Dimensions of Port´s Sustainability. An Analytical Framework

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Abstract. Ports are gateways to the world, at the crossroads of supply chains. They act as centres of energy, industry, and the blue economy, and increasingly centres of innovation and digitalisation. Ports are at the heart of various strategies and can be unique drivers of sustainability. All parties integrated and connected to a port have incentives to reduce energy consumption, emissions, and other environmental impacts. Port authorities must decarbonise logistics operations, offer alternative fuels for ships, and reduce energy costs. Energy companies must provide energy and heat at competitive prices, ensure supply and sustainability, and respond to the growing electrification. However, the literature shows a wide range of approaches to transitioning towards environmental sustainability in ports. This paper examines the roles that ports can play in advancing the transition. To this end, it proposes two complementary analytical perspectives. The first conceptualizes the port as an infrastructure whose activity is intrinsically linked to maritime transport, thereby functioning as a node within logistics chains that can foster energy and sustainability transitions. The second perspective approaches the port as an industrial cluster and logistics hub. Finally, a case study is presented to validate the proposed analytical framework and to assess whether the model adequately captures the range of measures implemented within the port context.

1 Introduction

Maritime transport plays a vital role in international supply chains and economic growth. According to the United Nations Conference on Trade and Development (UNCTAD), 80% of international trade in goods is transported by sea. This proportion is even higher in most developing countries [1]. Maritime transport is often seen as environmentally friendly in terms of emissions per kilometre [2]. However, given its large share of global trade, its overall environmental impact is not negligible.

A wide range of academic and grey literature addresses the role of ports in the energy and sustainability transition, covering conceptual frameworks such as green, smart, sustainable, and resilient ports, as well as concrete actions within port contexts. These actions include

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providing renewable fuels for maritime transport, implementing green port tariffs, and enabling ports to host renewable energy infrastructure or serve as bases for marine energy companies. Against this backdrop, the present study examines the role ports play in the sustainable transition and how to categorise the possible actions within ports.

The structure of this research is as follows. Section 2 outlines the methodology. Next, Section 3 presents the evolution of the port concept to clarify its underlying theoretical foundations. Building on the literature review, Section 4 proposes the analytical framework, which is then applied in Section 5 to a case study examining developments at the Port of Bilbao (Spain). Finally, the paper concludes with brief reflections mainly on the proposed analytical framework.

2 Methodology

This study uses a qualitative approach. It collects and interprets non-numerical data to explore meanings, perceptions, experiences, and processes [3]. This flexible, interpretive, and exploratory method aims to capture the complexity of reality. It allows in-depth, context-sensitive analysis and reflects stakeholders' views [4]. The analysis relies on the researcher's analytical skills and contextual knowledge [3] that, in this case, builds on the researcher's prior expertise in maritime transport and port management.

The research design uses several qualitative methods. These include a literature review, document/narrative analysis, and stakeholder validation. These methods help collect detailed information, identify patterns, relationships, themes, and perspectives. The research began with the two research questions mentioned earlier (the role of ports in the sustainable transition, and how to categorise the possible actions adopted within ports) and with a conceptual framework that defined the scope of a port (Figure 1). This framework was then validated through consultation with a port stakeholder.

