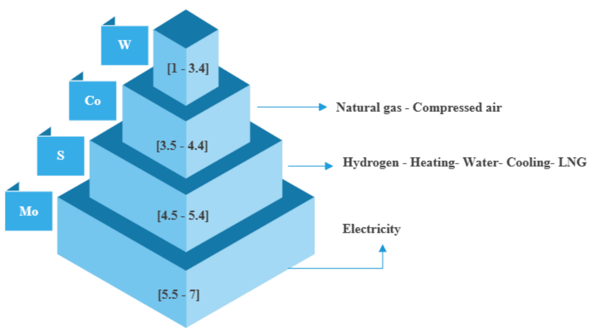


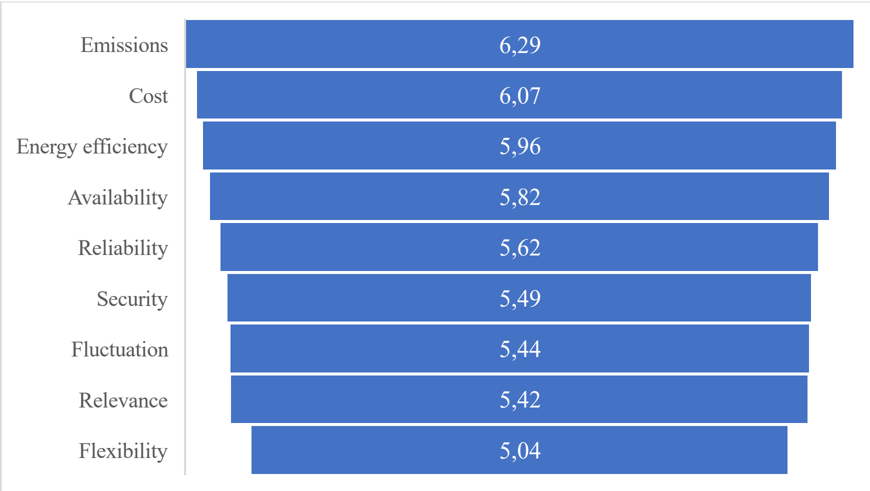
Figure 6. 9: MoSCoW classification of PREH outputs.



Source: Author's 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 6. 10: Output selection criteria.

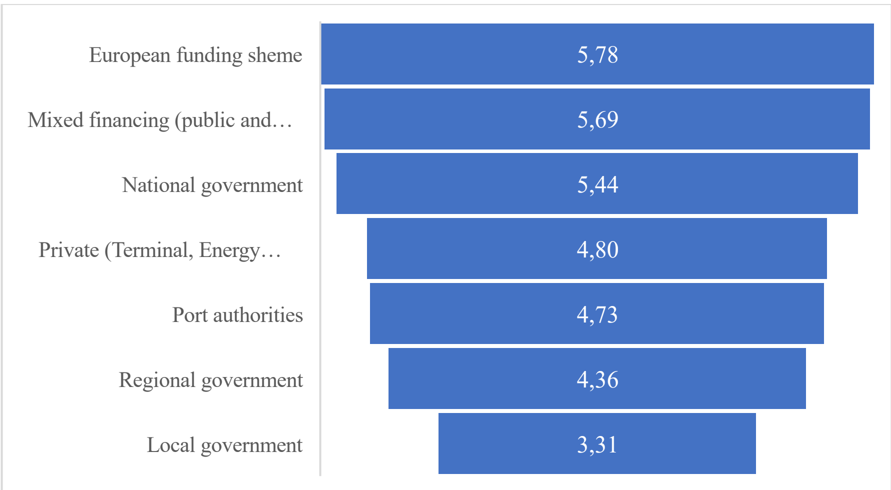


Source: Our elaboration

Funding, opportunities and threats

Figure 6.11 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. And to finish regional government (4.36) and local government (3.31) can also finance the implementation of GSs.

Figure 6. 11: Type of funding schemes for GSs.



Source: Author's 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

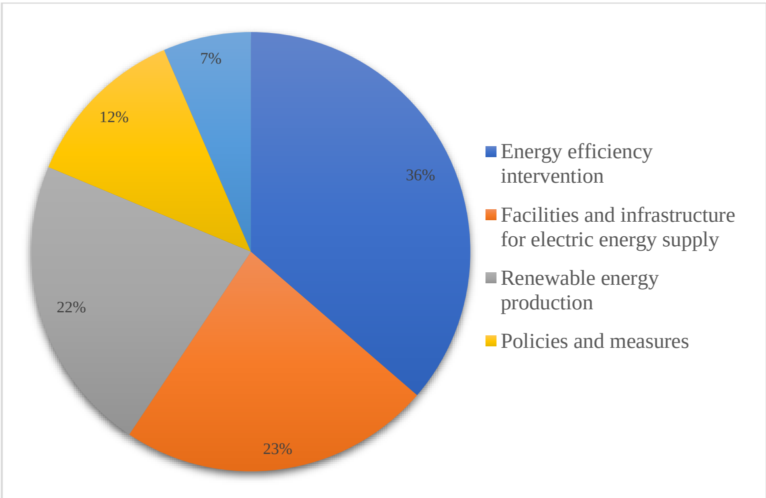
The empirical results emerging from the analysis of the as is situation of the Italian port system emphases the growing number of interventions for reducing the energy consumption and decarbonising port areas. In this vein, 36% of GSs account for energy efficiency interventions and 23% of them refer 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 6.12).

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 focused on implementing GSs project and demonstrate to have reached an almost mature phase in the ongoing patterns towards their transformation into innovative renewable energy hubs. And 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).

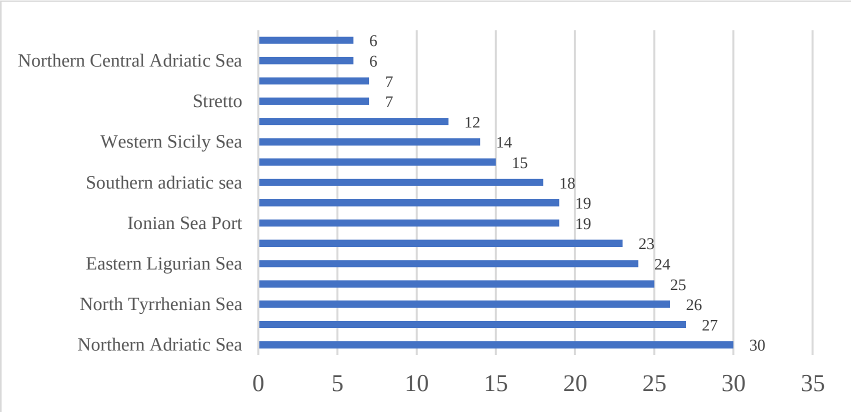
Concerning the financing, more than 70% of these GSs are financed by the National Recovery and Resilience Plan (NRRP)[7] and European Funds (e.g., Ealing project). The NRRP has allocated 700 million euro for the electrification of 34 Italian ports between 2021 and 2026 and 270 million euro for the implementation 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.

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.

Figure 6. 12: Green strategies typologies: The "As Is" situation of Italian port



[7] 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: Author's 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.

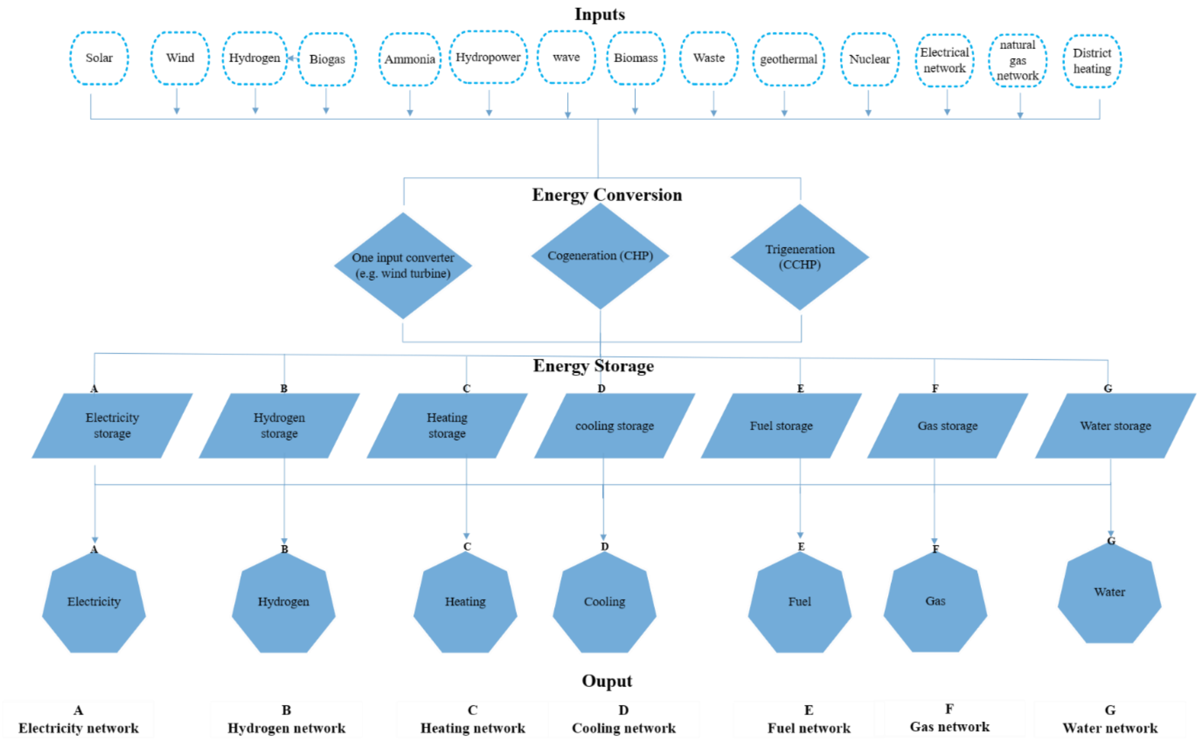
6.5. Discussion

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 6.13. This configuration includes the energy production, conversion, storage and consumption.

Figure 6. 13: PREH configuration.



Source: Author's 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 6.2) 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 6. 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: Author's 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 6.3).

Table 6. 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,	Fuel cell	Fuel cell	Hydropower turbines (Reaction Turbines, Impulse Turbines,	Wave energy converter

		Engines, fuel cell, absorption chiller)			Hydroelectric Generators)	
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: Author's elaboration

The "could have" inputs include biomass, waste, geothermal and nuclear (Table 6.4). 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 6. 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: Author's elaboration

As renewable energy source suffers from uncertainty, national energy networks could be used as a backup system (Table 6.5). 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 6. 5: PREH back up system

PREH components	**Back up 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: Author's 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.

6.6. 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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CHAPTER 7
A REVIEW ON PORT ENERGY MANAGEMENT AS A HOLISTIC APPROACH*

* An extended abstract of this paper has been presented at the IAME conference (29 June – 1 July 2022, South Korea). The full version of the paper has been submitted to the International Journal of Transport Economics (IJTE) for publication.

Abstract

Ports are traditionally considered as energy hubs because of the different types of energy production, storage and consumption that take place within the port, and their suitable location for importing and exporting different types of energy. However, these activities are known to be energy inefficient due to the lack of energy management strategies. Active energy management seems to be a great solution for energy inefficiency reduction as it can bring substantial efficiency gains, contribute to the development of alternative revenue sources and improve the port's competitiveness. In this perspective, this paper conducts a systematic literature review based on more than 130 journal articles that address the three port energy management concepts that underpin this study, namely energy efficiency, energy conservation and renewable energy.

These concepts are outlined in three main categories: strategies, technologies, best practices. The paper provides a systematic literature review on the current state of the art based on the energy hub approach. Current gaps in extant literature and the most promising research fields of investigation are highlighted for setting the future research agenda. Analysis shows that energy management offers great potential to ports to improve the energy efficiency of port activities and researchers have many opportunities for high-impact research.

Keywords: Port, energy efficiency, renewable energy, energy management system, sustainability, energy conservation.

7.1. Background

The port industry is traditionally argued to constitute an energy-intensive business, responsible for negative externalities and environmental impacts in several areas. The substantial energy consumption in port areas originates from the magnitude of highly impacting business processes and activities embedded in port spaces and the variety of economic actors located within/around port boundaries. With this accelerating energy consumption linked to port activities and the resulting climate change, it has become a top priority for Port Managing Bodies (PMBs) to develop a sustainable long-term energy solution to reduce the overall energy consumption of ports.

Indeed, the nature and the scope of the energy problem appear to be extremely general and vast. A successful solution is likely to require a carefully coordinated and highly integrated system of multiple solution approaches, which includes the development of renewable energy sources, innovation in energy generation and processing technologies, smart supply chain management (e.g., the demand-side control through variable pricing and smart grid technology), and the development of carefully thought-out policies (Lee, 2014). Therefore, the introduction of "smart" and "green" perspectives in port management and the development of strategic plans focused on energy and environmental issues are expected to optimize energy consumptions and mitigate the related harmful emissions in the business (Bergqvist & Monios, 2019).

According to Acciaro et al. (2014) active energy management can offer substantial efficiency gains, contribute to the development of new alternative revenue sources and improve the competitive position of the port. However, energy management in ports has been neglected for a long time both by scholars and practitioners. It was only in 2009 that energy was included for the first time in the top 10 environmental priorities of European ports under the heading "Energy consumption". Over the years, it moved from the 7th place in 2009 to the 2nd in 2019 and, in 2020, "Energy efficiency" substituted "Energy consumption" in the ranking. In 2023, "energy efficiency" still ranks third among the top ten environmental priorities of European ports. This fast increase in position shows the growing interest of ports to enhance energy efficiency, and by extension the implementation of energy management strategies. In addition, more recently, both scholars and academics are increasingly considering the role of port nodes and related local communities as potential energy producer, grounding on new concepts such as port energy communities. The increasing number of academic contributions on this issue and the implementation of energy policies and funding programmes for pursuing energy efficiency targets, demonstrate the attention towards the mitigation of the environmental impact at EU level. Next to this, empirical data regarding port energy consumption are still lacking because of the scarce diffusion of culture in energy management in Port Authorities and private terminal operators. As a result, prior studies on port energy management are argued to be still fragmented and the academic debate on this issue would greatly benefit from the development of an in-depth literature review aimed at analysing strategies, technologies, best practices that address the three port energy management concepts that underpin this study, namely energy efficiency, energy conservation and renewable energy. In this perspective, diverse theoretical angles and valuable topics are introduced and discussed, such as: drivers for the introduction of energy management systems in the port domain, advanced energy planning, demand response programs, port performance measures, policies and measures, sustainable practices, KPIs, decision support systems, facilities and infrastructure for electric energy supply, and renewable energy technologies.

The paper is structured as follows. The conceptual framework is presented in Section 7.2. Section 7.3 describes the methodology of the literature review along with the typology development. Section 7.4 presents the main findings regarding the strategies, technologies and best practices identified in the review. Section 7.5 highlights the research gaps in the literature and discusses the implications for practice and future research directions. Finally, the conclusions are drawn in section 7.6.

7.2. Conceptual framework: energy efficiency, energy conservation and renewable energy production

Energy efficiency is about using technology to reduce energy waste and related harmful emissions arising from port activities. The introduction of this concept in this framework is justified by the fact that over the years, energy efficiency has become a crucial goal for ports to achieve. To illustrate this, between 2009 and 2023 it has risen from seventh to third place among the priorities of European ports (ESPO, 2023). In addition, most ports around the world are increasingly implementing policies to improve the energy efficiency of their operations by adopting ISO 50001 certification or at least implementing corporate policies and energy management plans to define their energy efficiency goals and establish the related energy frameworks. For example, Hamburg Port Authority, Port of Antwerp, Port of Felixstowe, Port of Arica, Noatum Container Terminal Valencia have been certified with the ISO 50001 (Iris & Lam, 2019). Many other ports, including the ports of Valencia, Marseille, Livorno, Venice, Koper and

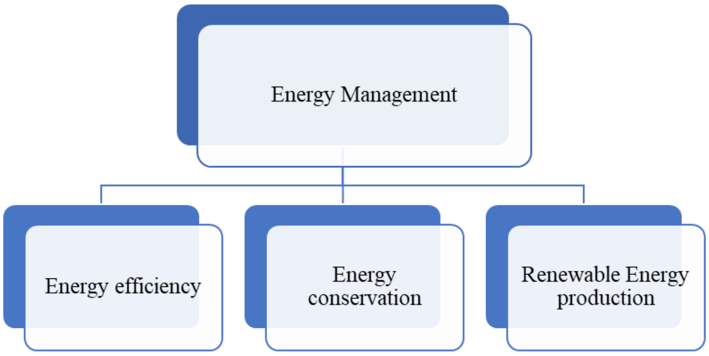
Rijeka, have introduced port energy management plans to improve the energy efficiency of their operations (Sdoukopoulos et al., 2019).

However, PMBs cannot rely on technology alone to achieve their goal of reducing energy waste but must also consider non-technological strategies to reduce energy consumption (e.g., peak shaving) and by cutting or reducing energy-consuming activities (e.g., reducing the number of port equipment in operation in a work cycle). For this reason, we introduced energy conservation within this framework. It has a similar goal as energy efficiency, i.e. reducing energy waste and related harmful emissions, but without relying on technology. Indeed, both aim at a more intelligent use of energy and lead not only to energy savings, but also to economic savings, hence to environmental, financial and economic sustainability.

Given the energy efficiency problems and the need to develop reliable port energy systems, ports must self-produce their own energy from renewable sources to achieve environmental, financial and economic sustainability. The energy hub approach proposed in this study implies expanding the use of distributed energy generation in the port by gradually increasing their use of renewable energy and the related innovative technologies (Akorede et al., 2010). Combining the self-energy production from renewable sources with energy conversion and storage technologies can lead to a significant improvement in the energy efficiency of ports. This ensures the effective utilization of renewable energy necessary to address the current issues related to the growth in energy demand, climate change, and the need for energy security (Maroufmashat et al., 2015). The utilization of energy conversion and storage technologies increases the reliability of the network thanks to the ability to generate energy (e.g., electricity, heat, fuel) during power outages that can occur in the entire energy system. Therefore, energy is supplied cost-effectively, as it is produced locally, accordingly lead to the reduction or the elimination transmission and distribution costs.

Hence, the port energy hub approach represented in Figure 7.1 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 and financial and economic sustainability.

Figure 7. 1: holistic approach of Energy management in the port domain.



Source: Author's elaboration

7.3. Systematic Literature Review: methodological issues

The aim of this study is to conduct a systematic literature review for investigating the current state of the art regarding energy management in ports. As energy management is a wide discipline, that includes the concepts of "energy efficiency", "energy conservation" and "renewable energy production", all these topics has been included in the analysis. To address the research objective, a three-stage procedure is carried out, including (i) planning, (ii) execution, and (iii) reporting, as suggested by Tranfield et al. (2003).

In particular, in the planning stage (i) we define the object and set the boundaries of the research review. In this perspective, we focus on academic papers selected from leading peer-review international journals. The papers are selected from the Scopus database (provided by Elsevier) carrying out queries with specific keywords. Both conference papers and books are excluded from the sample to ensure the homogeneity and consistency of data. In accordance with Crossan and Apaydin (2003), the second stage of the process, execution, consists of three steps: definition of initial selection criteria, grouping publications by pertinence, analysis and synthesis.

Initial selection criteria

The Scopus database is screened throughout ad-hoc queries using word strings consistent with the focus of this study, i.e., port energy management. The search was structured into two main searching categories of words. The first category places ports at the centre of interest, while the second category focuses on the three energy management concepts proposed in the study. This approach makes it possible to broadly determine relevant strategies, technologies, and best practices to reach the environmental, financial and economic sustainability of ports. The following string of words were used: ((port OR seaport OR ports OR harbor) AND ("energy efficiency" OR "energy conservation" OR "energy management" OR "energy management system" OR "renewable energy" OR "sustainable port"). The inclusion criteria were defined by focusing the search on the aforementioned word strings in the articles' title, abstract and keywords. No time span was defined.

The search in Scopus led to a preliminary result of 794 publications. These publications were first reviewed by reading the titles and abstracts before including publications deemed relevant in the initial database. As a result, a list of 272 papers was identified.

