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Adopting a Dynamic Business Modeling Perspective to pursue Sustainability in Seaport Performance Management: The Western Sicily Seaport Authority case study

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Abstract

Background: Ports play a crucial role in global trade, serving as essential hubs for the exchange of goods and services and significantly contributing to both national and local development by generating employment and fostering economic growth. However, beyond their economic relevance, port activities also pose significant environmental and social challenges, including noise pollution, greenhouse gas emissions, and waste accumulation. In recent years, awareness of these impacts and the need to mitigate them has led to the emergence of the concept of Port Sustainability, based on three dimensions: economic, social, and environmental. This concept has become a focal point in both international and national policies, as well as in academic debates. Achieving sustainability in seaports requires more than adopting isolated green initiatives; it necessitates a structural transformation that integrates sustainability into the core of strategic decision–making. Seaport performance management requires holistic, dynamic, and strategic frameworks that incorporate the three dimensions of sustainability into the seaport business model.

Purpose: Given this background, this study addresses the need to develop and adopt strategic frameworks that effectively integrate sustainability into seaport strategy design and performance management.

Methodology: This study proposes the adoption of a dynamic perspective to manage, develop, and guide port activities toward long-term sustainability goals by implementing the Dynamic Business Model for Sustainability (DBMfS). This business model integrates economic, social, and environmental dimensions into the management framework of these complex organizations, fostering value creation and promoting more responsible and sustainable operational practices. The DBMfS supports economic and social development while respecting the environment and the well-being of local communities. To illustrate the application of this framework, the research adopts a case study approach, focusing on the Western Sicily Seaport Authority.

Originality: This study aims to enrich the scientific debate on seaport performance management by providing both theoretical and practical contributions. From a theoretical perspective, it provides an integrated framework for embedding the three dimensions of sustainability into strategic performance management, addressing the need for strategic frameworks in the port sector. From a practical perspective, the DBMfS serves as a tool that seaport authorities can adopt to plan, implement, monitor, and manage their sustainable development path. By integrating environmental, social, and economic dimensions into seaport performance management, the DBMfS not only supports the achievement of sustainability goals but also enhances ports' long-term competitiveness in global trade. Furthermore, by adopting a dynamic and systemic perspective, which enables the identification of relationships between inputs, processes, outputs, and outcomes, it is possible to develop a set of key performance indicators (KPIs) that can be measured and monitored to assess the effectiveness of implemented strategies and achieve long-term sustainability goals. Finally, by applying the DBMfS to the selected case study, this research provides a replicable framework that can be adopted by other seaport authorities, serving as a strategic model for sustainable seaport management.

Keywords: Seaport Performance Management; Port Sustainability; Sustainable Development Goals (SDGs); Sustainable Business Models; Dynamic Business Model for Sustainability (DBMfS); System Dynamics.

List of acronyms

AdSP: Port System Authority (Autorità di Sistema Portuale)
AdSP MSO: Western Sicily Seaport Authority (Autorità di Sistema Portuale del Mare di Sicilia Occidentale)
AI: Artificial Intelligence
CLD: Causal Loop Diagram
DBMC: Dynamic Business Model Canvas
DBMfS: Dynamic Business Model for Sustainability
DEASP: Energy and Environmental Planning Document of the Port System
DPSS: Port System Strategic Planning Document
EU: European Union
GHG: Greenhouse Gas
ICT: Information and Communication Technology
IoT: Internet of Things
KPI: Key Performance Indicator
MIMS: Ministry of Infrastructure and Sustainable Mobility
MIT: Ministry of Infrastructure and Transport
OPS: Onshore Power Supply
PCS: Port Community System
PIAO: Integrated Plan of Activities and Organization
PNRR: National Recovery and Resilience Plan
POT: Three-Year Operational Plan
SBM: Sustainable Business Model
SD: System Dynamics
SDG: Sustainable Development Goal
SFD: Stock-and-Flow Diagram
TBL: Triple Bottom Line
UN: United Nations

1 Seaport performance management and sustainability

1.1 Introduction

The seaport sector plays a pivotal role in global trade, facilitating the transportation of more than 80% of the world's goods (UNCTAD, 2022; UNCTAD, 2023b).

Seaports serve as strategic infrastructures that not only support international commerce but also drive regional and national economic growth by generating employment, fostering industrial development, and enhancing logistics networks (Gavalas, 2024; UNCTAD, 2024).

They serve as vital crossroads for the exchange of goods and people, function as crucial logistics hubs, stimulate employment and industry, and play a significant role in tourism, contributing to the development of local economies. Furthermore, seaports are pivotal in shaping geopolitical dynamics and driving global competition, as nations vie to attract port investments, maritime traffic, and logistics operators.

However, the seaport sector is undergoing significant transformations due to modern challenges, such as globalization, digitalization, automation, environmental concerns, and security issues. These factors are reshaping governance models and operational priorities, compelling ports to innovate and adopt strategic management approaches that enhance efficiency, competition, and sustainability (Dooms & Vaggelas, 2023).

The growing environmental challenges of the twenty-first century, including air and water pollution, resource depletion, and ecological degradation, have raised significant societal concerns and redirected the focus of policies and scientific debate toward seaport sustainability (Gu et al., 2023).

Indeed, beyond their economic role, seaports also pose significant environmental and social challenges, including noise pollution, air pollution, and visual obstructions that cannot be ignored (Acciaro, 2015; Ducruet et al., 2024; Langenus & Dooms, 2018).

The primary concern related to the maritime transport system and port operations is the release of greenhouse gases (GHG) emissions into the water and atmosphere, which significantly contribute to climate change (Benamara et al., 2019; Lee et al., 2019). The need to mitigate the environmental and social externalities of ports while driving economic growth has led to the emergence of the concept of "Port Sustainability" (Lim et al., 2019).

Despite the growing attention to sustainability in national and international policies, its systematic integration into seaport performance management frameworks remains limited and fragmented.

Although many Port System Authorities (AdSPs) have adopted sustainable practices and new technologies to respond to regulatory pressures and environmental challenges, these efforts often lack cohesion and fail to be incorporated into long-term strategic planning and management (Ashrafi et al., 2019; Gavalas, 2024). Moreover, most existing research focuses predominantly on environmental sustainability, often overlooking the economic and social dimensions (Di Vaio & Varriale, 2018; Martins et al., 2024).