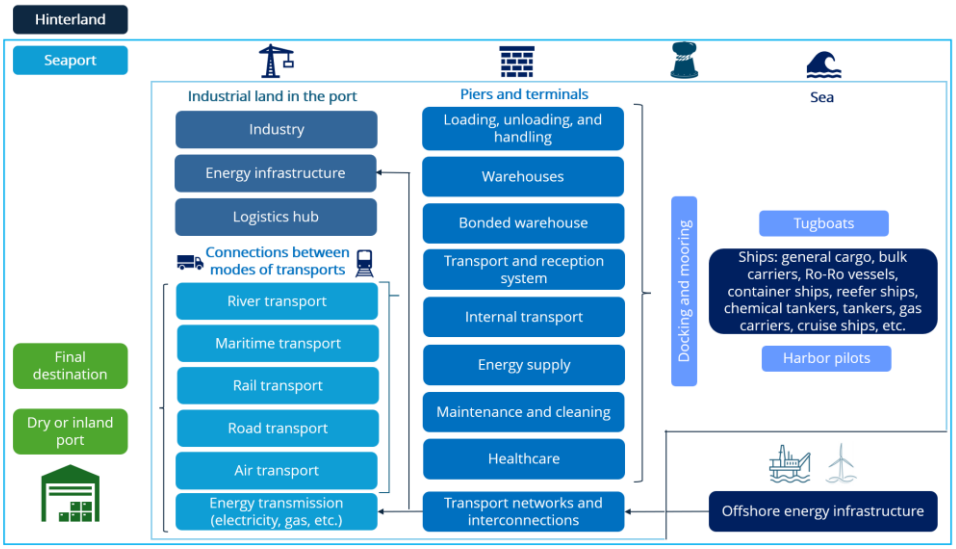

Fig. 1. Framework for analysing the port area

A non-exhaustive literature review [5] followed, using selected keywords. The review covered academic sources—mainly via Google Scholar and Scopus—and grey literature. This included reports from port, maritime, and logistics stakeholders, as well as institutional and corporate sources. The focus was on the energy, green, and sustainability transition,

especially for maritime transport and ports. The subsequent step involved synthesising and categorising this broad information.

After data collection, an interpretative synthesis was conducted. The information was coded, categorised, and compared to generate informed interpretations. The results fell into two categories, reflecting structural and functional port dimensions. These were then articulated as an analytical framework aligned with the research questions (Figures 3 and 4), as presented in Section 3.

Five stakeholders were chosen to validate the research's first stage. Three responded: an institutional port stakeholder (Bilbao PortLab), a business consultancy stakeholder (PortEco), and an academic (Texas A&M International University). This validation helped refine and strengthen the analytical framework.

The framework in Figures 3 and 4 is paired with several tables. Each subcategory has a table, as shown in Table 1. Another table lists the port's key features, like techno-economic characteristics, traffic, energy use, and sustainability indicators. These tables detail potential developments found in this research phase.

Table 1. The energy transition in the port-maritime transport relationship.

Energy efficiency in port operations, port electrification	
* Implementation of energy efficiency measures	
* Development of renewable energy facilities at the port for own use	
* Electrification of cranes and other port equipment and infrastructure	
* Alternative energy transport options at terminals	
* Climate resilience	
* Climate change adaptation strategy	
* Planned investments	

The framework was applied to a case study at the Port of Bilbao (Spain), allowing further refinement. Publicly available information was reviewed to find initiatives taken by the Port of Bilbao in each framework category. The right-hand table column was filled with 'yes', 'no', or details where suitable (see Table 2). Results were cross-checked with a Bilbao port representative.

Table 2. The energy transition in the port-maritime transport relationship in the port of Bilbao.

Energy efficiency in port operations, port electrification	
*** Implementation of energy efficiency measures**	
Building renovation	Replacing conventional boilers with heat pumps.
Implementation of waste heat recovery systems	No
Lighting	Replacement of light bulbs and lighting in communal areas with LED technology.
*** Development of renewable energy facilities at the port for its own use**	Solar PV panels.
*** Alternative energy transport options at terminals**	New fleet of vehicles. 90% powered by alternative fuels. Development of charging points at the port.

The adoption of a Case Study Research (CSR) methodology allows the development of new constructs and relationships across specific contexts (Ridder, 2017). It also provides a basis for in-depth exploration of particular phenomena and their contextual dynamics (Baxter & Jack, 2008). As noted by Yin (2003), CSR is suited to answering "how" and "why" research questions. To ensure analytical focus, the scope of the case study was delimited along several dimensions: spatial (the Port of Bilbao), temporal and functional (the analysis of policies and

measures by the Port Authority during the last five years and for the near future), and thematic (the transition towards sustainability).

3 From a port as a link in a transport system with environmental priorities towards sustainable ports

According to [6], research on the transition to sustainable, low-carbon economies has paid little attention to ports, though they drive economic activity. However, the literature shows that ports are being conceptualized differently, reflecting recent changes.