Grouping publications by pertinence

The initial database is further scrutinized to exclude studies that are not relevant to the purpose of the manuscript. Then, the abstracts of the 272 sample papers have been read by the three authors and two alternative labels have been assigned by each coder to each manuscript (pertinent vs. not pertinent). The authors further discussed on the papers obtaining two positive scores, before including them in the updated version of the database. This codification has driven to a database of 169 papers published in 63 international journals, including, Sustainability (Switzerland) (21), Energies (20), Journal of Cleaner Production (15), Transportation Research Part D: Transport and Environment (8), Applied Energy (9). Then, the entire text of these (169) scientific contributions has been read by the three authors and the abovementioned procedure is replicated, resulting in a final dataset made up of 147 relevant contributions.

Analysis and synthesis

Each sample manuscript has been carefully analysed and categorized according to the following dimensions: Title, authors, year, strategic goal, pursued benefit/s, geographical coverage, port name, paper type, theoretical perspective, user profile, managerial/academic implications: main focus, feasibility study, managerial/academic implications: detailed focus, managerial/academic implications: main insights, state of the technologies (Appendix 7.1).

All data has been then synthetized in ad-hoc files, to facilitate quantitative analyses and comparisons. The outcomes are then reported in the third phase of the literature review process, where the main strategies, technologies and best practices are presented. The outcomes are reported in Section 7.3.

Typology development: Taxonomies

The publications are categorized following the dimension "Managerial/academic implications: main focus" that includes strategies, technologies, and best practices. The review focuses on publications that cover at least one of the concepts of the framework i.e., energy efficiency, energy conservation and renewable energy production. Preliminary categories (i.e., the Managerial/academic implications: main focus) were aggregated into sub-categories sets including policies and measures, decision support systems, energy management systems, technologies (Table 7.1). The number of publications for each category and sub-category is reported in brackets.

Table 7. 1: Categories and subcategories

	CATEGORIES		
	Strategies (61)	Technologies (74)	Best Practices (12)
SUBCATEGORIES	Policies and measures (19)	Facilities and infrastructure for electric energy supply and alternative fuel (19)	Port performance measure (5)
	Energy management system (12)	Energy converters (7)	Sustainable practices (5)
	Decision support system (12)	Energy production (10)	
	Advanced planning systems (13)	Energy storage (7)	
	Demand response programs (5)	Feasibility study on technologies (17)	
		Innovation trend and other technologies (14)	

Source: Author's elaboration

The literature review papers identified within the analysed academic contributions focus on technologies and tools for port sustainability (Bjerkan & Seter, 2019; Iris & Lam., 2019; Sdoukopoulos et al., 2019). Bjerkan and Seter (2019) reviewed extant academic literature on tools and technologies for sustainable ports and Iris and Lam. (2019) conducted a systematic literature review to analyse operational strategies, technology, renewable energy, alternative fuels and energy management systems for improving the energy efficiency and environmental performance of ports and terminals. Sdoukopoulos et al. (2019) provided a pragmatic and comprehensive overview of the main policies, technologies and practices implemented by European ports for improving their energy efficiency.

Contrary to the literature review included in the sample, this paper focuses on energy management as a holistic approach, using the energy hub approach since active energy management can lead to the several including efficiency gains, development of new alternative revenue sources and improvement of the competitive position of the port (Acciaro et al., 2014).

7.4. Main findings

This section presents the results of the systematic literature review following the dimension “Managerial/academic implications: main focus” that includes strategies, technologies, and best practices (Annex). Strategy refers to approaches, methods, measures, incentives that encourage the use of technologies or not for reducing the energy consumption of port activities and the uptake of renewable energy sources for energy management. Technologies include energy production, conversion, storage technologies for port for energy management. And they also include facilities and infrastructure for energy supply, feasibility studies and innovation trend on technologies. Finally, best practices include sustainable practices and port performance measures for the application of strategies and technologies.

7.4.1. Strategies

The following section presents the main findings in publications that address strategies for port energy management that encompass at least one of the energy management concepts investigated in this study. An overview of the publications that refer to the different strategies is provided by the Table 7.2.

Table 7. 2: Overview of publications on strategies

Policies and measures	**Energy management system**	**Decision support system**
Gattuso et al., 2023; Agostinelli et al., 2022; Molavi et al., 2020; Paulauskas et al., 2020; Martínez-Moya et al., 2019; Moeis et al., 2020; Tsai et al., 2018; El-Amary et al., 2018; Styhre et al., 2017; Yang Y.-C. 2017; Yang L.et al., 2017; Erdas et al., 2015; Lee et al., 2015; Acciaro et al., 2014; Wang et al., 2020; He & Zhu., 2023; Kizielewicz & Skrzeszewska 2021; Lee et al., 2021; Tai & Chang., 2022.	Teng et al., 2023; Teng et al., 2022; Shan et al., 2022; Alasali 2019a; 2019b; Pietrosanti et al., 2020; Alasali et al., 2017; Antonelli et al., 2017; Papaioannou et al., 2017; Alasali et al., 2018; Attanasio et al., 2023; Nguyen et al., 2022.	Tan et al., 2022 ; Barone et al., 2021 ; Cloquell-Ballester et al., 2021 ; Fossile et al., 2020 ; Hartman & Clott 2012 ; Sabri et al., 2013 ; Fernández-Leal et al., 2023 ; Odoi-Yorke et al., 2022 ; Balbaa et al., 2019 ; Hua et al., 2020 ; Di Vaio et al., 2020 ; Christodoulou & Cullinane 2019.
Advanced planning systems	**Demand response programs**	
Chargui et al., 2023 ; Takalani & Masisi 2023 ; Tian et al., 2023 ; Chen et al., 2023 ; Shi et al., 2023 ; Fang et al., 2022 ; Mao et al., 2022 ; Hein et al., 2021 ; Xin et al., 2014 ; Shanmugam & Sharmila 2022 ; Iris & Lam 2021 ; Sifakis & Tsoutsos 2021 ; Wu et al., 2020.	Eggimann et al., 2023 ; Sifakis et al., 2022 ; Pei et al., 2021 ; Gennitsaris & Kanellos 2019 ; Fan et al., 2023.	

Policies and measures

A number of publications refer to port policies and measures as a potential instrument for a successful implementation of port energy management. The aforementioned publications include regulations, incentives, and tax policies to motivate ports to initiate energy sustainability and emission-reduction efforts (Molavi et al., 2020). The main taxation policy is carbon taxation (He & Zhu, 2023; Wang et al., 2020). Considering the carbon emission taxation policy, Rangasamy et al. (2022) proposes a study of the integrated berth allocation and quay crane assignment problem. Green port infrastructure policies and measures have also grabbed the attention of some authors. Agostinelli et al. (2022) provided an infrastructure digitization policy to optimize maintenance processes and energy efficiency to transform port areas to Zero Energy District (ZED). Lee et al. (2021) suggested a practical policy direction for designing a sustainable port hinterland policy from an environmental justice perspective.

In addition, optimization policies and measures to increase energy saving emerged in the literature. Lee et al. (2015) showed how the dual cycle operations for cranes, vehicles, and yard cranes can improve the operating efficiency and reduce the energy consumption in a container terminal. Moreover, several policies to reduce CO2 emission and increased the energy efficiency of port activities are outlined in the literature such as retrofitting (Gattuso et al., 2023), shore power system program policies (Kizielewicz & Skrzeszewska, 2021), slow steaming (Tai & Chang, 2022), staff training & highly skilled personnel (Paulauskas et al., 2020); awareness creation for energy efficiency (Erdas et al., 2015; Acciaro et al., 2014;); renewable energy use (El-Amary et al., 2018). Globally, the active energy management in the port can lead to substantial efficiency gains, contribute to the development of new alternative revenue sources and in the end, improve the competitive position of the port (Acciaro et al., 2014).

In this context, a solid set of policies and measures can foster the achievement of energy efficiency, energy conservation and the implementation of renewable energy within the port.

Energy management system

The energy management perspective that emerges from the literature is essentially based on energy management systems i.e., the development of systems for demand and supply planning. According to Iris and Lam (2019), an energy management system consists of energy demand planning, energy supply planning and smart energy management systems linking demand and supply. in this vein, Xie et al. (2023) proposed a resilience enhancement planning strategy for a seaport multi-energy system that integrates various energy modalities and sources, including heating, cooling, hydrogen, solar, and wind power. Nguyen et al. (2022) examined the smart port literature to clarify the common concepts of smart ports by analysing and discussing the approaches and applications of the technology in smart port energy management systems. Several publications in the literature addressed the used of the polymorphic distributed energy management method for the low carbon port microgrid (Teng et al., 2023; Teng et al., 2022; Shan et al., 2022). Considering a polymorphic network and by analysing the characteristics of different loads and the energy conversion system including the power to gas and combined cooling heating and power, Teng et al. (2023) constructed an energy management model for the port integrated energy system. In the same vein, Shan et al. (2022) proposed a polymorphic distributed energy management method for the low carbon port microgrid with carbon capture and carbon storage devices and energy conversion systems to reduce the carbon emission of the port and build a green port.

As Rubber Tyre Gantry cranes are known to be one of the main energy consumers in the port (Iris & Lam, 2019), numerous academic contributions propose the adoption of energy management system strategies for reducing the RTG energy consumption. The main contributions are provided by Alasali, who conducted several empirical studies in the port Felixstowe. The studies first proposed a deterministic optimal energy management controller and a Model Predictive Controller as suitable approaches for minimising the electricity considering a given energy storage system parameters and network specifications (Alasali et al., 2017). Then, the study provided a stochastic optimal management system based on a Genetic Algorithm for controlling an energy storage system equipped with a network of RTG cranes, with the aim to improve their reliability and economic performance (Alasali et al., 2019a). Taken into consideration the high volatility that characterizes the energy demand and the uncertainty in the RTG crane demand prediction, an optimal energy control strategy based on a Stochastic Model Predictive Control algorithm is also provided (Alasali et al., 2019b). Finally, the authors provided a Fuzzy Logic Controller approach to maximise the potential benefits that could emerge from adding energy storage units to RTG cranes (Alasali et al., 2020).

Decision support system (DSS)

The successful implementation of a port energy management system also depends on appropriate information management, given the large amount of information flowing through the energy system. In this perspective, Di Vaio et al. (2021) investigated management control systems to be used for supporting PMBs in their decision-making processes to prevent and reduce negative environmental effects from port activities. Tan et al. (2022) proposed a strategic level decision method for yard cranes transformation and deployment with the aim to develop efficient and energy-saving green ports with low carbon emissions.

In the same vein, Barone et al. (2021) used the bim-based building energy modelling approach to improve the implementation of effective energy-saving measures for a maritime passenger station in Naples. Container terminal activities are known to be energy intensive and in most of the time these activities are carried out in an inefficient manner. Therefore, measuring their energy efficiency is fundamental to understand the origin of inefficiencies in energy use.

In this perspective, Sabri et al. (2013) proposed a strategy based on Data Envelopment Analysis (DEA) to measure energy efficiency of a container terminal. After the identification of the origin of inefficiency, strategies such as Relevant Use of Energy (RUE) index proposed by Cloquell-Ballester et al. (2021) can be used to improve energy performance and reduce the energy consumption in a container terminal. Multicriteria decision models have emerged to be a useful tool to support PMBs in their energy management decisions (Odoi-Yorke et al., 2022; Fossile et al., 2020). Finally, Christodoulou and Cullinane (2019) applied a SWOT/PESTLE analysis to identify the political, economic, social, technological, legal and environmental factors that have a positive or negative effect on the adoption and successful implementation of a port energy management system.

Advanced planning systems (APSs)

APSs are strategies based on applications or softwares that enable port to plan and coordinate tasks such as advanced forecasting, energy demand planning, energy supply planning due to the high level of uncertainty that characterises the energy management activity. Chargui et al. (2023) proposed a novel robust exact decomposition algorithm for berth and quay crane allocation and scheduling problem (BACASP) considering uncertainty and energy efficiency with the objective to minimize both energy costs and vessel tardiness. Takalani and Masisi (2023) developed an optimal load-handling trajectory for port cranes with the aim to minimize load cycle time and reduce energy consumption. Then, Shi et al. (2023) provided an optimal strategy in two-time intervals for flexible operations of energy storage systems and combined electric-thermal power demands of reefer containers in the coordinated green-seaport energy-logistics systems (ELS). Xin et al. (2014) proposed a methodology to improve the handling capacity of an automated container terminal in an energy-efficient manner. Regarding the integration of multi energy network, Chen et al. (2023) proposed a multi-objective voltage/VAR control (VVC) method capable to coordinate multiple devices of electricity, heat, gas, and logistics in multiple timescales to minimize voltage deviation and operating costs. Finally, Iris and Lam (2021) provided a mixed integer linear programming model used to solve the integrated operations planning and energy management problem for seaports with smart grid and to solve a scheduling problem at an automated land–maritime multimodal container terminal with multi-size containers.

Demand response programs.

Demand response programs are strategies that encourage consumers to change their consumption behaviours in order to balance the energy demand and energy production through price changing or incentives. A handful of publications addressed the demand response programs strategies. Fan et al. (2023) provided an incentive-based cooperative coordination framework between port microgrid and berthed ships by using the flexibility of cold ironing power as a demand response tool. For electrified large ports, Gennitsaris and Kanellos (2019) proposed a real-time distributed demand response system by using a Multi-agent systems (MAS) with hierarchical structure and Pei et al. (2021) showed how the Time of Use (TOU) tariff and super-peak tariff can lead container operating costs saving and ensure that the internal temperature of the container does not exceed the limit while changing the distribution of energy which could help alleviate the peak load problem of the port electric system. To finish, Eggimann et al. (2023) analysed the impact of daylight-saving time (DST) in port which consist of shifting the working hours by one-hour.

7.4.2. Technologies

The following section presents the main findings in publications that address technologies for energy management. An overview of the publications that refer to the different technologies is provided by the Table 7.3.

Table 7. 3: Overview of publications on technologies

Energy production	**Energy converters**	**Facilities and infrastructure for electric energy supply and alternative fuel**
Calise et al., 2024 ; Kumar et al., 2023 ; Potapenko et al., 2023 ; Agostinelli et al., 2022 ; Masip Macía et al., 2021 ; Cascajo et al., 2022 ; Moore & Boyle C. 2014 ; Saket & Etemad-Shahidi., 2012 ; Hanssen et al., 2014 ; Busillo et al., 2008.	Calheiros-Cabral et al., 2022 ; Darwish A. 2023 ; Qing et al., 2023 ; Foteinis S. 2022 ; Abdullah et al., 2021 ; Huertas-Fernández et al., 2021 ; Amini et al., 2021.	Fallahzadeh et al., 2023 ; Misra et al., 2017 ; Kotrikla et al., 2017 ; Winkel et al., 2016 ; Vichos et al., 2022 ; Kim et al., 2012 ; Xia et al., 2023 ; Zhang et al., 2022 ; Bakar et al., 2022a ; 2022b ; Roy et al., 2021 ; Gutierrez-Romero et al., 2019 ; Pivetta et al., 2024 ; Pivetta et al., 2023 ; Xie et al., 2023 ; Abu Bakar et al., 2023 ; Kumar et al., 2019 ; Bakar et al., 2021 ; Roy et al., 2020.
Energy storage	**Feasibility study on technologies**	**Innovation trend**
Di Ilio et al., 2021; Corral-Vega et al., 2019; Lombardi et al., 2023; Borelli et al., 2021; Kermani et al., 2020; Alasali et al., 2019; Zhao et al., 2016.	Filgueira et al., 2021; Arabzadeh et al., 2021; Gabbar & Esteves 2023; Vakili & Ölçer 2023; Parhamfar et al., 2023; Buonomano et al., 2023; Colarossi & Principi 2023; Ali et al., 2022; Sifakis et al., 2022; Elnajjar et al., 2021; Baldasso et al., 2020; Filgueira-Vizoso et al., 2021; Yarova et al., 2017; G. Gaudiosicesari F.G., 1993; Ramos et al., 2014; Cascajo et al., 2019; Vlahopoulos & Bouhouras., 2022.	Szymanowska et al., 2023 ; Marichal et al., 2024 ; Alzahrani et al., 2021 ; Clemente et al., 2023 ; Bjerkan & Seter .2019 ; Sdoukopoulos et al., 2019 ; Iris & Lam 2019 ; Li et al., 2023 ; Cavalli et al., 2021 ; Wang et al., 2021 ; Philipp et al., 2021 ; Filina-Dawidowicz & Filin., 2019 ; Sifakis et al., 2021 ; Kumar et al., 2019.

Energy production

This section refers to the academic contributions addressing the most promising technologies for renewable energy production. Potapenko et al. (2023) investigated the extent to which renewable energies (wind, solar and wave) could cover the energy demand to meet all heating needs in the port. Busillo et al. (2008) assessed the energy efficiency of a wind plant installation in the port of Livorno. Shukla et al. (2023) presented a dynamic simulation model for the production of liquefied biomethane by anaerobic digestion. The production of green hydrogen also emerged in the literature. Masip Macía et al. (2021) provided the sizing of the key components that make up green hydrogen to ensure the supply of 1 MWe in replacing the diesel generator. Kumar et al. (2023) addressed the synergy of green hydrogen sector with offshore industries. Saket and Etemad-Shahidi (2012) investigated the wave power production along the northern coasts of the Gulf of Oman and, Cascajo et al. (2022) presented the most accepted criteria for successful wave energy projects implementation. The possible roles of biosolar energy systems in the Netherlands in the coming years with regard to the application in fuel production is assessed by Hanssen et al. (2014). And Winkel et al. (2016) showed how producing electricity from tidal movements can help defer investment in grid infrastructure, avoid grid transmission losses and help achieve the target for renewable energy mix in New Zealand.

Energy converters

Wave energy converter (WEC) represents the conversion technology most often discussed in the academic literature. Abdullah et al. (2021) presented the WEC as a platform to generate energy from waves and convert it into electricity. Foteinis (2022), studied the potential of WECs in low energy seas and concluded that in such seas wave energy can increase renewable energy penetration, decarbonize power generation, and promote job creation, and overall foster the advancing existing technology and help the industry progress. Calheiros-Cabral et al. (2022) instead introduced an innovative hybrid wave energy converter. Huertas-Fernández et al. (2021) jointly used an Oscillating Water Column and hydrogen electrolysis as a clean source of primary conversion for energy management, capable to satisfy a continuous designed demand. And Darwish (2022) provided a new modular power electronic converter for shore power systems with three functions including the energy harvesting from a renewable energy source, the control of the power flow from these sources to the battery storage and the control of the power flow from the battery to the vessels and/or to the utility grid when necessary.

Facilities and infrastructure for electric energy supply and alternative fuel

The main solutions regarding facilities and infrastructure for electricity supply emerged in the literature are cold ironing and microgrid. Several authors conducted literature reviews on port microgrids. Roy et al. (2020) after identifying the main components that occur in a port microgrid, proposed a review of studies dealing with their sizing and energy management and proposed an up-to-date review of microgrid development in seaports worldwide. In the same vein, Bakar et al. (2021) presented an overview of seaport microgrids considering their concepts and operation management. Bakar et al. (2022a) developed a design of hybrid system for a seaport microgrid with optimally sized components. Other authors considered clean energy-based, direct current microgrids as a revolutionary power solution (Misra et al., 2017). Roy et al. (2021) proposed a two-level optimization for the energy management and the sizing, applied to an original multi-energy scenario considering electricity and hydrogen as energy vectors in a microgrid. Concerning cold ironing, Gutierrez-Romero et al. (2019) conducted an investigation to identify the power requirements of ships at berth for implementing offshore power supply. Bakar et al. (2022b) proposed a data-driven approach for ship berthing forecasting of cold ironing with various models such as artificial neural networks, multiple linear regression, random forests, decision trees, and extreme gradient boosting. The contribution of Abu Bakar et al. (2023) provided an overview of cold ironing technology, including its operation, power requirement, standardization, challenges, and important assessment for evaluation. Cold ironing and microgrid are also used simultaneously. In this vein, Zhang et al. (2022) proposed a novel integrated day-ahead scheduling algorithm to jointly optimize the seaside/yard operation and the port energy system management within one unified framework by harnessing the synergy between onshore power supply and microgrid. Kumar et al. (2019) proposed a comprehensive review of technical aspects, practices, existing standards and the key challenges in designing and modelling of a port grid for shore to ship power supply.

Additional electricity generation systems have also appeared in the literature. Fallahzadeh et al. (2023) provided an innovative structure for the production of electricity and freshwater by using heliostat collectors to provide the necessary thermal energy in the supercritical carbon dioxide (S-CO2) cycle, the organic Rankine cycle (ORC) and desalination unit. While Pivetta et al. (2023) identified possible strategies for decarbonizing the energy systems of an existing port by creating a complete superstructure that includes the use of renewable and fossil energy sources, the import or local production of hydrogen, vehicles and other equipment powered by diesel, electricity or hydrogen and the associated refuelling and storage units.