Achieving sustainability in ports requires a structural transformation in how business activities are conducted, incorporating dynamic, adaptive, and systemic strategies to ensure long-term viability (Gavalas, 2024).

To address these gaps, this research proposes a methodological framework that enables ports to integrate the three pillars of sustainability – environmental, social, and economic – into strategic planning and performance management: the Dynamic Business Model for Sustainability (DBMfS) (Cosenz et al., 2020). The adoption of a dynamic and sustainable business model, such as the DBMfS, can provide a viable path forward, ensuring that ports remain both economically competitive and environmentally and socially responsible.

To demonstrate the practical application of the DBMfS, this research adopts a case study approach, focusing on the Western Sicily Seaport Authority (AdSP MSO), one of the 16 AdSPs within the Italian Seaport System.

This chapter provides a comprehensive overview of the seaport sector, analyzing its performance, regulatory framework, and sustainability dimensions. The analysis will focus on EU ports, with particular attention to Italian ports, which operate within the broader EU regulatory and economic framework. This approach ensures a clear contextualization of the case study. Given the shared characteristics of Italian ports, their analysis must be conducted within the European framework, as EU regulations significantly influence their operations, particularly in terms of sustainability policies and governance structures.

This chapter is structured as follows:

- Section 1.2 explores the historical evolution of seaport management, tracing key transformations in port operations and governance.
- Section 1.3 presents key statistics on European port performance, with a focus on Italian seaport performance, highlighting the economic significance of the sector.
- Section 1.4 examines the regulatory framework shaping port governance, with a focus on European and Italian policies promoting sustainability.
- Section 1.5 discusses the three pillars of seaport sustainability – economic, social, and environmental – and their interconnections. It also examines the role of seaports in advancing the United Nations (UN) Sustainable Development Goals (SDGs) and

integrating Environmental, Social, and Governance (ESG) principles into port management. Additionally, the section discusses the sustainability initiatives, tools, and technologies that ports implement to enhance environmental performance, operational efficiency, and long-term resilience.

- Section 1.6 examines the complexity of performance management systems, highlighting the importance of dynamic strategic frameworks.
- Section 1.7 summarizes key insights and outlines the research questions that guide this study.

By providing an in-depth exploration of the sustainability challenges and opportunities in the seaport sector, this chapter lays the foundation for the subsequent development of a strategic framework for sustainable seaport performance management.

1.2 The evolution of seaport management

Seaport management has been a key topic in policy discussions and academic literature for decades (Bucak et al., 2020; Dooms, 2014). Ports represent a fundamental pillar of a country's economic development and international trade (Bergantino et al., 2013; Confetra, 2024). Their history dates back to the early days of human civilization when maritime trade emerged alongside the development of society. Seaports have historically served as critical gateways for the movement of goods and people to and from the sea (Sargent, 1938).

Over time, seaports evolved from simple trading hubs into dynamic, multifunctional infrastructures integral to global supply chains (Notteboom, 2016). Geographic, economic, and technological factors have shaped this evolution.

Ports differ significantly in size and function based on their geographic location and contextual factors. Seaports can be situated in urban or remote areas, along natural coastlines, or engineered sites such as estuaries and canals. Geographical location directly influences requirements, as well as environmental and safety considerations, including dredging, breakwaters, locks, and pilotage (ESPO, 2014).

The scale of a port – determined by its area, annual cargo throughput, hinterland reach, and number of connected shipping services – establishes its economic and commercial significance, with larger ports often serving as gateways for entire economic regions.

Historically, the primary function of ports has been to facilitate trade and the exchange of goods between different regions, thereby promoting economic growth and development. Strategically located along coasts and navigable rivers, ports have served as key access and distribution points for imported and exported goods, facilitating large-scale exchanges of essential resources, including food, raw materials, manufactured goods, and luxury products. Additionally, ports functioned as docking points for military ships and as shelters for vessels during storms.

Today, globalization has reshaped the functions and structures of seaports, pushing them beyond traditional roles to address increasing competition (Haralambides, 2017).

Globalization has transformed seaport roles into complex nodes within global supply chains, characterized by the functional and spatial clustering of transportation, transformation, and information processes (Notteboom, 2016).

Moreover, technological advancements, particularly in automation, data analytics, and Artificial Intelligence (AI), are reshaping the seaport sector. Seaports are increasingly adopting these technologies to enhance decision-making, optimize shipping safety and efficiency, and reduce operational costs (Economist Impact, 2023). The integration of these technological solutions is increasing productivity by creating more automated, digitized, and connected supply chains (Deloitte, 2020). As a result, ports have evolved from static loading and unloading sites to dynamic platforms offering integrated logistics, distribution, and production services (Notteboom et al., 2022). These technological advancements have radically transformed port operations, enhancing efficiency, coordination, and adaptability and positioning modern seaports as key nodes in global supply chains (Notteboom & Haralambides, 2020).

However, while new technologies have led to significant improvements, digitalization also presents challenges. Ports must now manage vast amounts of data generated by digital tools, develop advanced data management capabilities, and build a skilled workforce capable of operating these advanced technologies. Addressing these challenges requires substantial investments in training and reskilling (ESPO, 2024).

Consequently, the role of ports has expanded significantly. Some ports have evolved into industrial complexes, hosting activities related to processing and transport, thereby contributing to the economic growth of the surrounding area. Additionally, port functions have become increasingly diversified and specialized, with some ports dedicated exclusively to containerized or bulk cargo. In contrast, others focus on passenger traffic, such as cruises and ferries, or port-related industries like the automotive sector (Notteboom et al., 2022).

Modern seaports have several functions that can be categorized into four main groups (Dooms & Vaggelas, 2023; Notteboom et al., 2022):

- Transit Hubs: seaports facilitate the movement of cargo, ensuring that goods reach their final destinations efficiently. Some ports also operate as transshipment hubs, linking broader regions and supporting global trade flows by enabling cargo transfers between vessels.