3.1 Ports as a link in a transport system with environmental priorities

Initially, the maritime and port industry was required to comply with a series of regulatory measures to monitor and reduce the environmental and global warming impact of its activities [7]. Consequently, ports could be considered a link in a transport system that prioritizes environmental considerations.

3.2 Ports as energy hubs

Ports have traditionally helped import, export, store, and consume energy. They act as suppliers to ships and other transport modes and distribute energy. Besides serving offshore oil and gas, ports are closely linked to the construction and maintenance of renewable energy facilities, especially offshore but also onshore.

An energy hub is a facility where multiple energy carriers can be converted, processed, and stored. In this sense, a port acts as an interface between different energy infrastructures and/or cargoes [6]. The concept of port "energy hubs" centres on transforming trade-specialized ports and blending petroleum products into sustainable energy hubs. [8] describe future ports as "decarbonisation centres", expecting their transformation to involve the direct and indirect electrification of port-related activities, industries, ships, and other modes of transport.

3.3 Green port

The term "green port", according to [9], was formally established internationally at the UN Climate Change Conference in 2009 (COP15). Although there is no single definition, implementing the concept of a green port involves modifying management practices, establishing objectives, commitments, and responsibilities towards society and the environment, and conducting port operations in accordance with requirements that reduce their negative impact.

[10] conceive of green ports as those that adopt energy-efficient and environmentally sustainable practices through strategies and policies. [11] identifies green ports as those committed to the proactive development, implementation, and monitoring of practices to reduce environmental impacts. For [12], a green port is one in which the port authority and users proactively and responsibly develop and operate it in line with a green economic growth strategy. For [13], the concept is closely linked to the growing environmental awareness of port stakeholders.

[14] characterise a green port as one with a sustainable environment, fair resource use, low energy consumption, and low emissions. [15] offer a more holistic definition, describing green ports as those that, in their management and operations, prioritize social, economic, and environmental aspects rather than solely business profits.

3.4 Smart ports: hubs of innovation and digitalisation

Smart ports employ automation, service integration, digitalisation, and data-driven techniques to function as ports dedicated to cargo management, primarily using technologies such as the Internet of Things (IoT), Big Data for predictive analytics, blockchain, augmented reality, and other intelligent, data-science-based interfaces; both to improve efficiency in freight transport and to achieve cost reductions in handling or faster customs clearance.

With maritime traffic constantly growing, smart port practices are essential for enhancing workforce management and controls [16], ensuring globalisation and market liberalisation, maintaining the dynamics of international trade and competitiveness amid the growing complexity of the logistics chain, and safeguarding operational and environmental sustainability.

A smart port can thus improve the efficiency, safety, security, and environmental performance of the supply chain, link peripheral regions and islands to the mainland, and contribute to territorial cohesion.

3.5 Sustainable ports

In contrast to the concept of a green port (which focuses primarily on environmental concerns), port sustainability is based on the three pillars of sustainable development [17]. A sustainable port is one that has strategies and activities that meet the current and future needs of the various port stakeholders, while protecting the environment and supporting the local population.

3.6 Resilient ports

The concept of the port as a resilient infrastructure refers to the digital and physical port infrastructure, which can adapt to changes (e.g., in climate and weather conditions) and demands (e.g., from maritime transport and land logistics) and ensure the long-term sustainability of a port and its operations, developing in harmony with local communities, nature, and heritage. It can therefore be understood as a long-term concept, in which the objectives relate to the potential for sustainable growth and survival in the face of future crises.

Investments in climate-resilient infrastructure to prevent future disruptions to transport operations are key, as rising sea levels or extreme weather events will affect ports; without adequate adaptation measures, this will impact the competitiveness of maritime transport [18].

As shown in the figure below, the literature review demonstrates a clear evolution in the conceptualisation of ports, moving from a general environmental concern to specific, technology-driven, comprehensive implementation strategies that include people and are long-term in nature, i.e., focused on resilience.