Energy storage and propulsion systems

Energy storage is mainly used in the literature to address the peak energy demand reduction of quay cranes. In this perspective, Kermani et al. (2020) investigated the economic efficiency of peak demand reduction in ship to shore cranes based on the ultracapacitor energy storage sizing. Always considering the peak demand problem, Alasali et al. (2019) attempted to increase the energy saving of electrical cranes by using energy storage system and Active Front End, while Zhao et al. (2016) investigated the potential of hybrid energy source systems for port cranes based on energy storage devices and peak power devices, highlighting the role of the energy storage device in reducing the rating for the main energy source, reducing the system mass and volume, and improving the energy conversion efficiency. In the same vein, Corral-Vega et al. (2019) described and evaluated a hybrid propulsion system based on diesel generator and supercapacitors as energy storage system for a rubber tyre gantry crane. Borelli et al. (2021) demonstrated the extent to which the installation of LNG tanks within the port area can be leveraged to increase the energy efficiency of the port and surrounding cities and reduce greenhouse gas emissions.

Feasibility studies on technologies

The following section addresses feasibility studies of technologies that foster the implementation of energy management solutions. Most of the authors have carried out a technical and economic analysis of the technologies involved for port energy management. Vakili and Ölçer (2023) performed a techno-economic-environmental feasibility of hybrid electrification system, solar and wind for stand-alone and grid-connected port electrification. Parhamfar et al. (2023) deepened the potentials challenges of the application of renewable energy technologies in port by conducting a tecno-economic analysis of technologies that operate only in aquatic environment, such as floating photovoltaic systems, offshore wind turbines, and ocean energy. Ali et al. (2022) performed a technological and economic analysis using the Hybrid Optimization Model for Multiple Energy Resources (HOMER) software for electricity supply. The system includes photovoltaic cells, wind turbines, converters, batteries, grid and diesel generators. Through the utilization of the HOMER software, Elnajjar et al. (2021) performed a techno-economic feasibility analysis of renewable energy technologies for Jabel Ali Port in UAE.

The contribution of Sifakis et al. (2022) proposes a comparative technoeconomic analysis between a hybrid renewable energy power plant combined with a hydrogen energy storage system and the implementation of the cold-ironing technique. In addition, different authors performed feasibility studies on hybrid wave photovoltaic. Filgueira-Vizoso et al. (2021) conducted a techno-economic assessment of a hybrid on grid PV-wave system consisting of photovoltaic, wave and oscillating water column converters to harvest the wave energy in the Caspian Sea while Arabzadeh et al. (2021) performed similar studies applied to the Persian Gulf context.

Feasibility study assesing wind (Yarova et al., 2017; Gaudiosicesari F.G., 1993), tidal (Ramos et al., 2014), wave (Cascajo et al., 2019); nuclear (Gabbar & Esteves, 2023) energy solutions emerged in the literature. Baldasso et al. (2020) investigated the technical feasibility of a combined system that use a thermal energy storage, and a waste heat recovery system based on the organic Rankine cycle technology. The contribution aimed at comparing its cost-effectiveness with the alternative solution of using batteries during harbor stays of ships. Most studies also explored the economic potential of cold ironing and its ability to reduce the port emissions (Vichos et al., 2022; Kotrikla et al., 2017; Winkel et al., 2016). Colarossi and Principi (2023) used the Life Cycle cost approach and environmental analysis to define an optimal sizing of a photovoltaic/energy storage/cold ironing system, while Vlahopoulos and Bouhouras. (2022) provided an up-to-date literature review on the techno-economic efficiency of the use of a RTG crane, with focus on the significant developments in their electrical systems and propose the best solution for achieving energy savings.

Innovation trend and other technologies

The following subcategory refers to literature review papers addressed the innovation trend within the port sector and other technologies that enable the implementation of energy management in ports. Szymanowska et al. (2023) identified the prominent innovation trends currently observed in ports and identified which of these innovations are most commonly implemented. Bjerkan and Seter (2019) reviewed the extant literature concenring tools and technologies for sustainable ports. Some of these review papers aims to improve energy efficiency of the port activities (Iris & Lam., 2019; Sdoukopoulos et al., 2019). Iris and Lam (2019) conducted a systematic literature review to analyse operational strategies, technology, renewable energy, alternative fuels and energy management systems for improving energy efficiency and environmental performance of ports and terminals, while Sdoukopoulos et al. (2019) provided a pragmatic and comprehensive overview of the main policies, technologies and practices implemented by European ports for improving their energy efficiency.

Several other technologies for port energy management appeared in the literature starting with charging batteries. Kumar et al. (2019) proposed a charging battery for modern vessels and supply onshore power and Li et al. (2023) investigated a fast-charging technology and a mixed integer programming model to address scheduling problem whit the objective to reduce charging cost and penalty cost related to makespan. Cavalli et al. (2021) attempted to investigate the opportunities of increase in the efficiency and sustainability of the ports of the future by using 5G technology, while Wang et al. (2021) analysed the implementation of the wall thermal insulation and energy-saving technology in the port buildings. To finish, Filina-Dawidowicz and Filin (2019) proposed and innovative energy-saving technology which aims to store refrigerated containers in port terminals in order to reduce the energy consumption.

7.4.3. Best practices

The following section reports the main findings emerged through the consultation of the main academic contributions concerning best practices for port energy management. An overview of the publications that refer to the different practices is provided by Table 7.4.

Table 7. 4: Overview of publications on practices

Sustainable practices	**Port performance measures**
Felício et al., 2023 ; Mahmud et al., 2023 ; Roh et al., 2023 ; Jaafar et al., 2021 ; Othman et al., 2022	Molavi et al., 2020 ; Muangpan & Suthiwartnarueput 2019a; 2019b; Di Vaio et al., 2018; Wang et al., 2022; Hardianto et al., 2023; Hoang et al., 2022

Sustainable practices

Sustainable practices positively influence port stakeholders' perceptions (Felício et al., 2023). These practices can be disentangled into economic, social, and environmental and ensure the sustainable development of port clusters and regions. Mahmud et al. (2023) identified an integrated set of drivers of green port management practices for sustainable port operations and Roh et al. (2023) provided a framework for empirically identifying and validating the sustainable port development practices considering all three aspects of sustainability. Finally, Jaafar et al. (2021) demonstrated how the concept of halal-friendly sustainable port and its implementation constitute sustainability practices that can stimulate innovation within the port.

Port performance measure

Different KPIs for measuring the effectiveness of sustainable practices for ports have been proposed in the extant academic literature. Molavi et al. (2020) developed a framework for a smart port and a quantitative metric, entitled “smart port index”, that ports can use to improve their resiliency and sustainability. The KPIs developed by Molavi et al. cover port operations, environment, energy, safety and security. In the same vein, Di Vaio et al. (2019) provided conceptual managerial key performance indicators for the development of environmentally sustainable and energy efficient ports. Wang et al. (2022) applied the super-efficiency SBM model in order to measure and calculate the energy conservation and emission reduction efficiency of ports. Then, they constructed an indicator system of influencing factors for energy conservation and emission reduction efficiency. Muangpan and Suthiwartnarueput (2019a; 2019b) identified sustainable port KPIs from both academic and corporate perspectives and tested and evaluated the success of their implementation. Finally, Hardianto et al. (2023) conducted a systematic literature review for mapping the parameters commonly used to determine port performance from an operational, financial, and sustainablity perspective.

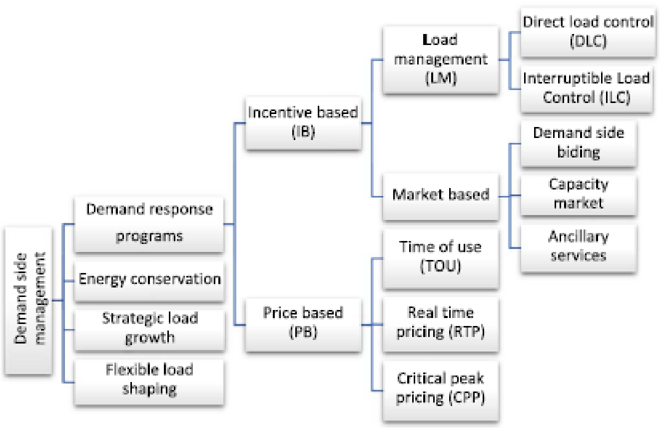
7.5. Discussion and implications

The aim of the paper was to provide a systematic literature review based on the energy hub approach to analyse strategies, technologies and best practices that address the three port energy management concepts that underpin this study, namely energy efficiency, energy conservation and renewable energy. The literature review performed returns a very fragmented picture from several viewpoints. Overall, a comprehensive framework of analysis on energy management in port is still lacking, in terms of theoretical perspectives, methodologies and scope of research. In particular, three broad research gaps are identified, and findings shed lights on promising technical issues in the port energy management field, with potential key insights for academics, practitioners and policy makers.

First, concerning the theoretical perspectives, it emerged that the energy management perspective that dominates the literature is that related to system for energy management in line with the definition provided by Iris and Lam (2019). And the three key concepts related to energy management in ports (energy efficiency, energy conservation and renewable energy production) are addressed separately in the literature and sometimes get confused with each other. Approaching energy management with a holistic approach appears to be crucial. Secondly, important gaps exist with regard to the theoretical perspective adopted for investigating the field of energy management. Almost all studies on energy management concern engineering. As a result, most studies are characterized by a highly technical content, whereas managerial implications tend to be underinvestigated. Several authors addressed technologies including renewable energy production ones to improve the energy efficiency of port. Energy conversion and storage technologies have also emerged as important enablers of energy efficiency in ports. The combination of energy production, conversion, storage technologies for satisfying port energy demand is in line with the energy hub approach of energy management. Further studies on port energy management dealing with theoretical models and quantitative methods, KPIs for investigating energy consumptions in ports and modelling energy production, distribution, storage, and consumption from an economic and managerial point of view are argued to constitute a fruitful research area. Port managers and policy makers, in fact, would greatly benefit from the development of conceptual frameworks and managerial tools for supporting the decision-making process when selecting strategies and investments related to energy management. In this perspective, technical tools should include also KPIs, and insights related to cost savings, investments' financial evaluation, environmental impacts. Finally, important gaps also exist regarding the scope of the research in the application of the energy management strategies. In fact, no study deals with energy management for the port as a whole, but it is applied to different energy user profiles. For instance, there are energy management strategies applied to port microgrid (Teng et al., 2022; Shan et al., 2022), RTG cranes (Alasali et al., 2019a; 2019b; Pietrosanti et al., 2020); Quay cranes and yard cranes (Iris & Lam., 2021); container terminals (Li, 2022; Xin et al., 2014), reefer containers (Shi et al., 2023); buildings (Eggimann et al., 2023). It is essential to develop a port energy management model that takes into account all the port's energy user profiles in order to maximise the benefits of active energy management.

Overall, an effective port energy management should start with good policy frameworks and/or standards. Even if the Plan-Do-Check-Act (PDCA) improvement cycle followed by the ISO 50001 seems to be difficult to implement, it appears to be a great method for port energy management as it is based on a principle of continuous improvement in the energy performance of ports. After the identification of good policy frameworks, energy management systems should be used for energy demand and supply planning. Energy demand and supply should be planned as accurate as possible using Advanced Planning Systems. Energy demand management for the prediction of demand and consumption patterns for the optimal allocation of resources is essential in order to address the issues related to port energy system reliability and stability. Indeed, for a long time, energy management systems were focused only on the production side. However, despite the efforts to address the issues of the sudden change in energy demand through increasing energy production, the issue of system reliability and stability still persists. This situation arises from the inherent discrepancy between the pace of growth in energy demand and the ability of production capacity to keep up, resulting in occasional failures to meet demand. For these reasons, energy systems should embed flexible demand-side management and control to guarantee the stability and the reliability of the system (Mohammadi et al., 2017). Given the multifaceted nature of ports as multi-energy systems, implementing integrated demand-side management (DSM) becomes paramount. This approach entails deploying programs for optimal demand scheduling, leveraging various energy carriers, as well as employing energy conversion and storage technologies to their fullest potential. DSM is a method for energy demand management and includes actions that aim to increase the load, the energy efficiency and energy saving in the system and also includes demand response programs (Figure 7.2).

Figure 7. 2: Demand side management programs



Source: Mohammadi et al. (2017)

Energy supply planning instead is characterized by different types of uncertainties, including the uncertainty of energy demand and feedstock supplies, the uncertainty of technologies cost and yields due to technology innovation. Consequently, predicting costs and yields in advance becomes challenging. In addition, energy policies are subject to continuous change, leading to confusion and making it difficult for ports to evaluate the benefits of a specific policy. So, for a good energy planning, ports must stay tuned on incoming policies on energy for better evaluating the benefits and the challenges related to new energy policies. Moreover, innovative methods and technologies as distributed energy system (DES) have to be used for a good balancing of energy demand and supply.

Additionally, non-technological aspect such as energy conservation strategies should also been taken into account through the implementation of operational strategies such as peak shaving, slow steaming, reduction of turnaround time at berth. In defining their energy policies, ports should also consider the social implications of energy usage and management for local communities. These considerations can be addressed by establishing steering committee for control, formally involve the local community in the decision-making process if necessary and guarantee the continuous staff training in order to guarantee highly skilled personnel. Finally, awareness rising on energy efficiency should be constant.

7.6. Conclusion

The paper aims to provide a systematic literature review for addressing the three port energy management concepts that underpin this study, namely energy efficiency, energy conservation and renewable energy based on the energy hub approach. The literature review performed returns a very fragmented picture from several viewpoints and the three key concepts related to energy management in ports are addressed separately in the literature and sometimes they get confused with each other.

The result shows that energy management offers great potential to ports to improve the energy efficiency of port activities, and the research gaps identified in the literature offer to researchers many opportunities for high-impact research. Moving to the policy implications of the review, innovation, and new technologies in the port activities are constantly evolving. Policy makers hardly can keep the pace with the transformations taking place in the port sector. This review provides an overview on the main issues originating from energy management in ports, shedding lights on the emerging strategies, technologies and best practices which can support policy makers in their decision-making process.

Finally, the main limitation of the review is based on the fact that it only includes journal articles. The review excludes conference paper and an important number of grey literature contributions which are expected to include references to implemented practices and ongoing initiatives developed by PMBs and other actors of the port industry. For this reason, this paper is in no way intended to provide a comprehensive overview of port energy management strategies, technologies and best practices. Rather, it seeks to provide a different perspective of energy management in ports, namely the holistic one that includes energy efficiency, energy conservation and renewable energy.

7.7. Bibliography

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Appendices

Appendix 7.1. Data gathering

Title	Authors	Year	Strategic Goal	Pursued benefit/s (cost saving and/or environmental benefits)	Port Name	Paper type	Theoretical perspective	User profile	Managerial/academic implications: main focus	Managerial/academic implications: detailed focus	Managerial/academic implications: main insights
A novel robust exact decomposition algorithm for berth and quay crane allocation and scheduling problem considering uncertainty and energy efficiency	Chargui K.; Zouadi T.; Sreedharan V.R.; El Fallahi A.; Reghioui M.	2023	Energy conservation	Cost saving	n.a	Research paper	Simulation & Optimization	Quay Crane	Strategy	Advanced planning systems	Berth allocation and QC assignment and scheduling problem (BACASP) considering energy price variations
Development of an Optimal Port Crane Trajectory for Reduced Energy Consumption	Takalani R.L.E.; Masisi L.	2023	Energy conservation	Cost saving	Port of Cape Town	Research paper	Simulation & Optimization	Quay Crane	Strategy	Advanced planning systems	Optimal Port Crane Trajectory for Reduced Energy Consumption
Climate change shifts the trade-of between lower cooling and higher heating demand from daylight saving time in office buildings	Eggimann S.; Mutschler R.; Orehounig K.; Fiorentini M.	2023	Energy conservation	Cost saving and Environmental benefit	Port of Angeles	Research paper	Economic & Ecological	Building	Strategy	Demand response program	Daylight saving time (DST)
Optimal decarbonization strategies for an industrial port area by using hydrogen as energy carrier	Pivetta D.; Volpato G.; Carraro G.; Dall'Armi C.; Da Lio L.; Lazzaretto A.; Taccani R.	2023	Renewable energy source	Cost saving and Environmental benefit	Port of Trieste	Research paper	Simulation & Optimization & Ecological	Terminal	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Hydrogen for port decarbonization
Multi-Stage Dispatch of Seaport Power Systems for Incorporating Logistical Flexibilities in Uncertain Operational Conditions	Huang Y.; Huang W.; Shahidehpour M.; Tai N.; Li C.; Li R.	2023	Energy conservation	Cost saving	Rizhao Port	Research paper	Ecological	Berth and Quay crane	Strategy	Advanced planning systems	Multi-stage robust dynamic programming model is developed for the real-time dispatch of seaport power systems
The role of hydrogen as enabler of industrial port area decarbonization	Pivetta D.; Dall'Armi C.; Sandrin P.; Bogar M.; Taccani R.	2024	Renewable energy source	Cost saving and Environmental benefit	n.a	Literature review	Economic & Ecological	All the port	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Hydrogen for port decarbonization

Policies and Models for Efficient and Eco-sustainable Ports	Gattuso D.; Pellicanò D.S.; Cassone G.C.	2023	Energy efficiency	Cost saving and Environmental benefit	Port of Gioia Tauro	Research paper	Simulatiom & Ecological	Terminal tractor	Strategy	Policies and measures	Retrofitting/use of cleaner fuel
Fueling the seaport of the future: Investments in low-carbon energy technologies for operational resilience in seaport multi-energy systems	Xie C.; Dehghanian P.; Estebsari A.	2023	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Simulation & Ecological	All the port	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Resilience enhancement planning strategy for a seaport multi-energy system
Multi-objective voltage/VAR control for integrated port energy system considering multi-network integration	Chen Z.; Fan F.; Tai N.; Li C.; Zhang X.	2023	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	All the port	All the port	Strategy	Advanced planning systems	Multi-objective voltage/VAR control for integrated port energy system
Distributed low-carbon energy management method for port microgrid based on we-energies under polymorphic network	Teng F.; Wang J.; Luo H.; Zhang Q.; Shen C.	2022	Energy conservation	Cost saving	n.a	Research paper	Simulation & Optimization	All the port	Strategy	Energy management system	Polymorphic energy management system
Stochastic Flexible Resource Operations in Coordinated Green-Seaport Energy-Logistics Systems Using Constraint Generation Approach	Shi Z.; Fan F.; Tai N.; Shahidehpour M.; Li C.; Yang H.	2023	Energy conservation	Cost saving and Environmental benefit	Jurong seaport	Research paper	Simulation & Optimization & Economic	All the port	Strategy	Advanced planning systems	A multi-stage stochastic optimization model
Shore Power Optimal Scheduling Based on Gridding of Hybrid Energy Supply System	Xia D.; He J.; Chi F.; Dou Z.; Yang Z.; Liu C.	2023	Renewable energy source and Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Optimization & Ecological	Quay Crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Optimal Scheduling
Polymorphic Distributed Energy Management for Low-Carbon Port Microgrid With Carbon Capture and Carbon Storage Devices	Shan Q.; Song J.; Xu Q.; Xiao G.; Yu F.	2022	Energy conservation	Cost saving	n.a	Research paper	Economic & Ecological	All the port	Strategy	Energy management system	Polymorphic energy management system
Optimal power scheduling of seaport microgrids with flexible logistic loads	Fang S.; Wang C.; Liao R.; Zhao C.	2022	Renewable energy source	Cost saving	n.a	Research paper	Simulation & Optimization	All the port	Strategy	Advanced planning systems	Optimal power scheduling of seaport
Energy Management Strategy for Seaport Integrated Energy	Teng F.; Zhang Q.; Zou T.; Zhu J.; Tu Y.; Feng Q.	2023	Energy conservation	Cost saving	n.a	Research paper	All the port	All the port	Strategy	Energy management system	Polymorphic energy management system