- Logistical Centers: seaports serve as key logistics hubs (Jakomin, 2003), offering critical services such as storage, distribution, and a range of additional logistics solutions. These services significantly enhance the efficiency and effectiveness of port operations, making them indispensable in the supply chain.
- Industrial Production Sites: many seaports house large industrial clusters, including sectors such as chemicals, steel, automotive, and food processing. These industries benefit from direct maritime connections, enabling efficient operations. In recent years, ports have also increasingly supported energy production and distribution, reflecting the shift towards renewable energy (GoComet, 2024).
- Passenger Traffic Centers: seaports play a crucial role in passenger transport, supporting coastal and cruise tourism, especially in island nations. By facilitating this type of traffic, ports contribute to local economies and promote tourism in nearby areas.

Seaport activities, as highlighted in the literature and official statistics (Eurostat, 2024; Rodrigue, 2024; UNCTAD, 2024), also vary depending on the type of traffic handled, reflecting the diverse operational and strategic needs of ports:

- Passenger Transport: one of the primary activities for many ports, particularly those located in areas with a strong tourism focus or characterized by robust regional and local connections. This category encompasses both local and regional transportation, including ferries used for daily or regular travel, as well as cruise traffic. Cruise traffic serves as a significant attraction for international tourism and constitutes a key source of revenue for local economies.
- Cargo Transport: encompasses all goods moved either in bulk or packaged form. Liquid bulk encompasses oil, natural gas, chemicals, and other liquid substances, whereas dry bulk refers to solid bulk materials, including minerals, coal, and agricultural products. Cargo transport plays a crucial role in supplying industries, facilitating international trade, and ensuring the efficient operation of logistics chains.
- Container Traffic: essential for international trade, facilitating the efficient transportation of industrial goods and finished products across long distances.
- Ro-Ro Traffic: involves the transportation of vehicles and mobile goods, including trucks, cars, and trailers. This type of traffic is particularly prominent in intra-European trade, where its flexibility and speed make it ideal for short-distance connections and integrated logistics networks.

Institutionally, many port authorities have transitioned into independent commercial entities, focusing on profitability and customer service. This shift reflects an increasingly market and business-oriented approach necessary to respond to global competitive pressures and maintain port efficiency.

Governance structures, often characterized by public ownership with privately operated terminals, play a crucial role in balancing public and private interests while adhering to regulatory and sustainability standards (Notteboom & Haralambides, 2020).

European seaports are characterized by a complex structure that involves both public and private actors, balancing economic objectives – such as ensuring the financial sustainability of the port, maximizing added value, and optimizing port traffic – with broader societal goals. These include facilitating trade and business, fostering the economic and social development of surrounding regions, and ensuring the long-term sustainability of port activities. This governance model requires maintaining an equilibrium between economic growth, social well-being, and environmental responsibility (Assoporti, 2016).

Given these factors, seaport management has evolved from a predominantly operational role to a strategic and multidimensional function. Ports no longer operate as isolated entities but as integrated nodes in global supply chains, coordinating maritime and land transport activities and serving as platforms for international trade and transportation (Notteboom et al., 2022). In a globalized context, ports must quickly adapt to trends in trade and economic conditions to remain competitive (Dooms & Vaggelas, 2023; UNCTAD, 2024). They not only compete to attract cargo flows but also to secure investments, as well as logistics operators and industries that contribute to the economic development of the port area. Additionally, they must contend with the infrastructure of other countries to capture international trade routes. Competition exists not only among ports within the same region or maritime area but also between ports serving overlapping hinterlands. Furthermore, competition can arise within individual ports themselves. Seaports also face pressure from alternative modes of transportation, such as rail and air freight. Globalization and increasing competition between ports have led to significant changes in port management strategies, prompting ports to develop new approaches to remain competitive in the global supply chain (ESPO, 2014).

This complexity is heightened by the fact that ports must navigate an increasingly challenging economic, social, and environmental landscape where responsibilities and challenges continually arise. To meet the demands of contemporary markets and society, ports must proactively address these challenges by adopting sustainable practices and promoting the well-being of the communities they serve (ESPO, 2014).

Additionally, seaport operations contribute to emissions in both water and air, exacerbating climate change (Benamara et al., 2019). This critical issue must be addressed to preserve the planet (Del Giudice et al., 2021). Air and sea pollution, as well as noise generated by port activities, can negatively impact the quality of life in the surrounding areas. As environmental concerns become increasingly pressing, ports must strike a balance between operational efficiency and social and environmental responsibility (Benamara et al., 2019; Dooms & Vaggelas, 2023).

In recent decades, both the political and scientific communities have increasingly focused on the environmental impacts of ports, as maritime transport accounts for a substantial and growing share of greenhouse gas emissions. Moreover, ports – often situated in densely populated areas – must address the challenge of gaining acceptance from local communities living nearby (Enel X & Legambiente, 2021).

Over the past decade, however, regulatory authorities and port sector experts have prioritized the identification of systems to measure, monitor, and manage environmental sustainability indicators in ports. These efforts aim to mitigate the negative externalities of operations on water and air, as well as to improve waste management (Di Vaio et al., 2018).

The focus on the environmental impacts of port activities, combined with increasing regulatory pressures to reduce emissions and the growing demand for environmental accountability, is reshaping the role, operations, and management of ports. Rising expectations for transparency and corporate responsibility – driven in part by public awareness and the influence of younger generations –are pushing ports to adopt stricter environmental standards and implement technologies that minimize their ecological footprint. As a result, ports are increasingly investing in green technologies, striving to strike a balance between operational efficiency and measures that reduce pollution, protect marine ecosystems, and support biodiversity (Deloitte, 2020; Economist Impact, 2023).

In summary, modern seaport management extends beyond traditional loading and unloading operations, requiring integrated strategies that leverage advanced technology, sustainability initiatives, and infrastructure improvements. These integrated strategies enable ports to remain globally competitive and better equipped to meet the evolving needs of international trade while also ensuring that their operations are environmentally responsible and socially beneficial.

Regardless of their size, location, or specialization, ports must manage a wide range of activities, including ship security, berthing, unloading, cargo handling, and the transit of goods through canals and channels. In this context, seaport management involves organizing, monitoring, and controlling seaport activities in an increasingly complex and competitive global industry. The goal is to achieve operational efficiency while aligning with regional and national priorities, ensuring that seaports remain adaptable and resilient in the face of the challenges posed by global trade (Burns, 2015).