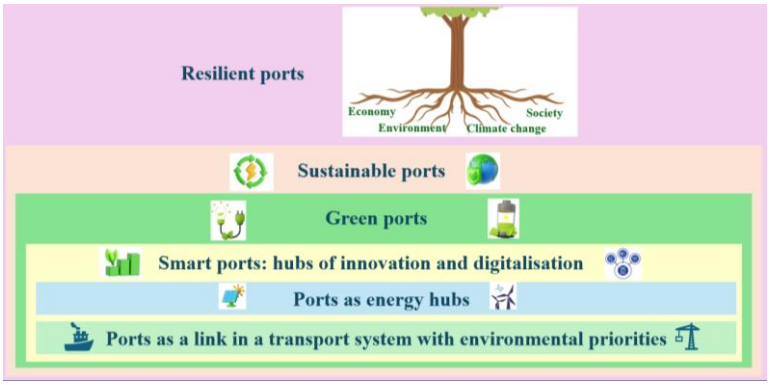

Fig. 2. Evolution of the concept of a port. Towards a broader vision.

These concepts are not independent. [19], for instance, highlight the implementation of digital technologies in green ports, particularly in data collection and real-time monitoring, and [20] identify digitalisation as one of three key development trajectories alongside decarbonisation. Furthermore, some studies do not distinguish between 'green ports' and 'sustainable ports' and use these terms interchangeably. [21] suggest that these terms refer to environmental sustainability and resilience, focusing on reducing pollutant emissions and improving environmental performance, whilst emphasising the importance of tailoring green projects to each individual port.

4 Framework for analysing the role of ports in the sustainable transition

The analytical framework, drawn from the literature review, examines the port from two main perspectives: (i) the port as an infrastructure whose activity is entirely linked to shipping and, as such, acts as a link in the logistics chains facilitating both its own transition and that of the maritime transport towards sustainability; and (ii) the port as an industrial cluster and logistics hub including its role as a logistics platform for activities in the hinterland.

4.1 The port driving more sustainable maritime transport and port operations

The sustainability of maritime transport is key for ports. Whilst many ports have chosen to comply with regulations, in some cases they have exercised—or are exercising—their leadership potential to address the social and environmental externalities associated with the supply chains of which they form part. To this end, ports can operate on three main topics, as shown in Figure 2, and described below.

Fig. 3. The port driving more sustainable maritime transport and port operations.

4.1.1 The sustainability of ships

The maritime transport sector is one of the main contributors to CO_2 emissions attributed to a port. To address the targets set by the International Maritime Organization (IMO) in the 2023 revised strategy, to reduce the carbon intensity of ships and to increase the adoption of technologies, fuels, and/or energy sources with zero or near-zero GHG emissions, the following approaches may be proposed:

- Improving the technical efficiency of ships. To this end, innovation and technology are crucial, as they drive and facilitate improvements in the sector's environmental performance. Modern eco-friendly designs will continue to replace older, less efficient ship designs. A wide variety of indicators can be used to assess the technical efficiency of ships (e.g., Energy Efficiency Design Index (EEDI), Environmental Ship Index (ESI), Environmental Port Index (EPI)).
- Improving operational energy efficiency of ships. It depends on factors that vary over time and, often, on ship design, including: distance, time at sea, volume of cargo carried, and cargo conditions (including ballast, displacement, and ocean and weather conditions). One possible measure to improve operational energy efficiency involves examining and analysing sailing speed and its optimisation, taking into account safety, the distance to be covered, potential market or commercial distortions, and ensuring that this measure does not affect the ability of maritime transport to serve remote geographical areas. Similarly, there are various indicators for measuring operational efficiency (e.g., Energy Efficiency Operational Indicator (EEOI), Individual Ship Performance Indicator (ISPI), and Annual Efficiency Ratio (AER)).
- Use of clean marine fuels: there are still no solutions that are efficient in economic and environmental terms, due, amongst other reasons, to the limited space available on ships for generating power or for carrying all the necessary renewable fuels. Numerous marine fuel options are being explored (e.g., liquefied natural gas – LNG, hydrogen, ammonia, synthetic fuels, and biofuels), which are expected to contribute to decarbonisation 'from well to propeller' as well as to carbon capture and storage (CCS) options on ships.