System under Polymorphic Network											
Optimal Port Microgrid Scheduling Incorporating Onshore Power Supply and Berth Allocation Under Uncertainty	Zhang Y.; Liang C.; Shi J.; Lim G.; Wu Y.	2022	Renewable energy source	Cost saving	Yangshan Port	Research paper	Optimization & Ecological	Berth and Quay crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Optimal Scheduling based on OPS and micro grid
Hybrid renewable energy system optimum design and smart dispatch for nearly Zero Energy Ports	Sifakis N.; Konidakis S.; Tsoutsos T.	2022	Renewable energy source	Cost saving and Environmental benefit	port of Crete	Research paper	Optimization	All the port	Strategy	Demand response program	Peak shaving
Optimal scheduling for seaport integrated energy system considering flexible berth allocation	Mao A.; Yu T.; Ding Z.; Fang S.; Guo J.; Sheng Q.	2022	Energy conservation	Cost saving	Port of Houston	Research paper	Simulation	Berth and Quay crane	Strategy	Advanced planning systems	Optimal power scheduling of seaport
A decision method on yard cranes transformation and deployment in green ports	Tan Z.; Zhang Q.; Yuan Y.; Jin Y.	2022	Energy efficiency	Cost saving and Environmental benefit	Shanghai Yangshan Deep Water Port	Research paper	Optimization & Economic & Ecological	Yard crane	Strategy	Decision support system (DSS)	A strategic level decision method for yard cranes transformation and deployment for the purpose of building efficient and energy-saving green ports with low carbon emission
Optimal Configuration and Sizing of Seaport Microgrids including Renewable Energy and Cold Ironing—The Port of Aalborg Case Study	Bakar N.N.A.; Guerrero J.M.; Vasquez J.C.; Bazmohammadi N.; Othman M.; Rasmussen B.D.; Al-Turki Y.A.	2022	Renewable energy source	Cost saving and Environmental benefit	Port of Aalborg	Research paper	Simulation & Economic & Ecological	All the port	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Optimal configuration and sizing based on OPS and micro grid
Improving the efficiency of maritime infrastructures through a bim-based building energy modelling approach: A case study in Naples, Italy	Barone G.; Buonomano A.; Forzano C.; Giuzio G.F.; Palombo A.	2021	Energy efficiency	Cost saving and Environmental benefit	Port of Naples	Research paper	All the port	Terminal (Passenger)	Strategy	Decision support system (DSS)	Building Information Modeling (BIM) model

A combined optimization of the sizing and the energy management of an industrial multi-energy microgrid: Application to a harbour area	Roy A.; Olivier J.-C.; Auger F.; Auvity B.; Schaeffer E.; Bourguet S.; Schiebel J.; Perret J.	2021	Renewable energy source	Cost saving	Port of Saint Nazaire	Research paper	Optimization & Economic & Ecological	All the port	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Microgrid optimal configuration and sizing
Renewable Energy System Controlled by Open-Source Tools and Digital Twin Model: Zero Energy Port Area in Italy	Agostinelli S.; Cumo F.; Nezhad M.M.; Orsini G.; Piras G.	2022	Renewable energy source	Cost saving	Anzio port	Research paper	Economic & Ecological	All the port	Strategy	Policies and measures	Renewable energy use
RUE index as a tool to improve the energy intensity of container terminals-case study at port of Valencia	Cloquell-Ballester V.; Lo-Iacono-Ferreira V.G.; Artacho-Ramírez M.Á.; Capuz-Rizo S.F.	2021	Energy efficiency	Cost saving and Environmental benefit	Port of Valencia	Research paper	Economic & Ecological	Terminal (Container)	Strategy	Decision support system (DSS)	Relevant Use of Energy (RUE) index
Stimulating sustainable energy at maritime ports by hybrid economic incentives: A bilevel optimization approach	Molavi A.; Lim G.J.; Shi J.	2020	Energy conservation	Cost saving and Environmental benefit	Port of Houston, Los Angeles and Long Beach	Research paper	Socio-economic & Ecological	All the port	Strategy	Policies and measures	Carbon emission taxation policy
The method to decrease emissions from ships in port areas	Paulauskas V.; Filina-Dawidowicz L.; Paulauskas D.	2020	Energy conservation	Environmental benefit	Klaipeda port	Research paper	Ecological	All the port	Strategy	Policies and measures	Staff training & Highly Skilled Personnel
Robust multi-layer energy management and control methodologies for reefer container park in port terminal	Pei R.; Xie J.; Zhang H.; Sun K.; Wu Z.; Zhou S.	2021	Energy conservation	Cost saving	n.a	Research paper	Economic	Terminal (reefer)	Strategy	Demand response program	Time of Use (TOU) tariff
Robustly coordinated operational scheduling of a grid-connected seaport microgrid under uncertainties	Hein K.; Xu Y.; Gary W.; Gupta A.K.	2021	Renewable energy source	Cost saving	Port of Oakland	Research paper	Simulation & Optimisation	All the port	Strategy	Advanced planning systems	Robustly coordinated seaport microgrid operational scheduling
Selecting the most viable renewable energy source for Brazilian ports using the FITradeoff method	Fossile D.K.; Frej E.A.; Gouvea da Costa S.E.; Pinheiro de Lima E.; Teixeira de	2020	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Optimization & Economic & Ecological	All the port	Strategy	Decision support system (DSS)	MCDM for port energy selection: Flexible and interactive tradeoff (FITradeoff) method

	Almeida A.										
Implementing Onshore Power Supply from renewable energy sources for requirements of ships at berth	Gutierrez-Romero J.E.; Esteve-Pérez J.; Zamora B.	2019	Renewable energy source	Cost saving	Cartagena Port	Research paper	Ecological	Berth and Quay crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Power requirements of ships at berth for implementing Offshore Power Supply (OPS)
Emission-Aware and Cost-Effective Distributed Demand Response System for Extensively Electrified Large Ports	Gennitsaris S.G.; Kanellos F.D.	2019	Energy conservation	Cost saving	n.a	Research paper	Optimization	Terminal	Strategy	Demand response program	A real-time distributed demand response system using MAS
Stochastic optimal energy management system for RTG cranes network using genetic algorithm and ensemble forecasts	Alasali F.; Haben S.; Holderbaum W.	2019	Energy conservation	Cost saving and Environmental benefit	Port of Felixstowe	Research paper	Economic & Ecological	Quay crane	Strategy	Energy management system	Stochastic optimal energy management system
Energy management systems for a network of electrified cranes with energy storage	Alasali F.; Luque A.; Mayer R.; Holderbaum W.	2019	Energy efficiency	Cost saving and Environmental benefit	Porft of Felixstowe	Research paper	Optimization & Economic & Ecological	Quay crane	Strategy	Energy management system	Stochastic optimal energy management system
Energy efficiency and CO2 emissions of port container terminal equipment: Evidence from the Port of Valencia	Martínez-Moya J.; Vazquez-Paja B.; Gimenez Maldonado J.A.	2019	Energy efficiency	Cost saving and Environmental benefit	Port of Valencia	Research paper	Economic & Ecological	Quay crane	Strategy	Policies and measures	Retrofitting/use of cleaner fuel
Sustainability assessment of the tanjung priok port cluster	Moeis A.O.; Desriani F.; Destyanto A.R.; Zagloel T.Y.; Hidayatno A.; Sutrisno A.	2020	Energy conservation	Cost saving and Environmental benefit	tanjung priok port	Research paper	Economic & Ecological	All the port	Strategy	Policies and measures	Free trade policy and shore power system (SPS) program policies
Power management system for RTG crane using fuzzy logic controller	Pietrosanti S.; Alasali F.; Holderbaum W.	2020	Energy conservation	Cost saving and Environmental benefit	Port of Felixstowe	Research paper	Economic & Ecological	Quay crane	Strategy	Energy management system	Stochastic optimal energy management system
Optimal energy management and MPC strategies for electrified RTG cranes with energy storage systems	Alasali F.; Haben S.; Becerra V.; Holderbaum W.	2017	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Optimization & Ecological	Quay crane	Strategy	Energy management system	Stochastic optimal energy management system

Self-management of greenhouse gas and air pollutant emissions in Taichung Port, Taiwan	Tsai Y.-T.; Liang C.-J.; Huang K.-H.; Hung K.-H.; Jheng C.-W.; Liang J.-J.	2018	Energy conservation	Cost saving and Environmental benefit	Taichung Port	Research paper	Ecological	All the port	Strategy	Policies and measures	Establishment of a Steering Committee
A Reconfigured Whale Optimization Technique (RWOT) for renewable electrical energy optimal scheduling impact on sustainable development applied to Damietta seaport, Egypt	El-Amary N.H.; Balbaa A.; Swief R.A.; Abdel-Salam T.S.	2018	Renewable energy source	Cost saving	of Damietta	Research paper	Economic & Ecological	All the port	Strategy	Policies and measures	Renewable energy use and Reconfigured Whale Optimization Technique
Greenhouse gas emissions from ships in ports – Case studies in four continents	Styhre L.; Winnes H.; Black J.; Lee J.; Le-Griffin H.	2017	Energy efficiency	Environmental benefit	Port of Gothenburg, Port of Long Beach, Port of Osaka and Sydney Ports	Research paper	Ecological	All the port	Strategy	Policies and measures	Reduced speed in fairway channels, on-shore power supply, reduced turnaround time at berth and alternative fuels
Hybridization of rubber tired gantry (RTG) cranes	Antonelli M.; Ceraolo M.; Desideri U.; Lutzemberger G.; Sani L.	2017	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	Quay crane	Strategy	Energy management system	Stochastic optimal energy management system
Analysis of energy usage for RTG cranes	Papaioannou V.; Pietrosanti S.; Holderbaum W.; Becerra V.M.; Mayer R.	2017	Energy conservation	Cost saving and Environmental benefit	Port of Felixstowe	Research paper	Economic & Ecological	Quay crane	Strategy	Energy management system	Stochastic optimal energy management system
Day-ahead industrial load forecasting for electric RTG cranes	Alasali F.; Haben S.; Becerra V.; Holderbaum W.	2018	Energy conservation	Cost saving and Environmental benefit	Port of Felixstowe	Research paper	Economic & Ecological	Quay crane	Strategy	Energy management system	Stochastic optimal energy management system
Operating strategies of CO2 reduction for a container terminal based on carbon footprint perspective	Yang Y.-C.	2017	Energy efficiency	Environmental benefit	port of Kaohsiung	Research paper	Economic & Ecological	Terminal (container)	Strategy	Policies and measures	CO2 reduction and complying with green port requirement
A carbon emission evaluation for an integrated logistics system-a case study of the port of shenzhen	Yang L.; Cai Y.; Zhong X.; Shi Y.; Zhang Z.	2017	Energy efficiency	Environmental benefit	Port of shenzhen	Research paper	Economic & Ecological	Terminal	Strategy	Policies and measures	Improving the efficiency of loading and unloading

Ecological footprint analysis based awareness creation for energy efficiency and climate change mitigation measures enhancing the environmental management system of Limassol port	Erdas C.; Fokaides P.A.; Charalambous C.	2015	Energy efficiency	Cost saving and Environmental benefit	Limassol port	Research paper	Ecological	All the port	Strategy	Policies and measures	Awareness creation for energy efficiency and climate change mitigation measures
Comparative evaluation of resource cycle strategies on operating and environmental impact in container terminals	Lee B.K.; Low J.M.W.; Kim K.H.	2015	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Optimization & Economic & Ecological	Terminal (container)	Strategy	Policies and measures	Improving the efficiency of loading and unloading (Use of single and dual cycle operations)
Energy management in seaports: A new role for port authorities	Acciaro M.; Ghiara H.; Cusano M.I.	2014	Energy Efficiency	Cost saving and Environmental benefit	Ports of Hamburg and Genoa	Research paper	Economic & Ecological	All the port	Strategy	Policies and measures	Awareness creation for energy efficiency and stimulating energy conservation
An economic model for sustainable harbor trucking	Hartman B.C.; Clott C.B.	2012	Energy efficiency	Cost saving and Environmental benefit	Port of Oakland	Research paper	Economic & Ecological	Terminal (container)	Strategy	Decision support system (DSS)	Economic model minimizing cost of truck emissions control
Energy-aware control for automated container terminals using integrated flow shop scheduling and optimal control	Xin J.; Negenborn R.R.; Lodewijks G.	2014	Energy conservation	Cost saving	n.a	Research paper	Optimization & Economic & Ecological	Terminal (container)	Strategy	Advanced planning systems	Pontryagin's Minimum Principle
Measuring "energy use efficiency"of container terminals	Sabri H.T.; Ha M.-S.; Kim G.-H.	2013	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	Terminal (container)	Strategy	Decision support system (DSS)	Data Envelopment Analysis (DEA)
A tool to select offshore renewable energy facilities. The case of study of shipyards and ports in Spain	Fernández-Leal F.; Castro-Santos L.; Rubial-Yáñez P.; Lamas-Galdo I.; Iglesias D.C.; Alcayde A.; Montoya F.G.; Filgueira-Vizoso A.	2023	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic	All the port	Strategy	Decision support system (DSS)	A tool to select offshore renewable energy facilities
Cooperative coordination between port microgrid and berthed ships with emission limitation and	Fan S.; Ai Q.; Xu G.; Xing H.; Gao Y.	2023	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Simulation & Economic	Berth	Strategy	Demand response program	Used of the flexibility of cold ironing power as a demand

peak awareness											response tool.
A HEURISTIC ALGORITHM FOR EQUIPMENT SCHEDULING AT AN AUTOMATED CONTAINER TERMINAL WITH MULTI-SIZE CONTAINERS	Li H.	2022	Energy conservation	Cost saving	n.a	Research paper	Optimization	Terminal (container)	Strategy	Advanced planning systems	A mixed integer programming model for scheduling
Composite decision-making algorithms for optimisation of hybrid renewable energy systems: Port of Takoradi as a case study	Odoi-Yorke F.; Owusu J.J.; Atepor L.	2022	Renewable energy source	Cost saving and Environmental benefit	Port of Takoradi	Research paper	Simulation	All the port	Strategy	Decision support system (DSS)	Multiple-criteria decision-making (MCDM)
Data-driven ship berthing forecasting for cold ironing in maritime transportation	Bakar N.N.A.; Bazmohammadi N.; Çimen H.; Uyanik T.; Vasquez J.C.; Guerrero J.M.	2022	Renewable energy source	Cost saving and Environmental benefit	Port of Aalborg	Research paper	Optimization	Berth	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Data-driven approach for ship berthing forecasting of cold ironing
Optimal energy management and operations planning in seaports with smart grid while harnessing renewable energy under uncertainty	Iris Ç.; Lam J.S.L.	2021	Energy efficiency and Renewable energy source	Cost saving and Environmental benefit	Port of Singapore and Jurong Port	Research paper	All the port	Quay Crane	Strategy	Advanced planning systems	A mixed integer programming model for scheduling
Berth allocation and quay crane assignment for the trade-off between service efficiency and operating cost considering carbon emission taxation	Wang T.; Du Y.; Fang D.; Li Z.-C.	2020	Energy conservation	Cost saving	n.a	Research paper	Economic	Quay Crane	Strategy	Policies and measures	Carbon emission taxation policy
Smart integration based on hybrid particle swarm optimization technique for carbon dioxide emission reduction in eco-ports	Balbaa A.; Swief R.A.; El-Amary N.H.	2019	Energy conservation	Cost saving and Environmental benefit	El Dekheila, Alexandria, Damietta, Port Said, Suez, and Sokhna port	Research paper	Ecological	All the port	Strategy	Decision support system (DSS)	Hybrid particle swarm optimization technique

Comprehensive Benefit Analysis of Port Shore Power Based on Carbon Trading	He Y.; Zhu Y. D.	2023	Renewable energy source	Cost saving and Environmental benefit	Shenzhen Port	Research paper	Economic & Ecological	Quay Crane	Strategy	Policies and measures	Carbon emission taxation policy and cap and trade
Identifying actions to prepare electricity infrastructure in seaports for future power supplying cruise ships with energy from land	Kizielewicz J.; Skrzeszewska K.	2021	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	Quay Crane	Strategy	Policies and measures	Shore power system (SPS) program policies
Evaluation and governance of green development practice of port: A sea port case of China	Hua C.; Chen J.; Wan Z.; Xu L.; Bai Y.; Zheng T.; Fei Y.	2020	Energy conservation	Cost saving and Environmental benefit	Zhuhai Port	Research paper	Economic & Ecological	All the port	Strategy	Decision support system (DSS)	Fuzzy importance-performance analysis (FIPA)
Prioritizing environmental justice in the port hinterland policy: Case of Busan New Port	Lee Y.; Song H.; Jeong S..	2021	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Ecological	All the port	Strategy	Policies and measures	Formal involvement of the local community in the decision-making process
Reducing pollutant emissions from vessel maneuvering in port areas	Tai H.-H.; Chang Y.-H.	2022	Energy conservation	Cost saving and Environmental benefit	ports in Taiwan (namely Kaohsiung, Keelung, Taichung, Taipei, Hualien, Anping, and Suao)	Research paper	Ecological	Berth	Strategy	Policies and measures	Slow steamming and Shore power system (SPS) program policies
Identifying the main opportunities and challenges from the implementation of a port energy management system: A SWOT/PESTLE analysis	Christodoulou A.; Cullinane K.	2019	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Strategy	Decision support system (DSS)	A SWOT/PESTLE analysis
Management Control Systems in port waste management: Evidence from Italy	Di Vaio A.; Varriale L.; Trujillo L.	2020	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Ecological	All the port	Strategy	Decision support system (DSS)	Management Control Systems (MCS)
A decomposition-based optimization method for integrated vehicle charging and operation scheduling in automated container terminals under fast charging technology	Li X.; Peng Y.; Tian Q.; Feng T.; Wang W.; Cao Z.; Song X.	2023	Energy efficiency	Cost saving	Qingdao Port	Research paper	Simulation & Optimization	Terminal	Technology	Other technologies	Fast charging technology

New procedure for an optimal design of an integrated solar tower power plant with supercritical carbon dioxide and organic Rankine cycle and MED-RO desalination based on 6E analysis	Fallahzadeh M.; Khoshgoftar Manesh M.H.; Ghorbani B.	2023	Renewable energy source	Cost saving and Environmental benefit	Kangan Port	Research paper	Simulation & Ecological & Economic	All the port	Technology	Energy production	Solar power tower/Heliostat collectors for heat production
A solar-assisted liquefied biomethane production by anaerobic digestion: Dynamic simulations for harbors	Calise F.; Cappiello F.L.; Cimmino L.; Dentice d'Accadia M.; Vicidomini M.	2024	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Energy production	Anaerobic digestion for liquefied biomethane production
Synergy of green hydrogen sector with offshore industries: Opportunities and challenges for a safe and sustainable hydrogen economy	Kumar S.; Baalisampang T.; Arzaghi E.; Garaniya V.; Abbassi R.; Salehi F.	2023	Renewable energy source	Cost saving and Environmental benefit	n.a	Literature review	Ecological	All the port	Technology	Energy production	Green hydrogen
Renewable Energy Potential for Micro-Grid at Hvide Sande	Potapenko T.; Döhler J.S.; Francisco F.; Lavidas G.; Temiz I.	2023	Energy efficiency	Cost saving and Environmental benefit	Port of Hvide	Research paper	Economic & Ecological	All the port	Technology	Energy production	Solar, wind and wave
Development and assessment of a hybrid breakwater-integrated wave energy converter	Calheiros-Cabral, T., Majidi, A. G., Ramos, V., Giannini, G., Rosa-Santos, P., & Taveira-Pinto, F.	2022	Energy efficiency	Cost saving and Environmental benefit	Port of Leixões	Research paper	Economic & Ecological	All the port	Technology	Energy converter	Wage energy
Integrating Renewable Energy Sources in Italian Port Areas towards Renewable Energy Communities	Agostinelli S.; Neshat M.; Majidi Nezhad M.; Piras G.; Astiaso Garcia D.	2022	Energy efficiency and Renewable energy Source	Cost saving and Environmental benefit	Lazio ports	Research paper	Economic & Ecological	All the port	Technology	Energy production	Solar and wind
A Bidirectional Modular Cuk-Based Power Converter for Shore Power Renewable Energy Systems	Darwish A.	2023	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Optimization	Terminal	Technology	Energy converter	Hydroelectric and solar photovoltaic (PV)