The evolution of seaport performance management reflects the complexities and challenges faced by the sector in an era of rapid technological change, global competition, and increasing environmental and social demands. The role of seaport management has expanded to encompass strategic decision-making, with a focus on integrating technological, environmental, and economic considerations.

Ports must strike a balance between efficiency and sustainability, reducing emissions, protecting marine ecosystems, and maintaining their competitiveness on the global stage. As such, modern seaport management necessitates a holistic approach, combining operational excellence with sustainability, resilience, and adaptability to meet the evolving needs of international trade and society as a whole. As a result, modern seaport management has become an intricate and multifaceted task, requiring proactive and strategic management to navigate the challenges of the 21st century.

In this context, understanding, assessing, and managing port performance have also evolved, reflecting the increasing complexity of environmental, social, and economic challenges. Once seen as a combination of two interconnected components– efficiency and effectiveness (Notteboom et al., 2022)– port performance is now recognized as a multidimensional concept (Bucak et al., 2020), encompassing key aspects such as governance, resilience, and environmental sustainability (UNCTAD, 2023a).

As hubs handling diverse cargo, interacting with urban areas, and responding to a broad range of stakeholders, ports must adopt management frameworks that integrate sustainability into strategic decision-making and performance evaluation (Bucak et al., 2020).

In summary, seaport management has evolved into a strategic and multidimensional function that balances efficiency, sustainability, and resilience. As the seaport sector faces increasing complexity, it requires proactive strategies to navigate global challenges while positioning ports as essential nodes in international trade.

Given these dynamics, the following section provides a comprehensive overview of seaport performance in Europe, with a focus on Italian seaports. It outlines key trends, analyzes traffic and passenger flows, and offers insights into their current status and challenges.

1.3 The seaport sector

1.3.1 EU seaports

The maritime sector is fundamental to Europe's economic vitality, as it facilitates trade, tourism, and connectivity across the continent and beyond (ESPO, 2024). European seaports serve as key drivers of economic growth (ESPO, 2014), as they represent critical pillars of international trade and act as strategic gateways for the transport of goods across continents.
They serve as catalysts for a wide range of economic activities, including cargo handling, freight transportation, industrial production, and retail commerce.
Ports coordinate a complex system that drives the economic engine of the continent, fostering international investment and cultural exchange (GOComet, 2024).
Approximately three-quarters of all international trade to and from the EU is transported by sea, making maritime transport the backbone of the EU's economy (European Maritime Safety Agency, 2024). Between 2016 and 2023, EU external merchandise imports and exports amounted to billions of tonnes of goods. As shown in Figure 1, seaborne transport significantly surpasses other transport modes in terms of volume, highlighting the indispensable role of maritime logistics (Eurostat, 2024).

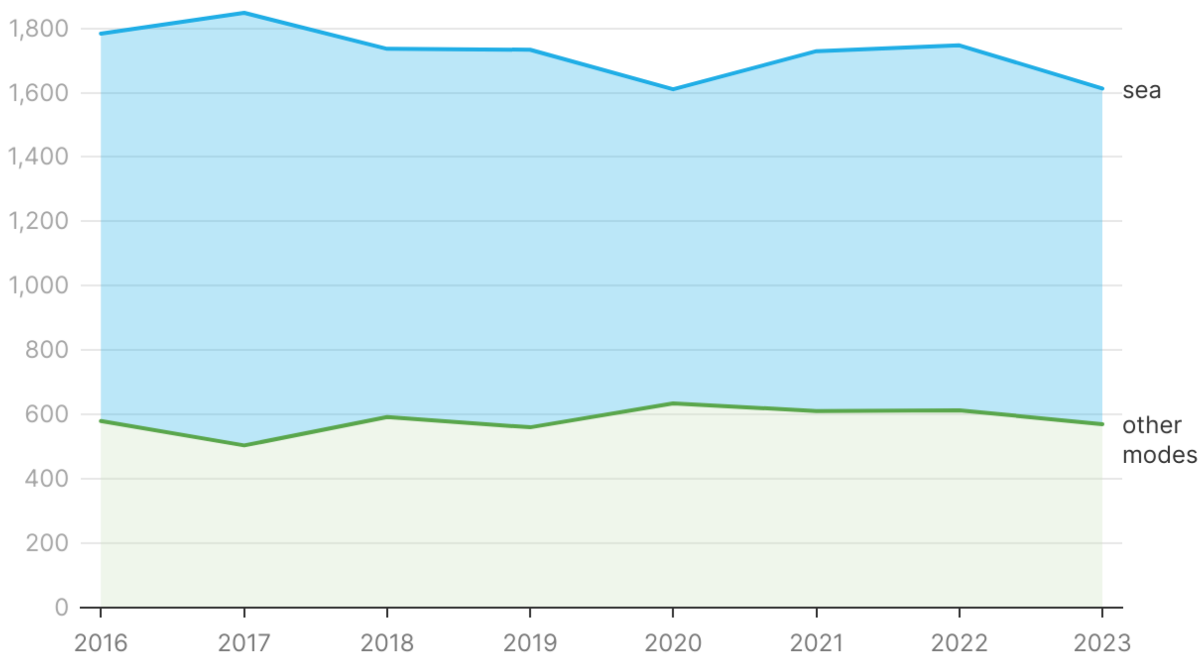

Figure 1. EU external trade per mode (weight). EU external total merchandise imports and exports in million tons from 2016 to 2023.

Source: European Maritime Safety Agency (2024).

EU ports handle vast volumes of cargo annually, generating employment opportunities for thousands of people and serving as essential nodes within both national and global supply chains. They represent the pillars of the maritime sector. Without ports, the maritime transport sector would not exist (European Maritime Safety Agency, 2024).

As illustrated in Figure 2, the total gross weight of goods handled by EU ports was estimated at 3.4 billion tonnes in 2023, representing a 3.9% decline from 2022 (Eurostat, 2024).