4.1.2 The energy transition in the port-maritime transport relationship

Many ships spend hours or days waiting to load and/or unload whilst running their diesel engines, which clearly impacts energy consumption and emissions, amongst other factors. Various short-term options may be proposed that, when combined, will optimise port operations and improve maritime transport services. They require the collaboration of multiple port operators and the entire transport chain. In this context, new information technologies play a significant role. There are three key approaches:

- Just-in-time operations and port call optimization. These help reduce maritime transport emissions, whilst also improving efficiency and safety. This requires a comprehensive definition of the port call process from a physical, technical, legal, and data exchange perspective. Digitalisation and automation are fundamental.
- Cold ironing, or shore-to-ship electricity/power supply, helps vessels reduce GHG emissions and other pollutants, improving air quality in ports and, consequently, in surrounding areas. It faces barriers such as connection power or billing methods due to the short connection times.
- Green port charges or fees are tools ports can implement to encourage ships to be more environmentally friendly. Green rebates often reflect the non-economic objectives pursued by the port, its owners, or the local community, and encourage positive behavioural change in ship performance beyond the port's activities.

4.1.3 Sustainability at the port terminal

- Although emissions from port activities contribute to a lesser extent to total emissions, and consumption levels vary by terminal type and size, ports are developing initiatives to improve operational energy efficiency and use their own renewable energy for operations. This is key to activities related to buildings, infrastructure, and transport, including cargo handling, storage, and internal transport. Ports have begun electrifying cranes, small trucks, and tractors. More efficient port lighting systems are being developed. Other port operators have begun replacing machinery and equipment with electric alternatives where possible and are adopting a phased approach, replacing existing solutions as new technologies mature and leases are renewed or expire.
- Furthermore, due to their location, ports are on the front line of some of the most severe effects of climate change (e.g., sea-level rise, frequent storms and waves). As a result, it is necessary to develop resilient ports. To this end, climate adaptation involves addressing and building resilience to (probably) inevitable events. Adaptation strategies typically consist of reactive measures taken after the impacts of climate change have already been felt.

4.2 The port as a link in maritime-port clusters

Ports must be considered from a dual perspective: 'the port as a transport hub', complemented by 'the port as an industrial cluster'. As a transport hub, a port is a gateway through which goods are transferred between ships and land [22]. On the other hand, a maritime-port cluster is a regional concentration of economic activities related to the arrival of goods and ships [23]. Figure 3 sets out the different perspectives from which it can be analysed.

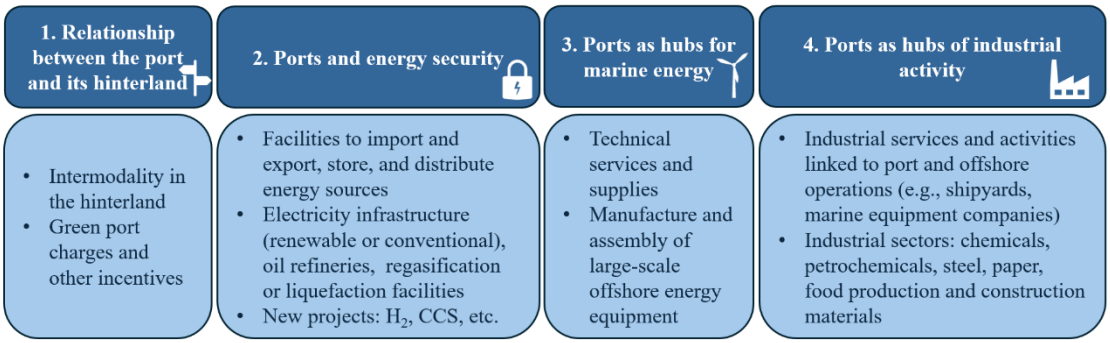

Fig. 4. The port as a link in maritime-port clusters.

4.2.1 The relationship between the port and its hinterland

A port's success depends on its multimodal connectivity with the hinterland. It is then necessary to improve road, rail, and inland waterway connections, and to provide alternative fuels for the various modes of transport. Few studies have examined the performance of ports in their hinterlands, despite the fact that port activities generate a variety of externalities. In any case, strategies for ports' hinterlands have become a crucial part of ensuring efficient and more sustainable supply chains.