Optimal operation of the green port system considering the multiport power electronic transformer in day-ahead markets	Qing C.; Tai N.; Fan F.; Yu J.; Wang J.; Hu Y.	2023	Energy efficiency	Cost saving	n.a	Research paper	Economic	Berth and Quay crane	Technology	Energy converter	Power electronic transformer (PET)
Wave energy converters in low energy seas: Current state and opportunities	Foteinis S.	2022	Renewable energy source	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Energy converter	Wage energy
Risk assessment of wave energy converter at kuantan port, pahang	Abdullah M.A.; Abidin N.Z.; Radzi Z.M.; Ahmad M.A.; Munikanan V.; Razali M.N.; Ismail N.	2021	Energy efficiency	Cost saving and Environmental benefit	Kuantan Port	Research paper	Ecological	All the port	Technology	Energy converter	Wage energy
Preliminary design of a fuel cell/battery hybrid powertrain for a heavy-duty yard truck for port logistics	Di Ilio G.; Di Giorgio P.; Tribioli L.; Bella G.; Jannelli E.	2021	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	Yard (heavy-duty yard truck)	Technology	Energy storage	Propulsion system for a heavy-duty yard truck
Combined Oscillating Water Column & hydrogen electrolysis for wave energy extraction and management. A case study: The Port of Motril (Spain)	Huertas-Fernández F.; Clavero M.; Reyes-Merlo M.Á.; Moñino A.	2021	Renewable energy source	Cost saving and Environmental benefit	Port of Motril	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Oscillating Water Column and hydrogen electrolysis
Green hydrogen value chain in the sustainability for port operations: Case study in the region of valparaiso, Chile	Masip Macía Y.; Rodríguez Machuca P.; Rodríguez Soto A.A.; Carmona Campos R.	2021	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Energy Production	Green hydrogen
Addressing efficiency and sustainability in the port of the future with 5g: The experience of the livorno port. a methodological insight to measure innovation technologies' benefits on port operations	Cavalli, L., Lizzi, G., Guerrieri, L., Querci, A., De Bari, F., Barbieri, G., ... & Lattuca, D.	2021	Energy efficiency	Cost saving	Port of livorno	Research paper	Economic & Ecological	All the port	Technology	Other technologies	5G

Comparative study of oscillating surge wave energy converter performance: a case study for southern coasts of the caspian sea	Amini E.; Asadi R.; Golbaz D.; Nasiri M.; Naeeni S.T.O.; Nezhad M.M.; Piras G.; Neshat M.	2021	Energy efficiency and Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Simulation	All the port	Technology	Energy converter	Wage energy
Sectoral Analysis of the Fundamental Criteria for the Evaluation of the Viability of Wave Energy Generation Facilities in Ports—Application of the Delphi Methodology	Cascajo R.; Molina R.; Pérez-Rojas L.	2022	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Wave energy
Energy Saving Technology Of Wall Insulation Of Harbor Building Based On Energy Cost Analysis	Wang X.; Lin Q.; Li J.	2021	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	Building	Technology	Feasibility study on technologies	Wall thermal insulation and energy-saving technology
Towards Green and Smart Seaports: Renewable Energy and Automation Technologies for Bulk Cargo Loading Operations	Philipp R.; Prause G.; Olaniyi E.O.; Lemke F.	2021	Energy efficiency and Renewable energy source	Cost saving and Environmental benefit	Port of Wismar	Research paper	Economic & Ecological	Terminal (bulk cargo)	Technology	Other technologies	Digitalization for automation
Dynamic modelling of LNG powered combined energy systems in port areas	Borelli, D., Devia, F., Schenone, C., Silenzi, F., & Tagliafico, L. A.	2021	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Simulation	All the port	Technology	Energy storage	LNG tank
Innovative energy-saving technology in refrigerated containers transportation	Filina-Dawidowicz L.; Filin S.	2019	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic	Terminal (reefer)	Technology	Other technologies	Technology to store refrigerated container
Ultracapacitors for port crane applications: Sizing and techno-economic analysis	Kermani, M., Parise, G., Chavdarian, B., & Martirano, L.	2020	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	Quay crane	Technology	Feasibility study on technologies	Ultracapacitors
Renewable Energy Based Smart Microgrids—A Pathway To Green Port Development	Misra A.; Venkataramani G.; Gowrishankar S.; Ayyasamy E.; Ramalingam V.	2017	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Direct current microgrid: Electricity production from renewable energy

Design and analysis of new harbour grid models to facilitate multiple scenarios of battery charging and onshore supply for modern vessels	Kumar, J., Memon, A. A., Kumpulainen, L., Kauhaniemi, K., & Palizban, O.	2019	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Optimization & Economic & Ecological	Berth and Quay crane	Technology	Other technologies	Batteries charging for modern vessels and supply onshore power
Abatement of air pollution at an aegean island port utilizing shore side electricity and renewable energy	Kotrikla A.M.; Lilas T.; Nikitakos N.	2017	Renewable energy source	Cost saving and Environmental benefit	port of Mytilene	Research paper	Economic & Ecological	Berth and Quay crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Cold ironing
Hybrid powertrain, energy management system and techno-economic assessment of rubber tyre gantry crane powered by diesel-electric generator and supercapacitor energy storage system	Corral-Vega P.J.; Fernández-Ramírez L.M.; García-Triviño P.	2019	Energy efficiency	Cost saving	Algeciras port	Research paper	Economic & Ecological	Quay crane	Technology	Feasibility study on technologies	Hybrid propulsion based on diesel generator and supercapacitors as energy storage system for a rubber tyre gantry
The tidal energy potential of the Manukau Harbour, New Zealand	Moore T.; Boyle C.	2014	Renewable energy source	Environmental benefit	Manukau Port	Research paper	Ecological	All the port	Technology	Energy production	Tidal energy
Shore Side Electricity in Europe: Potential and environmental benefits	Winkel R.; Weddige U.; Johnsen D.; Hoen V.; Papaefthimiou S.	2016	Renewable energy source	Environmental benefit	n.a	Research paper	Ecological	Berth and Quay crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Cold ironing
Wave energy potential along the northern coasts of the Gulf of Oman, Iran	Saket A.; Etemad-Shahidi A.	2012	Renewable energy source	Environmental benefit	Port of Chabahar	Research paper	Ecological	All the port	Technology	Energy production	Wave energy
The role of biosolar technologies in future energy supply making scenarios for the Netherlands: Energy port and energy farm	Hanssen, L., de Vriend, H., & Gremmen, B.	2014	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Energy production	Biosolar
Optimal design of an adaptive energy management strategy for a fuel cell tractor operating in ports	Lombardi S.; Di Ilio G.; Tribioli L.; Jannelli E.	2023	Energy efficiency	Cost saving	Port of Salerno	Research paper	Optimization	Yard tractor	Technology	Energy storage	Propulsion system for yard tractor

Challenges of integrating hydrogen energy storage systems into nearly zero-energy ports	Vichos E.; Sifakis N.; Tsoutsos T.	2022	Renewable energy source	Cost saving and Environmental benefit	port of Adamas	Research paper	Simulation & Economic & Ecological	Berth and Quay crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Cold ironing by using hydrogen storage system
Integrating a novel smart control system for outdoor lighting infrastructures in ports	Sifakis N.; Kalaitzakis K.; Tsoutsos T.	2021	Energy conservation	Cost saving	Port of Rethymno	Research paper	Optimization & Economic & Ecological	All the port	Technology	Other technologies	Energy control system
A comparative study of energy storage systems and active front ends for networks of two electrified RTG cranes	Alasali F.; Luque A.; Mayer R.; Holderbaum W.	2019	Energy efficiency	Cost saving	Port of Felixstowe	Research paper	Economic & Ecological	Quay crane	Technology	Energy storage	Energy Storage System and Active Front End
Energy storage system for a port crane hybrid power-train	Zhao N.; Schofield N.; Niu W.	2016	All	Cost saving and Environmental benefit	n.a	Research paper	Optimization & Economic & Ecological	Quay crane	Technology	Energy storage	Energy storage system for port crane hybrid power-train
Life-Cycle Emissions from Port Electrification: A Case Study of Cargo Handling Tractors at the Port of Los Angeles	Kim J.; Rahimi M.; Newell J.	2012	Renewable energy source	Environmental benefit	Port of Los Angeles	Research paper	Ecological	Yard tractor	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Handling Tractors
Energy efficiency assessment of an aeolic plant installation in the Livorno harbour: A wind turbine performance comparison based on meteorological model estimations	Busillo C.; Calastrini F.; Gualtieri G.; Gozzini B.	2008	Energy efficiency	Cost saving	Port of Livorno	Research paper	Economic & Ecological	All the port	Technology	Energy production	Wind
The future of energy management: Results of a Delphi panel applied in the case of ports	Attanasio G.; Battistella C.; Chizzolini E.	2023	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Strategy	Energy management system	n.a
Seaport innovation trends: Global insights	Szymanowska B.B.; Kozłowski A.; Dąbrowski J.; Klimek H.	2023	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Innovation trend	n.a
Blue Seaports: The Smart, Sustainable and Electrified Ports of the Future	Clemente D.; Cabral T.; Rosa-Santos P.; Taveira-Pinto F.	2023	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	Terminal (container)	Technology	Innovation trend	n.a

The Future of Energy in Ships and Harbors	Marichal G.N.; Prats D.Á.; Conesa A.; Rodríguez J.A.; Iglesias G.	2024	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Innovation trend	n.a
The Trend of Parameters for Evaluating Port Performance: A Systematic Literature Review	Hardianto A.; Marimin; Adrianto L.; Fahmi I.	2023	Energy efficiency	Cost saving and Environmental benefit	n.a	Literature review	Economic & Ecological	All the port	Best practice	Port performance measure	n.a
Electrification of onshore power systems in maritime transportation towards decarbonization of ports: A review of the cold ironing technology	Abu Bakar N.N.; Bazmohammadi N.; Vasquez J.C.; Guerrero J.M.	2023	Renewable energy source	Cost saving and Environmental benefit	n.a	Literature review	Ecological	Quay Crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Cold ironing
Energy-related approach for reduction of CO2 emissions: A critical strategy on the port-to-ship pathway	Hoang A.T.; Foley A.M.; Nižetić S.; Huang Z.; Ong H.C.; Ölçer A.I.; Pham V.V.; Nguyen X.P.	2022	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	Terminal (container)	Best practice	Port performance measure	n.a
Solution for RTG crane power supply with the use of a hybrid energy storage system based on literature review	Vlahopoulos D.; Bouhouras A.S.	2022	Energy efficiency	Cost saving	Jazan Economic City Port in Saudi Arabia	Literature review	Economic	Quay crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	RTG crane technology
Technical-Environmental Assessment of Energy Management Systems in Smart Ports	Nguyen H.P.; Pham N.D.K.; Bui V.D.	2022	All	Cost saving and Environmental benefit	n.a	Literature review	Economic & Ecological	All the port	Strategy	Energy management system	Smart seaport
Decarbonisation of seaports: A review and directions for future research	Alzahrani A.; Petri I.; Rezgui Y.; Ghoroghi A.	2021	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Innovation trend	n.a
A review of the conceptualization and operational management of seaport microgrids on the shore and seaside	Bakar N.N.A.; Guerrero J.M.; Vasquez J.C.; Bazmohammadi N.; Yu Y.; Abusorrah A.; Al-Turki Y.A.	2021	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Microgrid

Design, sizing, and energy management of microgrids in harbor areas: A review	Roy A.; Auger F.; Olivier J.-C.; Schaeffer E.; Auvity B.	2020	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Microgrid
Planning zero-emissions ports through the nearly zero energy port concept	Sifakis N.; Tsoutsos T.	2021	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Strategy	Advance planning systems	n.a
Reviewing tools and technologies for sustainable ports: Does research enable decision making in ports?	Bjerkan K.Y.; Seter H.	2019	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Innovation trend	n.a
Integration of eco-centric views of sustainability in port planning	Wu X.; Zhang L.; Yang H.-C.	2020	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Strategy	Advance planning systems	n.a
Energy efficiency in European ports: State-of-practice and insights on the way forward	Sdoukopoulos E.; Boile M.; Tromaras A.; Anastasiadis N.	2019	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Innovation trend	n.a
A review of energy efficiency in ports: Operational strategies, technologies and energy management systems	Iris Ç.; Lam J.S.L.	2019	All	Cost saving and Environmental benefit	n.a	Literature review	All the port	All the port	Technology	Innovation trend	n.a
Technical design aspects of harbour area grid for shore to ship power: State of the art and future solutions	Kumar J.; Kumpulainen L.; Kauhaniemi K.	2019	Renewable energy source	Cost saving and Environmental benefit	n.a	Literature review	Economic & Ecological	Berth and Quay crane	Technology	Facilities and infrastructure for electric energy supply and alternative fuel	Cold ironing
How do sustainable port practices influence local communities' perceptions of ports?	Felício J.A.; Batista M.; Dooms M.; Caldeirinha V.	2023	Energy efficiency	Environmental benefit	n.a	Literature review	Socio-Economic & Ecological	All the port	Best practice	Sustainable Practices	Influence of the economic, social and environmental practices of port management bodies on the perceptions of local communities
Green port management practices for sustainable port operations: a multi method study of Asian ports	Mahmud K.K.; Chowdhury M.M.H.; Shaheen M.M.A.	2023	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Best practice	Sustainable Practices	Dirvers of green port management practices (GPMP)

The best practices of port sustainable development: a case study in Korea	Roh S.; Thai V.V.; Jang H.; Yeo G.-T.	2023	Energy efficiency	Environmental benefit	n.a	Research paper	Optimization	All the port	Best practice	Sustainable Practices	Best practices of port sustainable development
Creating innovation in achieving sustainability: Halal-friendly sustainable port	Jaafar H.S.; Aziz M.L.A.; Ahmad M.R.; Faisol N.	2021	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Ecological	All the port	Best practice	Sustainable Practices	Halal-friendly sustainable port concept
A framework for building a smart port and smart port index	Molavi A.; Lim G.J.; Race B.	2020	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Socio-economic & Ecological	All the port	Best practice	Port performance measure	Smart Port Index: KPI for sustainable port
Sustainable port KPIs assessment: A case study of the eastern economic corridor in Thailand	Muangpan T.; Suthiwartnarueput K.	2019	Energy efficiency	Environmental benefit	n.a	Research paper	Ecological & Socio-economic	All the port	Best practice	Port performance measure	Assessment of key performance indicators for sustainable and energy-efficient ports
Key performance indicators of sustainable port: Case study of the eastern economic corridor in Thailand	Muangpan T.; Suthiwartnarueput K.	2019	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Socio-economic & Ecological	All the port	Best practice	Port performance measure	Assessment of key performance indicators for sustainable and energy-efficient ports
Key performance indicators for developing environmentally sustainable and energy efficient ports: Evidence from Italy	Di Vaio A.; Varriale L.; Alvino F.	2018	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Socio-economic & Ecological	All the port	Best practice	Port performance measure	Assessment of key performance indicators for sustainable and energy-efficient ports
Investigating the Influences of Smart Port Practices and Technology Employment on Port Sustainable Performance: The Egypt Case	Othman, A., El Gazzar, S., & Knez, M.	2022	All	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Best practice	Sustainable practices	Smart port practices
Analysis on Energy Conservation and Emission Reduction Efficiency and Influencing Factors for Ports around Bohai in China under the Low Carbon Target	Wang S.; Luo Y.; Liu Z.; Lu B.	2022	Energy conservation	Cost saving and Environmental benefit	n.a	Research paper	Optimization & Ecological	All the port	Best practice	Port performance measure	Assessment on energy conservation and emission reduction efficiency
Techno-economic assessment of a hybrid on grid PV-wave system: A case	Saheli, M. A., Lari, K., Salehi, G., & Azad, M. T.	2021	Renewable energy source	Cost saving and Environmental benefit	Bandare Anzali, Bandare Torkaman and Noshahr Ports	Research paper	Simulation & Economic & Ecological	All the port	Technology	Feasibility study on technologies	Hybrid wave-photovoltaic (PV)

study in Caspian Sea											
How important are ports for the offshore wind industry?: The case of Spain	Filgueira-Vizoso A.; Puime-Guillén F.; Cordal-Iglesias D.; García-Diez A.I.; Lamas-Galdo I.; Castro-Santos L.	2021	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Wind energy (Offshore)
Feasibility study of a hybrid grid-tied photovoltaic-wave system on the shores of Persian Gulf	Arabzadeh Saheli M.; Lari K.; Salehi G.; Torabi Azad M.	2021	Renewable energy source	Cost saving and Environmental benefit	Chabahar, Bushehr and Bandar Abbas Ports	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Hybrid wave-photovoltaic (PV)
Economic assessment of the alternative energy sources implementation for port enterprises	Yarova N.; Vorkunova O.; Khoteyeva N.	2017	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Hybrid wave-photovoltaic (PV)
A port towards energy self-sufficiency using tidal stream power	Ramos V.; Carballo R.; Álvarez M.; Sánchez M.; Iglesias G	2014	Renewable energy source	Cost saving and Environmental benefit	Port of Ribadeo	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Tidal
Wind energy potential on the Mediterranean harbour breakwaters	G. Gaudiosi cesari F.G.	1993	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Wind energy
Techno-economic-environmental feasibility of photovoltaic, wind and hybrid electrification systems for stand-alone and grid-connected port electrification in the Philippines	Vakili S.; Ölçer A.I.	2023	Renewable energy source	Cost saving and Environmental benefit	n.a	Research paper	Simulation & Economic & Ecological	All the port	Technology	Feasibility study on technologies	Photovoltaic, wind and hybrid electrification systems
Planning and Evaluation of Nuclear-Renewable Hybrid Energy Penetration for Marine and Waterfront Applications	Gabbar H.A.; Esteves O.L.A.	2023	Renewable energy source	Cost saving and Environmental benefit	Tanjung Priok Port	Research paper	Optimization & Economic & Ecological	All the port	Technology	Feasibility study on technologies	Nuclear energy
Towards the application of renewable energy technologies in green ports: Technical and	Parhamfar M.; Sadeghkhani I.; Adeli A.M.	2023	Energy efficiency and Renewable energy source	Cost saving and Environmental benefit	n.a	Literature review	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Photovoltaic, wind and hybrid electrification systems

economic perspectives										
Future pathways for decarbonization and energy efficiency of ports: Modelling and optimization as sustainable energy hubs	Buonomano A.; Del Papa G.; Giuzio G.F.; Palombo A.; Russo G.	2023	Energy efficiency and Renewable energy source	Cost saving and Environmental benefit	Port of Naples	Research paper	Simluation & Optimization	All the port	Technology	Feasibility study on technologies	Energy hub
Optimal sizing of a photovoltaic/energy storage/cold ironing system: Life Cycle cost approach and environmental analysis	Colarossi D.; Principi P.	2023	Renewable energy source	Environmental benefit	Port of Ancona	Research paper	Ecological	All the port	Technology	Feasibility study on technologies	Life Cycle cost approach
Techno-Economic Analysis of Hybrid Renewable Energy-Based Electricity Supply to Gwadar, Pakistan	Ali M.S.; Ali S.U.; Mian Qaisar S.; Waqar A.; Haroon F.; Alzahrani A.	2022	Renewable energy source	Cost saving and Environmental benefit	Port of Gwadar	Research paper	Optimization & Economic	All the port	Technology	Feasibility study on technologies	Photovoltaic, wind and hybrid electrification systems
Introducing the cold-ironing technique and a hydrogen-based hybrid renewable energy system into ports	Sifakis N.; Vichos E.; Smaragdakis A.; Zoulias E.; Tsoutsos T.	2022	Energy efficiency and Renewable energy source	Cost saving and Environmental benefit	Port of Milos	Research paper	Simulation & Economic & Ecological	All the port	Technology	Feasibility study on technologies	Photovoltaic, wind and hybrid electrification systems
Experimental and techno-economic feasibility analysis of renewable energy technologies for Jabel Ali Port in UAE	Elnajjar H.M.; Shehata A.S.; Elbatran A.H.A.; Shehadeh M.F.	2021	Energy efficiency and Renewable energy source	Cost saving and Environmental benefit	Jabel Ali Port	Research paper	Simulation & Economic & Ecological	All the port	Technology	Feasibility study on technologies	Photovoltaic, wind and hybrid electrification systems
Integration of marine wave energy converters into seaports: A case study in the port of Valencia	Cascajo R.; García E.; Quiles E.; Correcher A.; Morant F.	2019	Energy efficiency	Cost saving and Environmental benefit	Port of Valencia	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Wage energy
Organic Rankine cycle-based waste heat recovery system combined with thermal energy storage for emission-free power generation on ships during harbor stays	Baldasso, E., Gilormini, T. J. A., Mondejar, M. E., Andreasen, J. G., Larsen, L. K., Fan, J., & Haglind, F.	2020	Energy efficiency	Cost saving and Environmental benefit	n.a	Research paper	Economic & Ecological	All the port	Technology	Feasibility study on technologies	Thermal energy storage and a waste heat recovery system based on the organic Rankine cycle technology

Source: Author's elaboration

CHAPTER 8

PORT RENEWABLE ENERGY COMMUNITY: AN INNOVATIVE BUSINESS MODEL CANVAS*

* A full version of this paper has been presented at the EISIC conference (29-30 August 2024, Bergamo, Italy), ISBN number for the Conference proceedings: 979-10-415-5220-7

Abstract

Business Model Canvas (BMC) appears to be a convenient tool that makes business model intuitive and user-friendly while determining how a business creates, delivers, and captures values. Therefore, it represents a useful tool for understanding a company's business model and for conducting business model innovation even for Port Renewable Energy Community (PREC).