This reduction is primarily attributed to trade restrictions imposed on Russia following the escalation of geopolitical tensions. Although port freight activity showed signs of recovery after the COVID-19-induced downturn in 2020, freight levels in 2022 remained slightly below those of 2018. The overall trend since 2014 has been positive, reflecting a steady recovery from the economic downturn triggered by the 2009 financial crisis. However, recent global disruptions, such as pandemics and geopolitical conflicts, highlight the vulnerability of maritime logistics to external shocks (Eurostat, 2024).

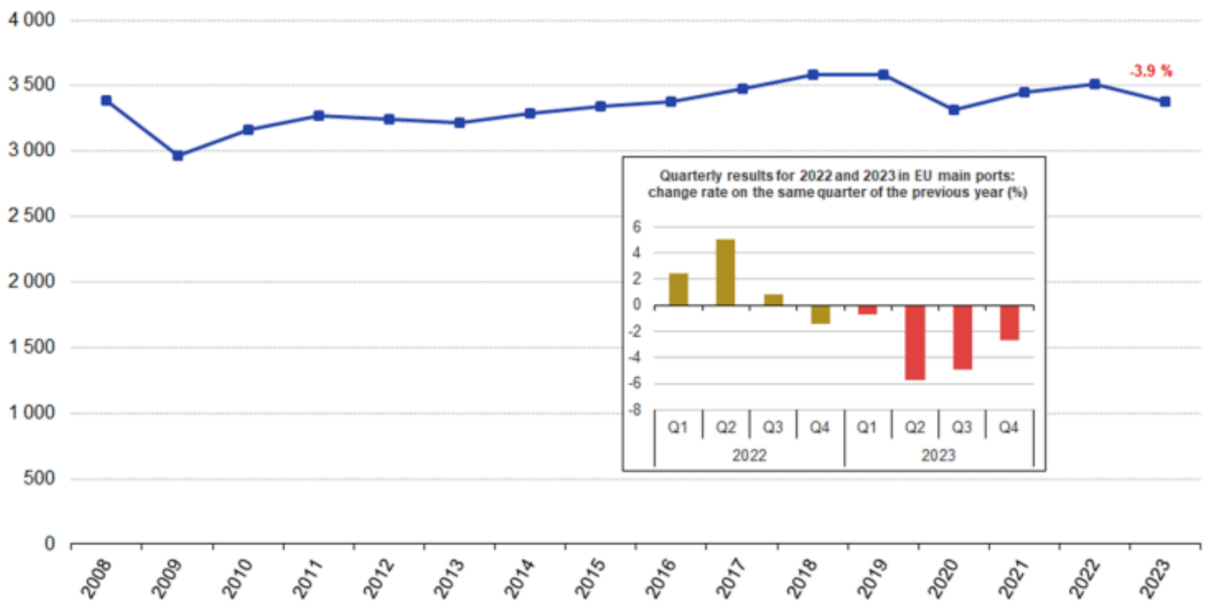

Figure 2. The gross weight of seaborne goods handled in all ports, EU, 2008-2023 (million tonnes).

Source: Eurostat (2024). Maritime Transport of Goods - Annual Data.

In 2023, the Netherlands remained Europe's leading maritime nation, handling 545 million tonnes of seaborne goods, which accounted for 16.1% of total EU cargo. It was followed by Italy (14.8%) and Spain (14.0%), as shown in Figure 3 (Eurostat, 2024).

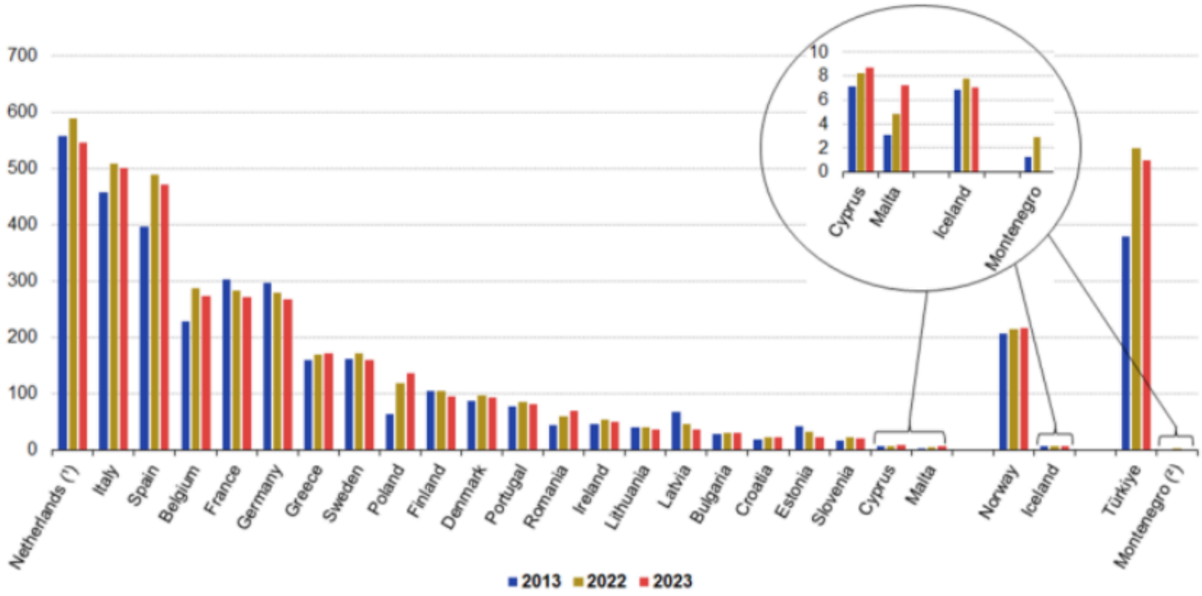

Figure 3. Gross weight of seaborne goods handled in all ports, 2013, 2022 and 2023 (million tonnes)

Source: Eurostat (2024). Maritime Transport of Goods - Annual Data.