- Intermodality: hinterland services depend on the seaport's location, positioning, and infrastructure. Some benefit from inland waterways, whilst others are limited to land-based modes of transport. Inland waterways and rail transport increase overall transport capacity,

benefit from economies of scale, generally perform better over longer distances, have a lower environmental impact, improve port efficiency, and experience fewer delays due to road congestion [24]. Road-rail intermodal transport chains can achieve cost-effective and environmentally friendly long-distance transport, whilst road transport, being more regular and competitive, allows for more flexible routes to the end customer [25]

- There are various measures that ports can adopt in line with the development of sustainable transport between the port and the hinterland, such as: (i) certification, (ii) engine standards, (iii) monitoring, (iv) regulation, or (v) green port tariffs, fees, or charges for hinterland transport.

4.2.2 Ports and energy security

Ports are a common location for energy infrastructure and, as such, are fundamental to countries' energy security. They play a key role in the import or receipt, export or dispatch, storage, and distribution of fossil fuels and other energy sources. They often feature electrical infrastructure (renewable or conventional), oil refining facilities, and regasification or liquefaction plants. Furthermore, the development of new infrastructure is anticipated to meet emerging needs (e.g., hydrogen (H_2), marine renewable energy, and CCS), alongside projects to produce, demonstrate, and implement clean and renewable energy.

4.2.3 A hub for the development of marine energy

Ports have served as important stopovers for ships, dredgers, and platforms to offshore oil and gas fields, which also saw a boom in trade in technical services and supplies for the offshore exploration and production sector, largely driven by local players.

Currently, the role of ports in the fossil fuel sector is expected to decline. However, new commercial opportunities are emerging with the development of offshore renewable energy, including services such as quality inspections and control, sheet metal work, and waste treatment. Services are also offered for the supply of fuel to vessels, as well as logistics, development, construction, maintenance, and decommissioning of facilities and platforms. In some cases, for example, with offshore wind farms that require large, heavy components, it may be preferable to manufacture or install these in port areas near the quays for transshipment.

4.2.4 The port as a site for industrial activity

This final element is linked to the previous one; however, it has been separated to distinguish energy-related activities from other industrial activities. Ports provide important logistics and other services that benefit their catchment areas. Thus, ports can open up market opportunities for both domestic and international companies.

- Industrial and logistics clusters in ports generate a large volume of resources, capacity, revenue, and employment linked to ship loading and unloading operations, operations and services (agencies, pilots, tugs and bunkering), land transport, logistics activities, freight services (e.g., freight transport and customs), industrial production facilities, and government agencies. Ports often host activities, including shipyards, marine equipment companies, manufacturers of cranes and terminal equipment, salvage companies, offshore operations, dredging, and naval bases.
- Furthermore, the chemical and petrochemical industries, steel production, paper manufacturing, food production, and construction materials production tend to be located in industrial ports (e.g., Antwerp, Rotterdam, Houston, Long Beach, and Shanghai).

In general, the success of these port clusters depends on the facilities, the availability of a skilled workforce, competitive energy prices, and public services; the role and support of port authorities and government bodies in offering incentives for infrastructure development; the availability of land, competitively priced supplies of raw materials, infrastructure (such as pipelines), etc.

5 Case study: Port of Bilbao

The Port of Bilbao is one of the most important transport and logistics hubs in the European Atlantic Arc, with traffic, infrastructure, and shipping routes connecting to around 900 ports. It is a multi-purpose port and has a container terminal, capable of accommodating any type of vessel or cargo. It has direct links to the motorway and railway networks and offers intermodal connections across the entire Iberian Peninsula. It has a balanced economic performance and positive environmental outcomes.

In terms of environmental sustainability, the port has an Energy Transition Plan to achieve decarbonization by 2050. It also holds the EPD International (Environmental Product Declaration) certificate for port operations, based on a product or service's life-cycle assessment, which enables quantification of the environmental impacts of its activities. In terms of environmental management, it holds EMAS certification, an Internal Contingency Plan for marine pollution, an Agreement on Good Environmental Practices, a monitoring system for air, water, and noise, and an Agreement on Good Practices at the terminals. In terms of wildlife protection, it has environmental monitoring systems and a biological monitoring plan. Also worth noting in the port-city relationship is the drive to develop future capabilities, ensuring knowledge transfer and attracting new talent.