However, the BMC model developed by Osterwalder cannot fully capture the business model of PREC, since the latter has different characteristics from other commercial enterprises, so the Canvas needs to be adapted to fully capture the value that PREC can create. Since the BMC is licensed under Creative Commons, new versions of the Canvas based on the characteristic of each business and the understanding of business model can be developed. Regarding the PREC, developing and selecting the right Canvas is crucial in order to properly define its business model. However, in the literature, all the renewable energy community business models are applied to residential context and no study focuses on the port context. The aim of this paper is to provide an innovative business model based on BMC framework useful to design, test, and communicate the benefits of PREC for the port community and the cities where they are located.

Applying the snowball sampling method, relevant studies on the business model canvas of renewable energy communities and social enterprises is collected on Scopus Elsevier in order to understand the characteristics of these business models and to evaluate adaptations of the canvas for defining the PREC BMC. The result shows that for the PREC business model, five blocks need to be added to the nine blocks of the BMC proposed by Osterwalder and Pigneur, for a total of 14 blocks. These five additional

blocks include “Vision”, “Problem and Solution”, “Impact Measurement”, “Non-targeted Stakeholders” and “Unfair Advantages”.
Keywords: Business model, Business model innovation, business model canvas, port renewable energy community, renewable energy production.

8.1. Introduction

The concept of business model (BM) is confused in the literature, as there is not a common agreement on its definition. However, according to Zott et al. (2011), emerging common themes, which could serve as basis to build a more unified study of business models exist among scholars' conception of business models: i) business models represent a new unit of analysis; ii) business models are considered as a holistic approach which explains how firms "do business"; iii) firm activities play an important role in the various conceptualizations of business models that have been proposed; and iv) business models aim to explain how firms create and capture value.

Caroli (2021) goes further, arguing that the business model synthesizes a set of characteristic aspects of the enterprise which, when they are conducive to appropriate sustainable development, tend not to be changed. However, there exist several situations where the business model needs to be innovated: when some changes occur in the market (market-based drivers) and through regulatory and normative impetus (regulatory-based drivers). The market-based drivers of business model innovation include the introduction of new technologies, which can make current ways of generating value obsolete and creates the conditions for new, more effective or efficient business models, and the evolution of key consumer characteristics (e.g. Consumer needs and consumption patterns). In addition, a company may also be forced to modify its business model in response to innovations introduced by competitors, who may be quicker to respond to changes in technology or in the competitive environment. Besides changes in the market, new conditions in the broader environment, starting with the regulatory and normative system relevant to the business, may lead to business model innovation.

The business model innovation in the energy market has been guided by these two drivers: the market and regulatory changes. The market changes in the energy market increase the interest on energy business model first, and the introduction and change of the regulatory framework increase the interest on energy community business model ECBM. Indeed, for long-time energy systems were centralized, the energy market was closed, and the energy service were provided in a monopolistic perspective. In this vein, prior to the liberalization of the energy market, limited attention was paid to energy business model since the monopolistic utilities' value proposition was based on providing an undifferentiated commodity to a large customer segment (Reis et al., 2021). However, changes in the energy market such as market unbundling alongside with the increase of renewable-based decentralized generation have forced changes on the classical utilities BM. This situation opened the room for new energy business model to emerge by giving the possibility to smaller energy retailers to develop and offer innovative electricity supply services (Specht et al. 2019; Bryant et al. 2018). These energy business models tend to be primarily service-oriented, where different types of services are provided including electricity supply, energy management, energy efficiency services. In this vein, utility companies and small energy retailers strive to offer competitive and customized energy solutions increasingly focused on decentralized renewable energy generation and consumption (Hamwi & Lizarralde, 2017).

Moreover, the increasing integration of renewable generation in the energy system is forcing the transformation of the traditional energy production structure into an increasingly distributed structure. In this perspective, to maintain a continuous service, it is necessary to increase the flexibility of the system. According to López et al. (2024) RECs represent a viable solution for increasing flexibility of energy systems through the development of active demand management, generation control and energy storage systems. They claim that RECs will help to restructure the energy system and transform it into a decentralized, sustainable, flexible and efficient system with a very low environmental footprint. In this vein, several EC projects has been launched around Europe. Germany leads the ranking with around 1750 EC projects, then follow Denmark with 700 EC projects, Netherlands with 500 EC projects, United Kingdom with 431 EC projects and Sweden 270 EC projects (López et al. 2024). But these projects were developed following a different regulatory framework. In general, the absence of a regulatory framework and/or its insufficient development for long time have been a major obstacle to the proliferation of REC. As a result, a general regulatory framework was needed to give confidence to possible investors, to simplify the administrative procedures, to reduce risk or investor perception, to increase the public interest, to increase the motivation of community members (López et al. 2024). For these reasons, the European Commission introduced the RED II 2018/2001 and Internal Energy Market Directive (IEMD 2019/944) for regulating the REC in Europe. Thanks to the impulsion given by these Directives, RECs are making their way in Europe, although there is still a long way to go. The enabling framework promoted by these directives is expected to boost the creation of innovative business models and attract private and public investments, giving the opportunity to energy communities to diversify their revenue streams through the supply of new energy services in addition to local energy generation (Reis et al., 2021).

However, the definition of REC provided by the EU Commission in the RED II, seems ambiguous, with regards to both the conceptual framework and the concrete implementation tools available for the EU Member States, bringing the risk of missing the sustainable community development and energy democracy goals targeted. Therefore, there is a need a solution able to customize the broad definitions of REC provided by RED II to specific contexts (through the definition of the actors, the legal structure, the activities, the resources, etc.) and motivations (by identifying the main beneficiaries of the project and the functioning). A specific context for REC application is the port domain. Indeed, for carrying out their activities, ports consume a lot of energy, thus generating harmful emissions which negatively impact the environment. To reduce their negative spillovers, ports are urged to start at least partially to produce the consumed energy grounding on renewable energy sources and to progressively turn into innovative energy hub. 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, 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. PRECs can also play a key role in supporting local economy growth and job creation and can foster a collaborative social transformation through the engagement of local communities to pursue common goals such as energy costs reduction and energy self-sufficiency.

Despite all the potential benefits of PREC, in the literature, all the renewable energy community business models identified are applied to residential context and no study focuses on the port context. Considering the existing gap in the literature, this paper endeavours to address the following research questions:

- Which business model is suitable for PREC?
- How the BMC can be applied to PREC to help visualise the development of its business model?

The paper makes a significant contribution to the academic field of management by presenting an innovative business model useful to design, test, and communicate the benefits of PREC to the port community and the cities where they are located. In addition, the paper offers insights for port decision-makers, providing them with a BMC framework for PREC, useful for potential application to a practical case.

The paper is structured as follows. The theoretical foundation is presented in Section 8.2. Section 8.3 describes the snowball sampling method applied in this paper to develop a PREC business model, Section 8.4 presents the main findings regarding the typology of the business model that can be adapted to PREC. Section 8.5 discusses the implications for practice and future research directions. Finally, the conclusions are drawn in section 8.6.

8.2. Theoretical foundations: Literature review

The implementation of REC implies moving away from the centralized energy system towards decentralized systems based on renewable sources. In this regard, new activities are expected to be created, and new actors are expected to emerge within the energy sector. Consequently, new business models based on the different activities and relationships between traditional and new actors are needed. Several decentralized energy system business models applicable to REC emerged in the literature. These business models include the prosumerism business model, Public private partnership business model, third party business model.

8.2.1. Prosumerism business model

Prosumerism business model, also known as customer-side business model (Reis et al. 2021), customer-owned product-centered (Hamwi & Lizarralde, 2017), plug and play (Provance et al., 2011), host-owned (Strupeit & Palm, 2016) or customer-owned PV (Huijben & Verbong, 2013) refers to a complete user ownership, in which customers finance and own the REC project by investing in energy generation and storage technologies in order to benefit from self-consumption, energy bill reductions and emission reduction. The end users become prosumers and take advantage of demand side management (DSM) programs.

Regarding the modality of the renewable energy trading, two modes can be used: the "*all sold to the grid*" mode where the entire energy generated is injected into the grid and the "*self-consumption with surplus sold to the grid*" mode characterized by the self-consumption and only the energy surplus of the produced energy is injected into the grid (Hamwi & Lizarralde, 2017). In this architecture, power purchase agreements (PPA) are established with energy buyers (e.g., national grid operator, energy retailers), which buy renewable energy surplus and remunerate the prosumers through feed-in-tariffs. This business model can also be used by the end user with the aim to take advantage of demand flexibility, which consists of shifting energy demand from peak hours to other periods in response to price signals. In this case end-users invest in DSM enabling devices such as sensors, smart meters, monitoring devices (Behrangrad, 2015).

However, this architecture is subject to several constraints including i) Financial constraints: prosumerism business models are characterized by high investment costs and long-term payback periods (Reis et al., 2021). Accordingly, the prosumers (e.g., homeowners, SMEs) are expected to have the necessary financial standing or at least have the capability to access financing sources including bank loans or incentive programs. ii) structural constraints: in addition of the financial constraints, the prosumers must demonstrate to have the needed conditions to install onsite energy generation systems (e.g. sufficient land or available rooftop area for the installation of solar panels). To take full advantages from this business model, prosumers need to be flexible in their demand for energy to take benefits from DSM programs.

This architecture is the most self-sufficient as the prosumers finance and own the project, but the design and construction of the installation are outsourced to key partners (e.g. technology providers, energy suppliers, distribution system operators). In this perspective, direct communication underpins the relationship between prosumers and "key partners". Salesmen, client support platforms and technical staff are at the disposal of prosumer and provide them with information on new products, offerings, solve technical and prosumers' issues and propose new tailored solutions and (Reis et al., 2021). The "key activities" of the prosumer business model include local energy generation, self-consumption and energy selling and if the end users aim to take advantage of demand flexibility, the key activities also include the changing consumption patterns. The "value proposition" of prosumer consists of reduction of energy costs through self-production and self-consuming, selling of energy to the national grid and benefits from participation in DR programs. The "cost structure" includes investment costs (e.g. assets purchase, installation and grid interconnection costs), reparation and maintenance costs. If the end users also aim to take advantage of demand flexibility, the cost structure also includes the costs of the DSM enabling devices such as sensors, smart meters, monitoring devices. Regarding the "revenues streams", prosumers are expected to return their investments by selling their surplus generated electricity and reducing their electricity bill.

8.2.2. Public private partnership business model

Also known as hybrid business model (López et al., 2024), in this business model, the ownership is shared between energy consumers (private) and another entity (usually public). As in the prosumer business model, the design and construction of the EC are outsourced. The main aim is to make the energy supply in the community where the project is implemented greener, healthier, and more affordable. In this vein, the "cost structure" includes investment costs (e.g. assets purchase, installation and grid interconnection costs), and reparation and maintenance costs. Regarding the "revenues streams", energy consumers are expected to reduce their electricity bill. If any, the energy surplus generated is not expected to be sold. As such, the "value proposition" of energy consumers consists of reducing the energy costs through self-production and self-consuming. In this architecture, the financial constraints are either nil or drastically reduced sine part or the entire financing is provided by the local authorities. The technical constraints persist and can be reduced by promoting the EC project only in regions where there are not these technical constraints. This may be possible through the mapping of these areas upstream by the local authority. In this business model, three different organizational structures can be addressed (Greenpeace, 2019):

- Local authorities as funder and administrative facilitators. The local authorities bring funds partly or totally for the development of the EC. The authorities can provide funds to some institutions such as schools, community centers and industrial estates for solar panel installation, or can support other community energy groups such as cooperatives, social enterprises, community interest companies, tenants' and residents' associations, who are committed to helping their community make the transition to clean energy. The technical and operational components of the EC are not managed by the local authority but by the EC consumers.

- Local authorities as project facilitators. In this structure, the local authorities associate themselves with cooperatives and encourage the creation of new ECs by providing them with everything they need. Local authorities' aim is to ensure effective problem solving and decision making throughout the implementation life cycle of the EC project.
- Local authorities as infrastructure managers. The local authorities bring funds partly or totally for the development of ECs, and are responsible for the management of both technical and operational components of the EC.

8.2.3. Third party business model

In the third-party business model, also known as top-down business model (López et al., 2024), third-party service centered business model (Hamwi & Lizarralde., 2017), third party-owned business model (Cai et al., 2019) or utility-side business model (Hamwi & Lizarralde 2019), ownership belong to a third party, which can be utilities. End users bear no financial risk, which is fully supported by the third-party company. The third-party company holds full control of the assets, and their value proposition is the creation of high-value energy services and remuneration streams (Reis et al., 2021). Typically, the third-party company that fully finances these business models owns several small-scale energy production units located remotely from each other and operates them as virtual power plants, centralizing the management of their energy resources (Brown et al., 2019).

The third-party company can also act as a local white-label supplier (Hamwi & Lizarralde., 2017; Hall & Roelich, 2015), by not taking the entire financial risk directly, but establishing a partnership with licensed energy suppliers in order to supply energy to consumers with its own brand identity.

As in the Prosumerism business model, the value proposition of third-party business model can also be to provide DSM-based services acting like energy aggregator. As aggregator the third-party company negotiates with producers of an energy service such as electricity on behalf of groups of consumers. Its main goal is to aggregate energy customers' demand flexibility and sell it to a system operator (Reis et al., 2021). Costumers sign agreement with the third-party company, in which they commit to provide a pre-determined amount of energy. This energy is then sold to the system operators in reserve, balancing and ancillary markets.

Lastly, third-party company can also act as Energy Service Company (ESCO) by proving energy efficiency services such as energy audits, space heating, and lighting (Reis et al., 2021). As ESCO, the third-party company can operate under energy supply contract or energy performance contract (Hamwi & Lizarralde, 2017; Cai et al., 2016). Under the energy supply contract, the third-party company commits to meet the final energy demand of customers by providing services as electricity, heat or steam and is remunerated thank to the useful energy output delivered. In the energy performance contract instead, the third-party company implements energy efficiency projects and is compensated by the income stream from customer savings. In this contract, the greater the energy savings for customers, the greater the benefits for the third-party company.

The "key partners" are technology providers including energy production technologies such as PV, energy storage technologies, manufacturers and sellers of efficient appliances, smart metering and ICT-based devices for energy management, technical staff and power system entities such as distribution system operator, transmission system operator. These key partners are involved in the 'key activities' such as energy supply, energy efficiency activities as well as demand flexibility aggregation services. The relationships with key partners are based on direct communication channels with customer support services, technical staff. Marketing campaigns and face-to-face meetings are also used for communication. According to Cai et al. (2019), the revenues streams of this business model are based on long-term contracts such as power purchase agreements or leasing contracts, established between customers and the third-party company. Such a contract guarantees competitive and stable prices and conditions throughout the project. The key resources are typically financial and technical, and the cost structure includes investment costs (e.g. assets purchase, installation and grid interconnection costs), and reparation and maintenance costs. If the third-party company internally develops its own technology, the cost structure also includes the costs of research, design, development and assembling of technologies. In addition, costs related to market analysis, marketing strategies and the use of distribution networks could be included in the cost structure.

8.2.4. REC Business model analysis according to RED II

The REC, well known as EC, takes its roots in collective energy projects. The term REC has been legally introduced in Europe by the RED II directive and several components of its business model is included in the directive. For the RED II, the primary purpose the REC business model is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits. The community members take all or part of the financial risks and the whole BM must be created by, for and with them (Mourik et al., 2020). Given the capital-intensive nature of the investments, the community members of REC are expected to have the necessary financial standing to participate in the REC. They can rely on external financing sources including bank loans or incentive programs. However, community members are strongly involved in decision making process including the design, implementation and operation of the REC. As a result, they influence the value creation process and share the risks and costs related to the REC (Mourik et al., 2020; Yildiz, 2014). Therefore, from the investment and assets ownership perspective, REC business model can be assimilated to the prosumer business model and/or the third-party business model, since both are possible (Reis et al., 2021).

According to Bauwens (2019), the financial profit doesn't constitute the main objective of the REC business model, but the return on investment represents one of the most important determinants for community shareholders to enroll REC projects. In this vein, the value proposition of the REC business model is partly based on the return on investment of the shareholders that is ensured by cheaper energy supply, energy surplus selling or participation shares, self-energy consumption and reduction of dependency from the national grid (Tounquet et al., 2019; CEER, 2019). Another key determinant of the value proposition are the environmental benefits emerged from the use of renewable energy, the ability of members to choose the right technologies for energy generation, the positive social impact such as energy poverty reduction, job creation, the increase in the welfare of the population created by the REC implementation (Koirala et al., 2016). The key activities indicated by the RED II include local energy generation, supply, storage, consumption, trading, aggregation, e-mobility, system management and energy related services.

The success of the REC relies on several key resources, including: i) the structural resources, which consists of the availability of sufficient area for implementing energy generation and storage facilities. ii) the financial resources for the implementation and the management of the REC project; iii) the members, which bring social and financial value to the project; iv) the technical know-how; v) enabling regulatory frameworks as well as the availability of incentives and subsidies for renewable energy producers, and DSM programs. The RED II also indicates part of the key partners i.e., shareholders or members including households, SMEs and public entities. The other keys partners are technology suppliers, external investors, DSO, energy suppliers and other power system entities (as aggregators).

As the REC is controlled by shareholders or members which are both customers and business developers, the customer relationship and the communication channels are expected to be personal and direct as they invest their money and hold share of the REC (Reis et al., 2021). The costs structure of these business model includes the investment costs such as the feasibility costs (both economic and technical), the cost related to planning and licensing, the material structural cost (i.e. the capital costs of building and installing generation, storage, management and distribution assets), the maintenance cost, the operating costs (e.g., the cost related to the use of the network) and the other costs related to the REC.

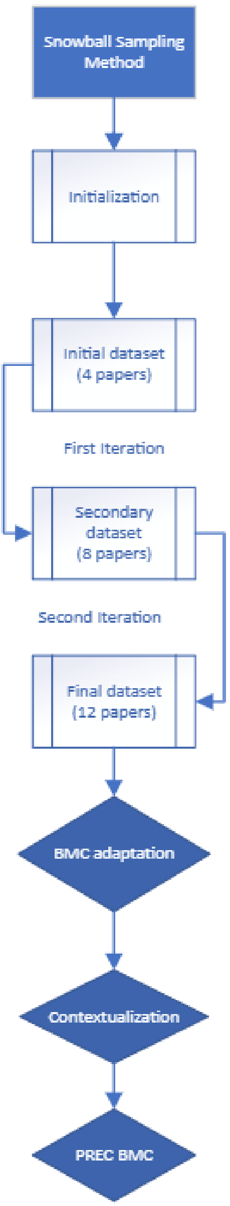
According to RED II, participation in RECs is autonomous, open and voluntary; anyone wishing to participate in a REC may purchase and hold shares in the REC. This purchase of REC share is part of the revenue stream. According to Hunkin and Krell (2018) the shareholding mechanisms allow RECs to be flexible to the entry and exit of members, without compromising the participation of the remaining ones. The energy surplus selling, renewables power purchase agreement, subsidies and incentives also constitute the REC revenue streams.

8.3. Methodology

The paper provides an innovative business model based on business model canvas (BMC) framework applicable to ports. The framework is based on the prominent literatures on energy community business model, following the RED II directive.

A qualitative research method is applied, for collecting and analysing qualitative data. In particular, the snowball sampling (Figure 8.1) is used to collect prominent studies on Scopus Elsevier (Biernacki & Waldorf, 1981). This method generally uses smaller data sets that are sufficient enough to reach reliable results, where the data collection continues until saturation is reached. It represents conceptual research, as it aims to develop new concepts or interpreting existing concepts. It includes historical research, theory development, literature reviews, and critical analysis and can be used to establish concepts in an area (Håkansson, 2013).

Figure 8. 1: Snowball Sampling Method applied to PREC



Source: Authors' elaboration

The initialization phase consists of analysing the BM of decentralized energy systems existing in the literature (i.e. prosumerism business model, Public private partnership business model, third party business model), the identification of businesses that have similarities with to REC (i.e. Energy community and social enterprise), and the application of the BMC to these businesses.