In 2023, liquid bulk cargo accounted for 37.9% of total cargo handled in major EU ports, followed by containerized goods (22.7%), dry bulk goods (21.6%), and Ro-Ro traffic (12.7%) (Eurostat, 2024). In the liquid bulk segment, the Netherlands led with 265 million tonnes, followed by Italy (205 million tonnes) and Spain (175 million tonnes). In the dry bulk sector, Dutch ports led with 130 million tonnes, followed by Spain with 98 million tonnes, and Romania, which accounted for 60.6% of the total tonnage due to its significant agricultural exports. Spain and the Netherlands dominated the containerized goods segment, handling 145 million tonnes and 105 million tonnes, respectively. Finally, in the Ro-Ro transport segment, which is crucial for facilitating the movement of vehicles and rolling cargo, Italy led with 113 million tonnes. According to Eurostat data, in the first quarter of 2024, major EU ports handled 809.1 million tons of cargo, indicating positive growth in traffic volumes. Rotterdam maintained its leadership, handling 99.9 million tonnes, followed by Antwerp-Bruges (63 million tonnes) and Hamburg (23.8 million tonnes) (Eurostat, 2024).

Another significant segment that reflects the scale and significance of the port sector is passenger traffic, as depicted in Figure 4.

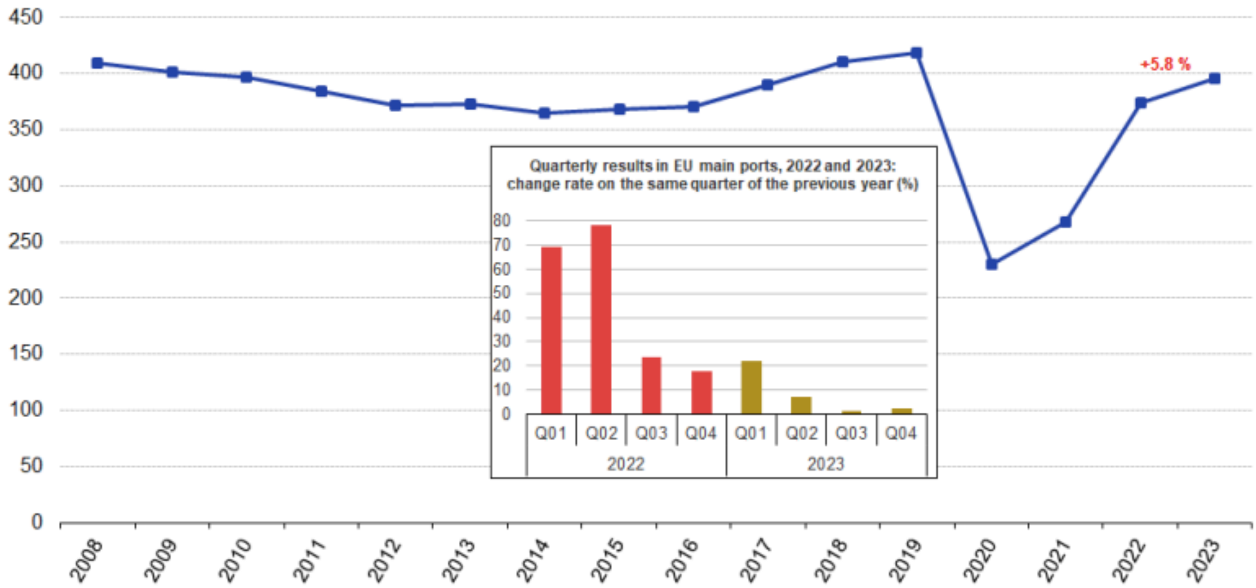

Figure 4. Seaborne passengers embarked and disembarked in all EU ports, 2008-2022 (million).

Source: Eurostat (2024). Maritime passenger statistics.

Passenger transport has shown a post-pandemic recovery, reaching 395.3 million passengers in 2023, with Italy ranking first at 85.4 million. The cruise sector has surpassed pre-COVID levels, with 16.4 million passengers, 72% of whom traveled through Italy, Spain, and Germany (Eurostat, 2024).

Key statistics underscore the pivotal role of European ports, not only in global trade but also in connectivity and tourism, which collectively make a significant contribution to the EU economy.

1.3.2 Italian seaports

With a 7,456 km coastline, Italian ports play a crucial role in the national economy, facilitating international trade, driving regional development, and contributing significantly to the country's GDP.

Italy has 58 major ports, organized into 16 AdSPs, which are public entities responsible for managing and organizing goods and services within their respective port areas. The Italian port system generates an added value of approximately €64.7 billion, accounting for 3.7% of the national GDP, and employs 1 million workers, representing 4% of Italy’s total workforce (Randstad, 2024).

Thanks to its strategic position in the Mediterranean, Italy is highly dependent on its ports for both imports and exports, with 40% of the country's total trade passing through maritime routes. Bordered by the Adriatic, Ionian, Tyrrhenian, and Ligurian Seas, Italy serves as a vital maritime hub. Its proximity to the Suez Canal and the Strait of Gibraltar further strengthens its role as a key connector between Europe, Asia, and North Africa. Italian ports hold strategic positions along major transportation routes, handling substantial volumes of both cargo and passenger traffic.

In 2022, Italian ports managed 490 million tonnes of goods and served 61 million passengers (Assoporti, 2022). Italy also plays a dominant role in short-sea shipping in the Mediterranean and ranks first in Europe in terms of cruise passenger numbers (Randstad, 2024).

In 2023, Italian ports handled 473 million tonnes of cargo, reflecting their significance in global shipping, although this marked a slight decline of 3.2% from 2022 (Assoporti, 2024).

In 2023, liquid bulk accounted for 35% of maritime traffic, Ro-Ro traffic represented 26%, and container traffic made up 24% (Manageritalia, 2024).

Italian ports handled a total of 6,943,468 twenty-foot equivalent units (TEU) in 2023, with the Port of Genoa managing 2,176,561 TEU. Meanwhile, transshipment traffic expanded, particularly in Gioia Tauro and Trieste (Shipping Italy, 2024).

However, commodity trends exhibited some notable variations: liquid bulk traffic experienced a slight decline of 1%. In comparison, solid bulk traffic recorded a significant 15.1% drop, primarily due to reduced coal consumption and industrial slowdowns.

Conversely, passenger traffic recorded robust growth, reaching 70,849,072 passengers, with increases in local traffic (+10.9%), ferry passengers (+9.8%), and cruise passengers (+48.3%) compared to 2022. Notably, cruise passengers totaled 13.35 million, surpassing pre-COVID levels (Shipping Italy, 2024).