Figure 5 provides an overview of the activities and developments currently underway, organised according to the previously outlined analytical framework for ports' sustainable transition, briefly explained below. Progress is shown in bold, whilst pending issues are shown in light in the boxes with a white background.

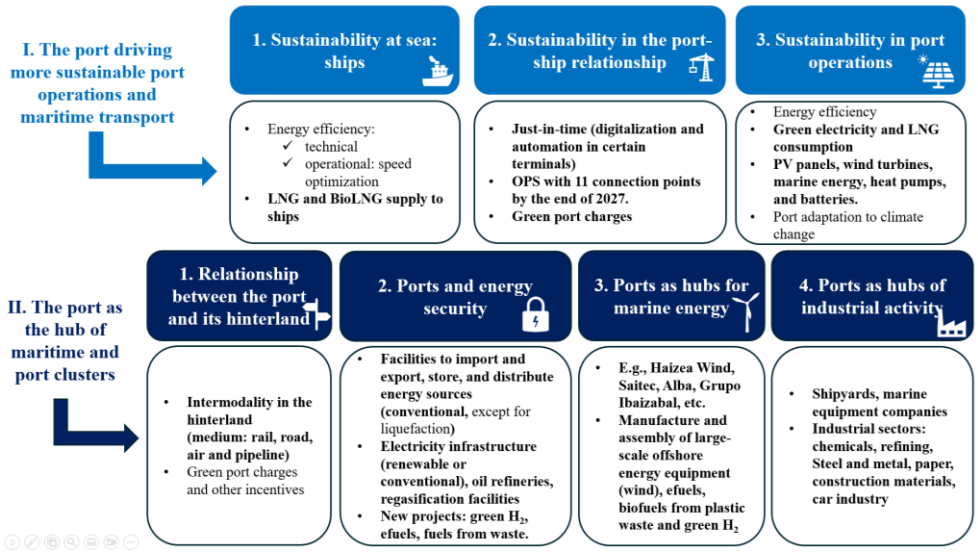

Fig. 5. The port of Bilbao and the sustainable transition.

Sustainability at sea: ships

Although the port does not provide detailed information on the age of the vessels calling at it, and no specific measures addressing the energy efficiency of ships are in place, Bilbao is a key player in the supply of LNG (Liquefied Natural Gas) and bio-LNG to ships, with a 1,000 m³ LNG bunkering terminal. In addition, there is a barge for LNG bunkering services that operates on LNG and uses a truck-to-ship supply system.

Sustainability in the port-ship relationship

The Port of Bilbao, which has a system of green port charges, also offers the e-puertobilbao platform, available to users, which features a one-stop shop. This platform improves document exchange and communication with businesses in the port area, enabling it to achieve an optimal competitive position.

The port is developing cold-ironing facilities at the quays for cruise ships, container ships, ferries, and Ro-Ro vessels, with an investment of €51 million. Additionally, the aim is to supply renewable electricity generated within the port.

Sustainability in port operation

The main source of energy consumption at the port is the buildings and the equipment required for the handling and movement of goods (vessels, forklift trucks, cranes, and port transport vehicles), which tend to run on petrol or diesel. During the refurbishment of port buildings, conventional boilers have been replaced with heat pumps, and communal areas have been upgraded to LED lighting. Bilbao has the tugboat Ibaizabal Quince, which operates on a dual-fuel propulsion system using LNG and diesel since 2020. Cosco Shipping Ports installed six hybrid container cranes. Furthermore, a few years ago, the port acquired a fleet of vehicles, 90% of which are powered by alternative fuels. It also developed charging points at the port. As part of the development of the OPS (cold-ironing) scheme at the port, it was decided to install a photovoltaic plant to supply power to moored vessels.

Relationship between the port and its hinterland

The hinterland area of the port of Bilbao extends over 1,000 kilometres. It maintains close links with the Pancorbo (Burgos) rail-port logistics terminal (TELOG), with the inland ports of Azuqueca de Henares (Guadalajara), Coslada (Madrid), Villafría (Burgos), Júndiz-Vitoria (Álava), and Noaín (Navarra), and with the rail terminals at PLAZA (Zaragoza) and Nonduermas (Murcia), which specialises in perishable goods. Nevertheless, in terms of decarbonisation, it is estimated that 88% of goods are transported by road and just 12% by rail. In this regard, the port has no initiatives for cleaner transport, nor any green port charges or fees.