By using keywords as “business model” and “energy community”; “business model” and “social enterprise”, a prior literature reviews about EC BMC, and social enterprise BMC is performed. The initial sample consists of four papers: Two related to EC BMC (Kubli & Puranik, 2023; Reis et al., 2021) and two related to social enterprise BMC (Sparviero, 2019; Qastharin, 2016). These papers were consulted and used as initial sample of papers. We included the social enterprises in the sample because they have the same goals as REC, which is not only to generate the profit but above all to achieve social and environmental.

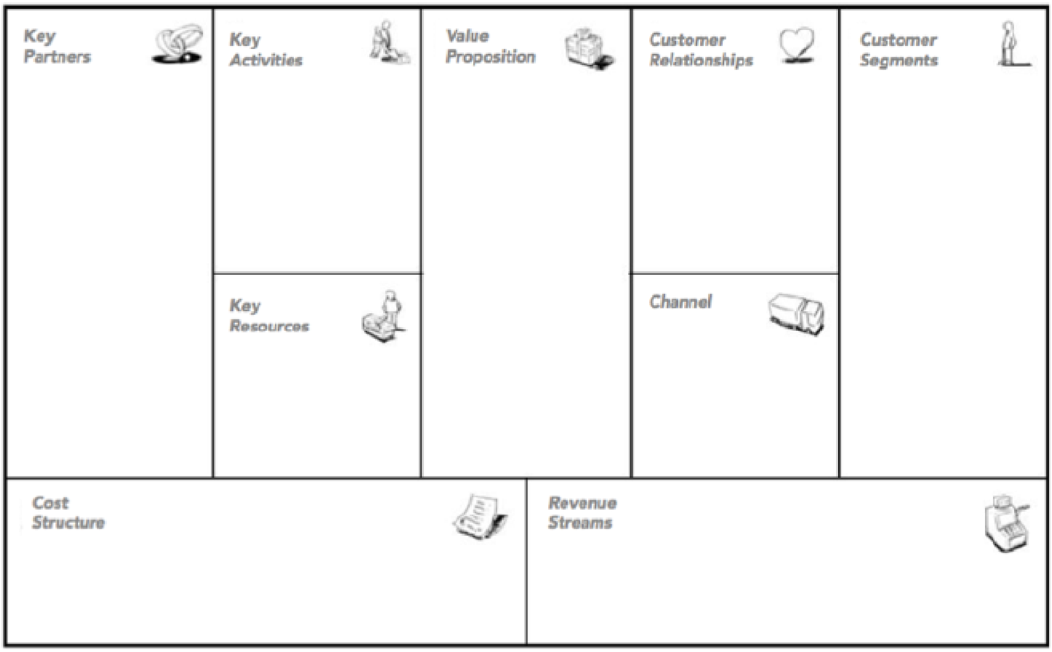
Subsequently, we looked at the references cited in those papers to identify essential contributions; then, we looked at the references in the new ones to recognise even more significant papers addressing REC BMC and social enterprise BMC. This process was repeated until we thoroughly selected the most relevant papers for our research objective. As this paper apply a qualitative method, the qualitative data for this paper is the available Business Model Canvas adaptations for REC and social enterprise.

Successively, we conducted a comprehensive examination of the BMC adaptation for REC and social enterprise business proposed in the selected sample papers to identify the most valuable elements for constructing a novel and original BMC for PREC. In this perspective, four questions were considered to guide and frame the research based on the BMC (Osterwalder & Pigneur, 2010) and the morphological box (Kubli & Puranik, 2023): 1) who are the relevant stakeholders of the PREC and what are their needs? 2) what are the key activities to be performed to meet their energy needs? 3) what is the value proposition? 4) what are the key resources to be combined to offer the value proposition? At what costs and with what revenue stream?

Application of BMC for the definition of the PREC business model

Osterwalder and Pigneur (2010), in defining the business model, they distinguished themselves among others by offering not only the definition and components of the business model, but they also provided a visualisation of the model itself. They claim that the Business Model Canvas allows business model to be simple, relevant and intuitively understandable, while not oversimplifying the complexities related to the functioning of an enterprise (Osterwalder & Pigneur, 2010). Given the above, the business canvas (Figure 8.2) is considered as a shared language and a useful tool for stakeholders to talk about business model (Reis et al., 2021; Qastharin, 2016).

Figure 8. 2: Business Model Canvas



Source: Osterwalder and Pigneur (2010)

Despite the flexibility and strengths of this approach, BMC brings some limitations: i) there is not a strong representation of relationships among businesses elements, as a result it overlooks strategic dimensions such as competitive position (Lima & Baudier, 2017; Euchner & Ganguly, 2014); ii) few details are presented because of the canvas-structured model, which hinders creativity and the disclosure of other dimensions of the business (Fritscher & Pigneur, 2009); iii) BMC lacks a section to define vision statement or goals and ambitions of a project or company; iv) the BMC only takes into account the economic dimension of profit, i.e. revenues minus costs, whereas there are several other dimensions to be taken into account. For example, in addition to economic impacts, environmental and socio-economic impacts should also be taken into account; v) the BMC allows assumptions within the business model but doesn't offer a clear way to verify them. A good strategy should include these elements. However, these weaknesses do not seem to affect the growing application of the BMC, which remains the most widely used approach for business description (Reis et al., 2021). Therefore, it will be used in the scope of this work. Taking into account the criticisms of BMC, we don't focus only on the BMC as proposed by Osterwalder and Pigneur (2010), but we used its adaptation (e.g. lean canvas) applied to the REC and social enterprise context to assess and compare their BM in order to propose a BMC applicable to ports. The choice of canvas adaptations to be examined in more detail are based on the recognisability and accessibility of the adaptations in the literature. Recognizability is determined by the facility with which the adaptation based on Osterwalder's framework is recognized. We assessed whether the building blocks are arranged in a canvas and whether the blocks are more than 50% similar in title and meaning to the Osterwalder canvas. Accessibility is defined by the ease of which the adaptation is accessed by using search engine. Using inductive approach, theories and propositions with alternative explanations are formulated from observations and patterns found in the collected data.

8.4. Results/Findings

Table 8.1 shows the relevant papers that address an adaptation of business model canvas that we retain useful for the scope of this study. We identified 12 papers that address the BMC distinguishing from energy community BMC (7 papers) and social enterprise BMC (5 papers).

Reis et al. (2021) propose a review of business models for energy communities by analysing community projects across Europe. They found a dominance of traditional self-consumption place-based communities business model, while business models dealing with ancillary energy services such as demand flexibility, energy aggregation, energy efficiency and electric mobility are still scarce. In addition, they identified eight community business model archetypes based on the European regulatory framework. Successively, they used BMC and the Lean Canvas frameworks to characterize and compare these archetypes. The authors used the BMC for describing and comparing the key dimensions of EC BM emerged from the literature. The Lean Canvas is used as a solution to overcome the BMC limitations in order to identify the market challenges and the proposed solutions offered by the 8 BM archetypes. By combining both BM frameworks, they provided a thorough set of boxes and tasks that help for the visualization and conceptualization of the BM, shedding light on their main strengths and weaknesses, which could facilitate the analysis for decision-makers and EC promoters.

Table 8. 1: Business Model Canvas Adaptations for EC and Social Enterprises comparisons

Authors	***Key partners***	***Key activties***	***Key resources***	***Value propostion***	***Customer relationships***	***Channels***	***Customer segments***	***Cost structure***	***Revenue streams***	***Additional blocks***
Reis et al., (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Problem and solution Key metrics Competitive advantage
Qastharin, A. R. (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Mission Impact and Measurement

Sparviero, S. (2019).		Yes	Yes	Yes (Social value proposition)		Yes	Yes (costumers and beneficiaries)	Yes	Yes (Income)	Governance Non-targeted stakeholders Costumer and Beneficiaries engagement Mission values Objectives Impact measures Output measures
Abdu, S. (2024).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Dobrowolski, Z., & Sułkowski, Ł. (2021).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Mission Impact and accountability
Iazzolino et al., (2022).	Yes	Yes	Yes	Yes (offered value)	Yes	Yes	Yes	Yes	Yes	
Kubli & Puranik (2023).	Yes	Yes (Key functions)		Yes			Yes (Energy community members)		Yes (Energy value capture)	Network effects
Horváth, & Szabó (2018).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Problem and solution Key metrics Unfair advantage
Bryant et al. (2018).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Herbes et al., (2017).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Yeoman & Moskovitz (2013)		Yes (solution)		Yes		Yes	Yes	Yes	Yes (Financial sustainability)	Unfair advantage Key metrics Problem existing activities
Graves, T. (2011)	Yes	Yes	Yes	Yes	Yes (Relations)	Yes	Yes (Co-creators)	Yes (value stream)	Yes (Value stream return)	

Source: Authors' elaboration

In the combined framework, in addition to the BMC blocks, they introduce the Lean Canvas blocks. The structure of Lean Canvas is based on the BMC which replaces some of its blocks. The Lean Canvas replaces the BMC "key partners" by the "problem" block. The aim of this block is to clearly identify the customers' problems which justify the need for a new product, service. After understanding the problem, the "solution" block is provided by the Lean Canvas. This block aims to propose solutions to the identified problems, and it replaces the BMC "key activities" block. Successively, a block entitled "key metrics" made up of a dashboard of observable KPIs is introduced. These KPIs aim to keep a record of the most important operation elements, that allow to evaluate the BM performance. The Lean Canvas also includes an "unfair advantage" block (or ‘competitive advantage’ block). This block aims to identify the barriers (e.g. financial and profitability barriers, institutional and policy barrier, technical barriers) that can hinder potential competing companies from entering the market. Finally, in the Lean Canvas, the “key resources” as well as “customer relationships” blocks are removed as they are indirectly presented in the ‘key metrics’, ‘unfair advantage’ and ‘channels’ blocks (Horváth & Szabó, 2018). The value proposition become Unique value proposition.

Horváth and Szabó (2018) instead address the barriers that may obstacle the deployment of distributed energy solutions. They used a literature review to identify the main inhibiting factors. In order to identify how to address the obstacles to the deployment of distributed energy they investigated the evolution of photovoltaic business models. Applying the Lean Canvas, they showed the principal differences between analysed models (i.e. the community shared model, host-owned and third party-owned solutions) and describe the benefits of these models. Then, using Osterwalder and Pigneur's business model definition, they summarized the most important value propositions, value creation, delivery and capture mechanisms of each business model. Energy bills reduction appears to be common to all three models, even if the saving level may be different for each. They claim that the community-owned model represents the model with the highest benefits which are principally based on the possible economies of scale that may result. In order to overcome regulatory and institutional issues that can hinder the deployment of distributed energy, they claim that policymakers have to develop extensive regulatory and incentive schemes that provide multiple options for fostering the spread of renewable energy sources. Indeed, financing mechanisms and innovative business models tailored to local or regional context could deeply increase the use of renewables.

Kubli and Puranik, (2023) propose a morphological analysis of 90 energy communities and pioneering companies that apply business model design options that can be adopted in energy communities. They identified 25 emerging business model design options applicable to energy communities. These options can be used by users to configure tailor-made business models for energy communities. The morphological box that is not a complete business model, represent an instrument for supporting community facilitators and promoters in the development process. It works as a toolbox to configure an energy community business model based on design option. Table 8.2 provides the five dimensions of energy community business model developed by Kubli and Puranik (2023).

Table 8. 2: Morphological box for energy community business models.

Business model dimension	**Energy community design options**					
Community value proposition	Generating renewable energy	Increasing self-consumption	Increasing grid reliability	Reducing energy consumption	Reducing energy costs	Becoming a living lab
Energy community members	Residential prosumers	Large-scale prosumers	Local energy producer	Energy service company	Community platform operator	
Energy value capture	Revenues from energy services	Saving energy costs	Revenue from external services	Community service fee	Data valorization	
Key functions	Facilitating P2P trading	Aggregating energy and flexibility	Managing storage systems	Co-optimizing energies	Coordinating partners	
Network effects	Peer effects & creating a community feeling	Economies of scale and scope	Learning effects	Co-benefits and co-amortization of investments		

Source: Kubli and Puranik (2023)

The value proposition dimension represents the scope behind the development of an energy community. This scope can include reducing energy consumption, reducing energy costs, generating renewable energy, ect. The dimension members of energy community, identifies the keys actors of EC including the prosumers, consumers, and service providers as well as their role.

The dimension energy community capture value refers to the ability of energy community member to capture value for profit-making. The key functions dimension shows how the energy community members create and deliver value. Finally, the network effects dimension represents the value or utility that community members can gain from increasing the number of community members. These effects include the peer effects and community feeling creation, economy of scale and scope, learning effects, and co-benefits and amortization of shared investments.

Qastharin (2015) proposes a BMC for social enterprise. The author evaluates the Canvas adaptations for understanding the definitions and characteristics of business model, business model canvas, and social enterprise in order to design an appropriate BMC for social enterprise. Then a new BMC for social enterprise by combining other Canvas adaptations is provided. The author added two key blocks (i.e. “mission” and “impact and measurement”) to the BMC proposed by Osterwalder and Pigneur. The author claims that the business model of social enterprise is mission-focused and impact-driven since their whole business model is based on the social/environmental mission and the success on the social/environmental impact to be achieved. The "Mission" block defines the purpose of the social enterprise. Specifically, this block defines the problem, the customer, the method and the impact in a single clear sentence which will represent the guidance for the enterprise. The "Impact and Measurements" block instead describes the benefits for the social enterprise's customers along with the indicators for measuring the success and progress of the social enterprise. The author also provides a different sequence of the social enterprise's building blocks. This sequence starts from Mission block, then proceeds as suggested by Osterwalder to Customer Segments, and ends with Impact and Measurements after Cost Structure.

Sparviero (2019) introduces a BMC for social enterprise builds for designing the organizational settings of social enterprises, for resolving the mission measurement paradox, and for meeting challenges related to the strategy, legitimacy and governance. The author performs a literature review of the BMC from multiple disciplines and fields and applied the result to a case study. To build the BMC for social enterprise the author put emphasis on social value and building blocks that take into account several blocks including non-targeted stakeholders, principles of governance, the involvement of customers and targeted beneficiaries, mission values, short-term objectives, impact and output measures.

Table 8.3 shows the BMC for social enterprises composed of 14 building blocks proposed by Sparviero (2019). Four of them are exactly the same as the BMC proposed by Osterwalder & Pigneur and contain the same type of information; five of them correspond to the remaining building blocks of the BMC but have been redefined to fit the analysis and terminology of social enterprise, and finally, five building blocks are new and specific to the analysis of social enterprise.

Table 8. 3: The Social Enterprise Model Canvas

<table>
<tr><td colspan="4">Governance (GOV)</td></tr>
<tr><td rowspan="2">Non-Targeted Stakeholders (NtS)</td><td>Key Resources (KR)</td><td>Channels (CH)</td><td rowspan="2">Customers & Beneficiaries (C & B)</td></tr>
<tr><td>Key Activities (KA)</td><td>Customer & Beneficiaries Engagement (C&B E)</td></tr>
<tr><td colspan="2">Mission Values (MV)</td><td rowspan="2">Social Value Proposition (SVP)</td><td>Impact Measures (IM)</td></tr>
<tr><td colspan="2">Objectives (Obj)</td><td>Output Measures (OM)</td></tr>
<tr><td colspan="2">Cost Structure (C$)</td><td colspan="2">Income (I$)</td></tr>
</table>

Source: Sparviero (2019)

The five building blocks inherited from the BMC (as defined in Osterwalder & Pigneur 2010) are: Key Resources, Key Activities, Channels, and Cost Structure.

The building blocks that have been reframed to align with the analysis and terminology of social enterprise include: “Social Value Proposition” block that substitutes Value Proposition in the BMC and describes the bundle of products and services that create social value for specific customers and beneficiaries. The building block “Non-targeted Stakeholders” replaces the Key Partnerships of the BMC and focuses on stakeholders that might be likely affected by the activities of the organizations. The building block “Customers and Beneficiaries”, replaces the Customer Segments of the BMC, defines groups of people that the social enterprise aims to reach and serve. “Customers and Beneficiaries Engagement” building block replaces the Customer Relationships of the BMC, suggests a deeper analysis of the relationships established by the organizations with its targeted beneficiaries. This relation is considered as two-ways, because customers and beneficiaries are also involved in the creation of value for the organization. The building block “Income” replaces the Revenue of the BMC, suggests the inclusion of all types of financial and in-kind resources received by non-profit and for-profit organisations.

The five building blocks that are new and specific to the analysis of social enterprise include: the “Mission Values” block, which defines the higher, long-term, ultimate goals of the organizations; the “Objectives” block, which defines desirable modes of conduct and more practical targets of the organizations in the short term; the “Impact Measures” block, which defines how mission values are assessed and measured, the “Output Measures” block , which defines the assessment measures of the objectives; and finally the “Governance” block, which sets out the key rules and/or boards and committees set up to manage the organization.

Yeoman and Moskovitz (2013) proposes Social Lean Canvas, based on Lean Canvas. The Lean Canvas used by the authors include different building blocks such as Purpose, Problem, Solution, Key Metrics, Unfair Advantage, Financial Sustainability and Social/Environmental Benefit.

The “Purpose” building block represents the guidance of the business model. The “problem and solution” building block aims to guarantee that the right solution is chosen to answer the problem identified by the enterprise. “Key Metrics” block defines measurements framework for assessing the performance of the social enterprise. “Unfair Advantage” block focuses on what makes the social enterprise different and successful. “Financial Sustainability” replaces Revenue Stream and include all the potential revenue streams for social enterprise. “Impact” block addresses the impact of the social enterprise activities.

Graves (2011) proposes changes on the labels of the building blocks proposed by Osterwalder and Pigneur (2010): Customer Segments becomes “Co-Creators”; Customer Relationships turn into “Relations”; Cost Structure becomes “Value Streams – outlay and costs”; and Revenue Stream turn into “Value Streams – returns”. These changes in labels aim to broaden the scope of the social enterprise, for example do not narrow customer segments to those that merely pay for product/service, but also include those that benefit from it, and not restrict the value to monetary value or costs. Therefore, the expected success of a social enterprise can be put in Value Streams – returns.

8.5. Discussion

According to Acciaro et al. (2014) as energy hub, ports represent an area 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 the related cities, and energy efficiency, economic and financial sustainability of port activities remain a major challenge for ports to address.

PREC can participate to address these challenges by considering ports as an ideal location for the implementation of innovative energy generation systems grounding on the economies of scale principle (Notteboom et al., 2022). In this perspective, ports could play a more strategic role within the respective regional energy systems, acting as energy generation and distribution platforms and turning from energy hubs to renewable energy communities.

Responding to the first RO1 "Which business model is suitable for PREC", we claim that PREC could use both the prosumerism business model and the third-party business model depending on investment and assets ownership perspective. In the prosumerism business model the customers and beneficiary finance and own the REC project by investing in energy generation and storage technologies in order to benefit from self-consumption, energy bill reductions and emission reduction. They are prosumers and take advantage of demand side management (DSM) programs. In third party business model instead, the third-party company (in the port context the port authority for example), can own several small-scale energy production units within the port or located remotely from each other and operates them as virtual power plants, centralizing the management of their energy resources (Brown et al., 2019). But the RED II directive promotes the energy community of place model in which participants are close to the place where the renewable energy projects are developed. In the port context, such model corresponds to the port micro grid, which is a decentralized electricity system, designed to operate in a limited community area. But another decentralized energy system existing in the port context is the smart grid, which is a large-scale power supply network designed to operate on large community power supply technology without any constraint of proximity to the area where the renewable energy project is realized. But this model is excluded by the RED II. This limitation can drastically reduce the benefits of PREC, thus, in the port context, we claim that PREC should be understood as locally and collectively organized energy systems, encompassing both the concepts of micro grid and smart grid. Specifically, the definition of PREC should consider all the energy-related activities proposed by the RED-II and IEMD but should not be restricted to a specific geographical area. All types of technologies should be used without restrictions including renewable generation, smart-grid infrastructures, as well as storage devices. This should allow the development of differentiated energy services and the exploitation of demand flexibility.

When it comes to the RO2 regarding "How the BMC can be applied to PREC to help visualise the development of its business model?", we were guided by the BMCs of the REC and social enterprise. The PREC Business Model Canvas we developed consists of 14 building blocks (Table 8.4).