The analysis of traffic volumes in Italian ports in 2023, conducted by Shipping Italy (2024), underscores the strategic importance of Italian ports in both trade and passenger transportation. Despite the strong performance of the Italian port sector, several key challenges need to be addressed to ensure long-term competitiveness. In particular, Italian ports require significant upgrades to enhance logistical efficiency and reduce cargo handling times, which remain higher than in other major EU ports (Assoporti, 2024; Manageritalia, 2024).

Moreover, greater investments in port digitalization and automation are crucial for streamlining freight and passenger traffic management, thereby improving operational efficiency (Randstad, 2024).

This comprehensive analysis of EU and Italian seaports highlights their economic significance, their role in international trade, and the need for resilience in the face of trade fluctuations and geopolitical shifts.

To sustain their strategic role, ports must implement resilience-focused strategies, invest in digitalization, and adopt dynamic management models that allow them to swiftly adapt to shifts in global trade patterns, ensuring long-term competitiveness in the international market.

However, while economic performance remains a priority, it must be pursued without compromising environmental and social well-being. This requires a fundamental shift in port management strategies toward sustainability.

The intensity of maritime operations, although economically significant, also presents critical environmental and social concerns. From an environmental perspective, the port industry is an essential contributor to air pollution and greenhouse gas emissions, necessitating the implementation of sustainable measures. Additionally, port activities generate marine pollution, waste management challenges, and noise pollution, all of which impact coastal communities and biodiversity. (European Commission, n.d.; ESPO, 2024; Transport & Environment, 2022).

Recognizing these challenges, regulatory frameworks have increasingly focused on integrating economic efficiency with environmental and social sustainability. Ports now operate within a complex legislative environment where compliance with green regulations and the adoption of corrective measures are essential to mitigating their negative externalities.

The following section will examine the regulatory landscape, analyzing how Italian regulations within the broader EU normative framework influence the pursuit of economic efficiency, environmental sustainability, and social responsibility in the port sector.

The regulatory analysis will highlight the increasing legislative focus on sustainability, driven by the growing awareness of the significant externalities generated by port activities and the necessity to implement corrective measures to mitigate these effects.

It will also outline key regulatory priorities, emphasizing the strategies necessary to enhance economic efficiency, environmental protection, and social responsibility in the port sector.

1.4 Regulatory framework

A comprehensive analysis of the regulatory framework governing ports and port activities is crucial for understanding the structural characteristics of the sector, as well as the key regulatory priorities that shape its evolution.

These regulations have a significant impact on the strategic decisions and management approaches adopted by port authorities and operators.

The port regulatory system is complex and multi-level, as it derives from numerous sources reflecting the involvement of multiple entities with legislative and administrative powers in this domain. This complexity highlights both the strategic importance of the sector and the challenges associated with its regulation and management.

The comprehensive regulatory framework under analysis aims to ensure the competitiveness of the port system in the global context, promote environmental and social sustainability in port activities, and enhance the operational and managerial efficiency of port infrastructure. These aspects are critical factors for the growth of the port sector and its ability to adapt to evolving logistics scenarios and the ecological transition.

At the European level, the regulation of the port sector is designed to establish a competitive and transparent system, ensuring a balance between economic development and environmental sustainability. A key regulatory act in this context is Regulation 2017/352, which introduces a common legal framework for EU seaports.

This regulation aims to foster a competitive, transparent, and efficient environment, promote financially responsible management by AdSPs, and encourage operational efficiency through a more effective use of resources.

EU Regulation 2017/352 highlights the strategic importance of European ports in the global economy. It serves as a crucial instrument for enhancing their competitiveness and efficiency, thereby laying the groundwork for closer integration between the EU port system and sustainable development strategies.

In Italy, seaports are classified as public domain assets, meaning they are inalienable state-owned properties designated for navigation purposes (Assoporti, 2007).

Their governance underwent substantial reform with the enactment of Law No. 84 of January 28, 1994, which represented a significant milestone in the modernization of the Italian port system. This law introduced provisions that fundamentally restructured its organizational and managerial framework.

The Law established Port Authorities – now AdSPs –, which are public entities responsible for planning and developing port infrastructure, to modernize the seaport system and enhance its competitiveness.

A key provision introduced by the law was the distinction between regulatory functions related to infrastructure management and operational activities, such as cargo handling, which were delegated to private operators. This approach facilitated the private sector involvement in port operations, transforming Port Authorities into entities focused on regulation, oversight, and strategic development.

Additionally, the law introduced a concession system for the use of port areas and the execution of operational activities, which were allocated based on predefined criteria and subject to compliance with quality and safety standards.

The Port Master Plan, also mandated by law, serves as a key instrument for the long-term planning of port infrastructure development.

The main objectives of Law No. 84/1994 include:

- Modernizing the Italian port system to enhance its competitiveness;
- Promoting operational efficiency through private sector involvement and autonomous management;
- Fostering local economic development through infrastructure improvements;
- Ensuring transparency and safety in operations while enhancing working conditions and refining operational procedures.

In summary, Law No. 84/1994 initiated a process of liberalization and modernization, laying the foundations for the current organization of Italian ports, which was further reformed by Legislative Decree No. 169 of August 4, 2016 (Confetra, 2024).

This Decree introduced significant benefits to the sector by fostering fair competition and promoting the development of an institutional and operational framework aligned with European regulations. It profoundly transformed the port system to enhance the competitiveness, efficiency, and governance of national ports.

A key aspect of the 2016 reform was the replacement of the former Port Authorities with the AdSPs, entrusted with balancing public interests while ensuring efficient and strategic management aimed at attracting investments and improving services.

Additionally, the reform reduced the number of port authorities from 24 to 16 AdSPs, each responsible for a system of ports within specific geographic areas. These newly established AdSPs, replacing the former Port Authorities, oversee the governance and strategic development of ports under their jurisdiction. This centralized governance model aims to enhance integration between ports and their surrounding territories while promoting economic and logistical development at both national and international levels.

In this context, the Ministry of Infrastructure and Sustainable Mobility (MIMS) plays a central role in supervising and coordinating the AdSPs. It is responsible for appointing the President of each authority, in agreement with the relevant regional administrations, and for requiring the preparation of a Three-Year Operational Plan (POT), which outlines the strategic and operational objectives.