Ports and energy security

Over the past few decades, the Port of Bilbao has established itself as a key hub in energy supply chains. In this regard, it has a comprehensive infrastructure for loading, unloading, storage, transport, and distribution of these energy sources. As mentioned earlier, hydrocarbons form a key part of its operations (crude oil and its derivatives, as well as LNG and biofuels). It is also home to one of the three combined-cycle power stations in the province of Vizcaya, with a second located in the immediate vicinity. The transition towards sustainability is driving it to diversify into renewable energy, and as a result, it is currently home to projects involving hydrogen, other renewable fuels, and floating solar power.

Ports as hubs for marine energy

At the Port of Bilbao, the significance of liquid bulk cargo (primarily crude oil, its derivatives, and natural gas) is striking, accounting for 63% of the total cargo in 2024. This implies a very high degree of dependence on port activity, which, given possible future scenarios of the economy's decarbonisation, could place it in a precarious position. Consequently, it is essential to seek out new markets and new activities.

This is reflected in the allocation to Petronor of a plot for the construction of a plant to produce synthetic fuels from green hydrogen, generated using renewable energy, and, in a second phase, a plant to generate gas from urban waste (such as paper, cardboard, plastics,

textiles, etc.). Similarly, the Port of Bilbao's support for wind energy equipment manufacturers in the creation of logistics corridors, as well as its membership of the Wind Europe Ports Platform, could be cited as examples of the port's progressive adaptation to decarbonisation.

Ports as hubs of industrial activity

Although compared to other industrial ports, Bilbao's port is smaller and its industrial activity is less integrated and cohesive (for example, compared to Rotterdam's energy and petrochemical cluster), 87% of its area is under concession. The port hosts energy-related activity (a refinery, a regasification plant, a combined-cycle power station, a wind farm, fuel storage capacity, and transport and distribution capacity), as well as activity in the metal, automotive, and shipbuilding sectors. However, whilst its strategic plan focuses on making the port a benchmark for environmental performance, promoting the port's energy transition, and viewing environmental sustainability as a critical factor for competitiveness, it is necessary for this industrial sector to develop measures for industrial sustainability that go beyond promoting self-consumption.

6 Conclusions

The growth in international maritime trade and the resulting expansion of ports have significantly impacted the environment. As a result, ports are facing increasing pressure to meet regulatory and social requirements that will enable them to achieve environmental sustainability and support other links in the logistics chain in this endeavour, such as maritime and road transport. In this field, ports can act as drivers of the energy transition, decarbonisation, and environmental sustainability in two key areas. Firstly, by promoting more sustainable port operations and maritime transport, stakeholders can work together to advance the energy transition at sea and within port facilities. Furthermore, ports can act as links within maritime-port clusters, where they interact with stakeholders from different value chains who share common objectives and interests.

As the Port of Bilbao analysis shows, this framework highlights the port's progress toward sustainability. The results provide a holistic view of the transformation currently underway and suggest that, despite the difficulties, environmental sustainability is becoming a factor in the port's competitiveness. Nevertheless, there are still issues to be resolved.

One limitation of this analytical framework is that whilst it enables the mapping of port activities aimed at sustainable transition, it only allows for qualitative assessments and comparisons. Consequently, further research could explore transforming this qualitative model into a tool that incorporates environmental performance by translating the various categories into indicators. This would enable comparative studies of ports, which, beyond simple comparisons, could result in a ranking of their sustainability.

These results also open the possibility of applying this analytical framework to river and fishing ports as well as to multidisciplinary European projects related to ports and maritime transport, with a focus on environmental sustainability. In this regard, future research could analyse the scope of European projects, such as the European SmartDec project (About the project - SMARTDEC), which aims to contribute to a sustainable and competitive maritime sector, among others, thereby enabling an understanding of the scope and interrelationships of the initiatives to be developed.

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