Table 8. 4: Business Model Canvas for PREC

<table>
<tr><td colspan="5">1. Vision
I) Contribute to climate change mitigation; II) Contributing to the achievement of the goals dictated by energy transition; III) Decarbonizing the port activities and the related supply chain</td></tr>
<tr><td colspan="2">2. Problems and Solutions</td><td rowspan="2">3. Value Proposition</td><td rowspan="2">4. Unfair advantages</td><td rowspan="2">5. Customers and Beneficiaries</td></tr>
<tr><td>Problems</td><td>Solutions</td></tr>
<tr><td>* Capital intensive investments
* Lack of energy efficiency
* Reliability and stability of energy supply
* Energy demand flexibility
* Lack of area for assets installation</td><td>* Shared investments and partnerships
* Use of technologies for increasing the energy effiency
* Implementation of distributed enegy resources (DERs)
* Participaton to demand side management (DSM) programs
* Combination of inside and outside energy generation</td><td>* Self-sufficiency in energy
* Self-production of renewable energy
* Reduction of pollution and energy costs
* Increasing the energy system reliability
* Financial compensation for participating to demand response program</td><td>* Energy autonomy from the national network
* Good location of ports
* Port land use conversion for social purposes
* Local community education
* Employment creation</td><td>* Terminal operators
* Carriers
* Port users
* Other concessionaires
* Passengers
* Port's employees</td></tr>
<tr><td>6. Non targeted-stakeholders

* Local community and societal groups of interests</td><td>7. Key Activities
* Renewable energy supply
* Energy demand planning (demand-side management)
* Energy supply planning
* Balancing energy demand and supply
* Operation management and maintenance
* Marketing activities
* Energy efficiency and energy conservation activities</td><td>8. key Partners
Port stakeholders
* Terminal operators
* Carriers
* Port users
* Other concessionaires
* Passengers
* Employees
* Shareholders/owners
* Financial community
*Regulatory agencies
Other stakeholders
* Technology Suppliers
* Energy suppliers
* Power system entities
* Technical staff</td><td>9. Key Resources
Funding schemes
* International funding (e.g., from the European Commission),
* Funding from national, regional and local governments,
* Private funding (terminals, energy companies, banks)
* Self-financing (PREC members)
* Public incentives</td><td>10. Customers and Beneficiaries Engagement
* Personal and direct interaction
* Long term and trustworthy contract
* Relationship based on shared interests</td></tr>
</table>

	* Recruitment and training activities	* Distribution system operators (DSO)	**Technical resources** *Port location * Use of the national network as backup **Human resources** * PREC members)	
11. Channel * Technical Meetings * Focus group * Online and off-line marketing strategies * Customer service	**12. Cost Structure** * Capex * Opex * Maintenance cost * Marketing cost	**13. Revenue Streams** * Sale of energy surplus * Subsidies from European commission, national/regional/local government * Remuneration from feed-in tariff * Participation to demand response program Sale of ancillary services	**14. Impact measurement** **Environmental** * Reduction of GHG emissions * Use of renewable energy **Economic** * Investment confidence index * Net profit margin * Total expenditures * Disposable income (DI) * Utility bill rate	**Social** * Awareness rate * Community amenity * Community structure disruption * Energy justice * Employement rate * Involvement rate *Social justice * Level of social acceptance

Source: Author's elaboration adapted from Business Model Canvas (Osterwalder and Pigneur, 2010)

Seven of the building blocks are inherited from the BMC as defined by Osterwalder and Pigneur (2010) and contain the same type of information; two of them represent the remainder building blocks of the BMC, but they have been reshaped to fit the analysis and terminology of PREC, and finally, five new building blocks have been introduced and are specific to the analysis of PREC.

The seven building blocks inherited from the BMC are: "Key Partners", which describes the most important partners needed to develop a successful PREC. They include port stakeholders (e.g. terminal operators, shipping companies) and other stakeholders (e.g. DSO, technology suppliers). The "Key Activities" building block, which describes the most important actions a PREC must carry out to make its business model work. This building block includes activities such as renewable energy supply, energy demand and supply planning. The “Key Resources” building block, which describes the most important assets needed to develop a successful PREC includes funding schemes (international, national, regional), human resources (e.g. PREC members), technical resources such as a good port location. The “Value Proposition” building block, which describes the range of products and services that create value for specific customers and beneficiaries of the PREC. It includes the energy self-sufficiency, the self-production of renewable energy, the reduction of pollution and energy costs, the increase of energy system reliability.

The “Channels” building block, which describes how PREC communicates with and reaches the customers and beneficiaries to deliver the value proposition. Communication channel includes technical Meetings, focus group, customer service. “Cost Structure”, which describes all costs incurred by the PREC to operate. It includes the capex i.e. the investment costs (e.g. assets purchase, installation and grid interconnection costs), the operation costs and maintenance costs. The “Revenue Streams”, which describes the various sources from which the PREC earns money. It includes the sale of energy surplus, subsidies from European commission and national/regional/local government, remuneration from feed-in tariff, participation to demand response program and the sale of ancillary services.

Building blocks redefined to suit PREC analysis and terminology include: The “Customers and Beneficiaries”, which substitutes “Customer segments”, defines target groups that the PREC aims to reach and serve. As prosumers are expected to co-create the value in the PREC, customers and beneficiaries include port stakeholders such as terminal operators, carriers, port users…ect. The building block “Customers and Beneficiaries Engagement”, which substitutes “Customer relationships”, stresses the engagement of the prosumers in the PREC activities. They are expected to be involved in the decision-making process of PREC. The PREC could engage them through communication about upcoming port authority meetings, newly proposed energy related infrastructure projects, notices of environmental impact documents, port commission meeting minutes and monitoring of environmental socio and economic performance.

The five new building blocks that have been introduced and are specific to the analysis of PREC include: “Vision” building block, that represents the “what” of the PREC. It describes the main goal the PREC aims to address in the long term. These objectives include the contribution to the climate change mitigation, the achievement of the goals dictated by energy transition for achieving energy efficiency, and the decarbonization of the port activities and the related supply chain. In this perspective port should choose the partners with the same vision (e.g. suppliers who comply with environmental, quality and social standards). The "Problem and Solution" building block, describes the mission of the PREC by defining how the PREC intend to reach the vision. In this vein, the problem the PREC wants to address is first identified, and successively, the right solution to address this problem is found. For example, to respond to the capital-intensive nature of the investments related to REC implementation, a shared investment strategy can be adopted by the PREC participants. To tackle the lack of area for assets installation, a strategy consisting of combining inside and outside energy generation can be adopted. Therefore, a network of microgrids can be developed, and using the smart grid concept, this network could be efficiently managed using digital technologies. Another important building block is "Impact Measurement", which aims to first identify the potential impact of PREC (both positive and negative) including environmental and socio-economic impacts and develop a dashboard of KPIs for assessing these impacts. As the participation to PREC is open and voluntary participation, stakeholders that don't participate to the REC or have left it may be affected by the impacts of the PREC, so it is necessary to identify them and assess the magnitude of such impacts on them. For this reason, we introduced the "Non-targeted stakeholders", which can include the local community and societal groups of interests. The last building block is the "Unfair advantages", which describes the competitive advantages of the PREC. It includes the energy autonomy from the national network, the good location of ports, the port land use conversion for social purposes…etc.

8.6. Conclusion

The paper provides an innovative business model based on BMC framework useful to design, test, and communicate the benefits of PREC to the port community and the cities where they are located. The snowball sampling is used to collect prominent studies on Scopus Elsevier considering EC and social enterprise BMs. The BMC appears to have several limitations, so several adaptations emerged in the literature. In this vein, the Lean Canvas appears to be a great solution for overcoming the limitations of BMC. It helps for the visualization and conceptualization of the BMs, highlighting their main strengths and weaknesses, and facilitating the analysis of decision-makers (Reis et al. 2021; Cai et al., 2019; Horváth & Szabó, 2018).

PREC could use both the prosumerism business model and the third-party business model depending on investment and assets ownership perspective. BMC effectively can help to visualise the development of PREC. However, an adaptation is needed to align with the scope of PREC. In this perspective, the business model BMC we developed consists of 14 building blocks. Seven of the building blocks are inherited from the BMC (as defined by Osterwalder & Pigneur, 2010) and contain the same type of information; two of them represent the remainder building blocks of the BMC, but they have been reshaped to fit the analysis and terminology of PREC, and finally, five new building blocks have been introduced and are specific to the analysis of PREC.

This paper contributes substantially to the academic debate regarding business model innovation, by providing drivers for business model innovation and using the snowball sampling method to develop a PREC BMC. Additionally, the findings provide policymakers with valuable insights that can serve as a cornerstone for developing a specific regulatory framework for PREC (for example going beyond the energy community of place). It also brings valuable insights to support port managers in enhancing their decision-making processes regarding the decarbonization of the port activities. These insights can potentially advance the environmental sustainability and energy efficiency efforts of ports, by fostering the self-energy sufficiency, the self-production of renewable energy, the reduction of pollution and energy costs, the increasing of the port energy system reliability.

Nevertheless, it is crucial to recognise specific limitations in this paper, which provide opportunities for future research. By applying the snowball sampling method, the paper excludes conference paper and an important number of grey literature contributions which are expected to include references to implemented practices and ongoing initiatives developed by ports and other actors of the port industry. In addition, the paper considers only BMC adaptation from EC and social enterprise. For this reason, this paper is in no way intended to provide a perfect BMC for Port. Rather, it seeks to provide a theoretical BMC for PREC, that can be used as a starting point for the implementation of real cases. Further research can extend the BMC adaptation to other sectors where innovation is high like ICT sectors. Then the BMC could be validated through a questionnaire administered to port and related stakeholders.

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CHAPTER 9

CONCLUDING REMARKS AND FUTURE RESEARCH AGENDA

9.1. Concluding Overview

The following PhD thesis deals with the role of the port renewable energy community in decarbonizing the port supply chain. The energy-intensive nature of port activities and the constant tightening of environmental regulations at European and international levels, have increased the pressure on port authorities to find innovative solutions to reduce pollution arising from port-related activities.

In addition, the increasing energy demand originating from port activities, coupled with the need for reducing GHG emissions have urged greater attention from port decision makers on energy management issue. As a result, energy transition and port decarbonization appear to be the core goals to be achieved in the next years.

Given the above, the present PhD thesis aim was to evaluate how the introduction and development of effective port renewable energy community can allow to overtake the issues and concerns related to energy management in the port domain. In this perspective, PREC is considered to be a viable solution that might help policymakers and port authorities to achieve the goals dictated by the energy transition, as it not only considers the decarbonisation of the port as a node but the decarbonisation of the entire port supply chain. In particular, a step-by-step framework was developed to guide the development of the thesis, with the aim to provide a clear path towards PREC.

The research design consisted of the two parts: the theoretical part and empirical part. The theoretical part included four chapters and the second part, which is the empirical one included 4 papers authored or co-authored by my myself during the PhD programme.

Chapter 1 addressed the green port concept, with a focus on green strategies. Relevant managerial theories related to CSR was developed and a taxonomy of green strategies applicable to port was provided and discussed. This chapter also discussed the potential benefit of introducing a green business model in port governance such as value creation maximization for port stakeholders. Finally, some green finances for implementing this green business model are presented.

Chapter 2 considered ports as energy hubs in order to analyse the benefits that the energy hub approach could bring to the ports. This consideration emerged from the energy intensive nature of port activities. As such, port is considered as a major energy consumer and also producer due to the energy-intensive nature of day-by-day port-related activities. In this chapter, the different types of energy hub are presented along with the main technical components and the drivers of port renewable energy hub. It emerged from this chapter that as multi energy systems, ports integrate different types of energy generation loads and energy transformation technologies that can be used to improve the energy efficiency of port operations. Then, the coexistence of different types of energy supply makes the port a multi-energy system. As such, basing the port energy management systems on the energy hub approach, the port energy system could be smarter and capable to manage energy fluctuations through conversion and storage solutions for meeting volatile port energy demand and specific energy needs, which could bring several benefits including energy efficiency, flexibility, energy cost reduction. Given these potential benefits of the multi energy system, chapter 3 addressed the energy management in the port using the energy hub approach. This chapter addressed the policy framework and certification for port energy management. Then, the energy demand and supply planning in the port are discussed, finally, the smart energy management system as well as the operational strategies for energy efficiency are analysed. From the analysis of the first three chapters, it emerged that ports represent effective location for energy production, where energy generation facilities can be installed. Therefore, ports could play a more strategic role within the respective regional energy systems, acting as energy generation and distribution platforms and using their energy hub features to move towards renewable energy communities. In this vein, the chapter 4 closed the theoretical part of the thesis by discussing the applicability of the renewable energy community to ports, with a focus on the business model.

However, the second part of the thesis completes the theoretical part by providing four papers related to each chapter of the first part. These papers consist of 4 research objectives:

- ***RO1***. *To identify Green Strategies (GSs) implemented by ports aiming at making port operations more sustainable, especially reducing energy consumptions and increasing energy production from renewable sources.*
- ***RO2***. *To provide a conceptual framework for supporting port decision makers in transforming ports into renewable energy hubs.*

- ***RO3***. *To evaluate the introduction of an ad hoc port energy management approach as a preliminary condition for the energy transition process of ports.*
- ***RO4***. *To propose an innovative (green and smart) business model for the establishment of effective PREC*

9.2. Research outcomes and managerial implications

The first empirical research (Chapter 5, "Green strategies of port managing bodies: empirical evidence of stakeholder prioritisation in Italian ports") investigates the as is situation of green strategies in Italian ports. It theoretically and empirically investigated stakeholder prioritisation practices of PMBs when designing and implementing GSs. Moreover, a taxonomy of GSs is provided for a deeper understanding of the environmental benefits of these GSs and related beneficiary port stakeholder groups (PSG). The empirical research applies the CSR and stakeholder relationship management principles to develop a conceptual framework for exploring GSs in ports and identifying related salient beneficiary PSGs. The identification of salient beneficiary PSGs of GSs may support port managers when dealing with strategic decision-making and may allow to improve CSR strategies. Therefore, the paper contributes to the academic debate on sustainability in the port domain providing an overarching taxonomy of GSs. It also estimated the stakeholder prioritisation for GSs through the indirect methodological approach empirically applied on four Italian PMBs. The findings stress multiple objectives of GSs consistent with the CSR perspective and trace the trends of green initiatives in the Italian ports to meet the diverse PSGs' expectations. Port managers can benefit from the proposed empirical indirect approach for stakeholder prioritisation and relate insights to improve the decision-making process concerning GSs. In this perspective, they can optimise the portfolio of GSs to maximise the benefits for specific target PSGs.

The second empirical research (Chapter 6, "Port as renewable energy hubs: insights from the Italian case") applies the concept of energy hub to ports. It scrutinized the most relevant opportunities and challenges which ports are expected to experience as PREHs for achieving environmental, economic and financial sustainability goals. This empirical research provided 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 provided, the most important components that constitute a successful PREH configuration by applying a stakeholders' perspective to achieve environmental, financial and economic sustainability. Finally, 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. This chapter contributes to the academic debate on energy transition in the port domain from an energy hub perspective by providing a categorization of energy hubs. This energy hub perspective, which represents a transformative approach for the management and optimization of port energy systems, represent an effective approach to align with the global shift towards sustainability and renewable energy sources. From a 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, 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 and reduce or eliminate the threats that can hinder its implementation.

The third empirical research (Chapter 7, "A review on port energy management as a holistic approach") addresses the energy management within the port. Indeed, active energy management appears to be a great solution for energy inefficiency reduction in the port as it can bring substantial efficiency gains, contribute to the development of alternative revenue sources and improve the port's competitiveness. In particular, the empirical data regarding port energy consumption are still lacking because of the scarce diffusion of culture in energy management in Port Authorities and private terminal operators. As a result, prior studies on port energy management are argued to be still fragmented and the academic debate on this issue would greatly benefit from the development of an in-depth literature review aimed at analysing strategies, technologies, best practices that address the three port energy management concepts that underpin this study, namely energy efficiency, energy conservation and renewable energy. In this perspective, diverse theoretical angles and valuable topics are introduced and discussed, such as: drivers for the introduction of energy management systems in the port domain, advanced energy planning, demand response programs, port performance measures, policies and measures, sustainable practices, KPIs, decision support systems, facilities and infrastructure for electric energy supply, and renewable energy technologies.

In this perspective, this empirical research conducts a systematic literature review based on more than 130 journal articles that address the three port energy management concepts that underpin this study, namely energy efficiency, energy conservation and renewable energy. The literature review performed returned a very fragmented picture from several viewpoints and the three key concepts related to energy management in ports are addressed separately in the literature and sometimes they get confused with each other.

The result shows that energy management offers great potential to ports to improve the energy efficiency of port activities, and the research gaps identified in the literature offer to researchers many opportunities for high-impact research. Regarding the policy implications, innovation and new technologies in the port activities are constantly evolving. Policy makers hardly can keep the pace with the transformations taking place in the port sector. This review provides an overview on the main issues originating from energy management in ports, shedding lights on the emerging strategies, technologies and best practices which can support policy makers in their decision-making process.

The theoretical part and the first three empirical studies paved the way for PREC, therefore, the last empirical research (Chapter 8, “Port renewable energy community: an innovative business model canvas”) develops a business model for PREC. Business Model Canvas (BMC) is applied to PREC for understanding how it is expected to create, deliver, and capture values for port stakeholders. In this vein, a snowball sampling method is used to identified relevant studies on the business model canvas of renewable energy communities and social enterprises on Scopus Elsevier in order to understand the characteristics of these business models and to evaluate adaptations of the canvas for defining a PREC BMC. The paper provided an innovative business model based on BMC framework useful to design, test, and communicate the benefits of PREC to the port community and the cities where they are located.

The BMC appears to have several limitations, so several adaptations emerged in the literature. In this vein, the Lean Canvas appears to be a great solution for overcoming the limitations of BMC as it helps for the visualization and conceptualization of the BMs, highlighting their main strengths and weaknesses, and facilitating the analysis of decision-makers (Reis et al. 2021; Cai et al., 2019; Horváth & Szabó, 2018).

Furthermore, it emerged that PREC could use both the prosumerism business model and the third-party business model depending on investment and assets ownership perspective. Although BMC effectively can help to visualise the development of PRE, an adaptation is needed to align with the scope of PREC. In this perspective, the business model BMC we developed consists of 14 building blocks. This empirical study contributes substantially to the academic debate regarding business model innovation, by providing drivers for business model innovation and using the snowball sampling method to develop a PREC BMC. The findings provide policymakers with valuable insights that can serve as a cornerstone for developing a specific regulatory framework for PREC. Finally, it also brings valuable insights to support port managers in enhancing their decision-making processes regarding the decarbonization of the port activities. These insights can potentially advance the environmental sustainability and energy efficiency efforts of ports, by fostering the self-energy sufficiency, the self-production of renewable energy, the reduction of pollution and energy costs, the increasing of the port energy system reliability.

9.3. Limitations and future research directions

According to Connelly (2013), any research is subject to some limitations including this PhD Thesis. The first limitation is related to the thesis structure which results in some duplications of data and information provided. This is due to the fact that the empirical part of the Thesis is strongly related to the theoretical part which, inevitable creates some duplications.

Chapter 5 also brings some limitations. First, the sample of PMBs is limited and should be extended to investigate a wider number of GSs and compare the results emerging from different national port systems. Second, the paper evaluates the benefits for PSGs according to the perspective of the international experts included in the panel to which the survey has been administered, thus bringing some bias to the empirical analysis. To improve the consistency of the coefficients related to the GSs-PSGs matrix, future studies should consider PSGs' perspective and evaluate their perception of benefits arising from each typology of GSs.

Regarding Chapter 6, some specific limitations emerged and underlying them might provide opportunities for future research. In fact, the conceptual framework only provides the layers for the development of a PREH configuration in term of inputs and output without providing any 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 studies 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.

Concerning Chapter 7, the main limitation of the literature review is based on the fact that it only includes journal articles. The review excludes conference paper and an important number of grey literature contributions which are expected to include references to implemented practices and ongoing initiatives developed by PMBs and other actors of the port industry. For this reason, this empirical research is in no way intended to provide a comprehensive overview of port energy management strategies, technologies and best practices. Rather, it seeks to provide a different perspective of energy management in ports, namely the holistic one that includes energy efficiency, energy conservation and renewable energy. Future studies investigating port energy management might consider other source including conference papers, reports, books…etc.

Finally, also Chapter 8 brings some specific limitations. By applying the snowball sampling method, the paper excludes conference paper and an important number of grey literature contributions. In addition, the paper considers only BMC adaptation from EC and social enterprise. For this reason, this paper is in no way intended to provide a perfect BMC for Ports. Rather, it seeks to provide a theoretical BMC for PREC, that can be used as a starting point for the implementation of real cases. Further research can extend the BMC adaptation to other sectors where innovation is high like ICT sectors. Then, the BMC might be validated through a questionnaire administered to port authorities and related stakeholders.