The primary objective of the 2016 Legislative Decree is to enhance the international competitiveness of Italian ports by simplifying administrative procedures and fostering investment and innovation. To this end, the Decree mandates collaboration between AdSPs, logistics operators, customs authorities, and other institutions to optimize transport flows, reduce cargo handling times, and promote environmentally sustainable practices and infrastructure. These measures include the adoption of green technologies, the electrification of docks, and initiatives aimed at reducing emissions.

Legislative Decree No. 169 of August 4, 2016, as amended by Legislative Decree No. 232 of December 13, 2017, requires AdSPs to draft the Energy and Environmental Planning Document for the Port System (DEASP). This document is developed based on guidelines jointly issued by the Ministry of the Environment and the Protection of Land and Sea, as well as the Ministry of Infrastructure and Transport (MIT). It defines the strategic directions and measures aimed at improving energy efficiency and promoting the use of renewable energy sources within the port sector (Enel X & Legambiente, 2021).

National regulatory interventions for port sustainability are embedded within a broader international framework that seeks to balance economic development with environmental and social protection, fostering the transition of the maritime sector toward more sustainable models. In particular, regulatory measures aimed at mitigating the environmental impacts of seaports have significantly increased in recent years (Di Vaio & Varriale, 2018; UNCTAD, 2024).

At the global level, a central role is played by the International Maritime Organization (IMO), the United Nations agency responsible for regulating international shipping, which has significantly intensified its efforts to reduce GHG emissions. A major milestone in this process is the adoption of the 2023 IMO GHG Strategy, which provides an ambitious framework for the decarbonization of maritime transport. The strategy establishes a long-term vision under which international shipping should reach net-zero GHG emissions “by or around 2050,” while ensuring a just and equitable transition (IMO, 2023a; IMO, 2023b).

In addition to this long-term vision, the strategy sets out quantitative emission-reduction targets and indicative checkpoints guiding the transition pathway. Specifically, the IMO calls for:

- a reduction of at least 40% in CO_2 emissions per transport work by 2030 compared to 2008;

- the uptake of zero- or near-zero GHG emission fuels, technologies, and energy sources to represent at least 5%—striving for 10%—of the energy used by international shipping by 2030;
- a reduction in total annual GHG emissions of at least 20%, striving for 30%, by 2030 (relative to 2008 levels);
- a reduction in total annual GHG emissions of at least 70%, striving for 80%, by 2040 (relative to 2008 levels);

Overall, the 2023 IMO GHG Strategy has become a foundational governance instrument for the environmental regulation of the maritime sector, providing a strategic reference for port authorities as they plan investments, modernize infrastructure, and adopt management frameworks that support long-term decarbonization and enhance climate resilience.

The European Union has identified the decarbonization of maritime transport as one of its top priorities under the European Green Deal, aiming to reduce emissions in the transport sector by 90% by 2050.

Among the regulatory instruments designed to reduce emissions in maritime transport, the FuelEU Maritime Regulation establishes maximum emission limits for ships over 5,000 gross tons, with a 2% reduction target by 2025 and an 80% reduction goal by 2050. Additionally, the regulation requires a mandatory connection to an onshore power supply (OPS) while ships are docked in ports, aiming to minimize emissions during port operations (Manageritalia, 2024).

Furthermore, EU Directives 2014/94 and 2016/802 promote the development of alternative fuel infrastructures and cold ironing systems, helping to mitigate the environmental impact of port activities.

At the national level, the National Recovery and Resilience Plan (PNRR) focuses on three main dimensions (Manageritalia, 2024):

- Digitalization;
- Environmental sustainability, including investments in shore power electrification, energy efficiency, maritime accessibility, and climate resilience;
- Intermodality and integrated logistics, with investments aimed at enhancing port capacity.

Specifically, the Complementary Fund to the PNRR, which allocates a total of €2.86 billion to the port sector for strategic interventions (as outlined in Decree-Law No. 59/2021), has earmarked funds for the MIMS to support fleet renewal, improved maritime accessibility, infrastructure resilience to climate change, and shore power electrification, thereby reducing the use of auxiliary engines while ships are docked (Camera dei Deputati, 2022).

In conclusion, the analysis of the port regulatory framework highlights the presence of a multi-level governance structure that seeks to balance economic, environmental, and social priorities within the port sector.

Recent regulatory developments reflect a clear shift toward sustainable transition, requiring ports to adopt greener practices and increase investments in technological innovation. The evolving regulatory landscape underscores the strategic significance of the port sector and its increasing commitment to modernization, competitiveness, and sustainability, thereby laying the groundwork for a more efficient, integrated, and environmentally and socially responsible port system.

In particular, the integration of environmental regulations and decarbonization strategies demonstrates how ports are evolving to address climate change challenges and drive the ecological transition. The growing focus on sustainability in ports aligns with a broader transformation of the maritime sector, where ESG principles and technological innovation are playing a central role. The increasing relevance of ESG principles underscores the need for AdSPs to adopt strategic and managerial frameworks that effectively integrate economic growth, environmental protection, and social responsibility.

To ensure that seaports are not only economically efficient but also environmentally and socially sustainable, a comprehensive strategic management approach is required that harmonizes economic, environmental, and social dimensions.

The next section will explore the concept of port sustainability, examining the growing role of ports in the ecological transition and their contribution to achieving the UN SDGs. It will also address the key environmental challenges associated with port activities, including GHG emissions, air and marine pollution, and resource consumption. Finally, the section will assess the impact of new technologies and digitalization in optimizing port operations and minimizing environmental impact, outlining future perspectives for a more sustainable and efficient port management system.

1.5 Seaport sustainability

1.5.1 Port sustainability: the Triple Bottom Line approach

In the twentieth century, increasing pollution, resource depletion, and climate change emerged as critical global challenges for society, sparking an international dialogue on the urgent need for sustainability. As these issues became more pronounced, threatening the well-being of both present and future generations, sustainability evolved into a global priority (World Commission on Environment and Development, 1987). It has taken center stage in the development strategies of all industries, emphasizing the necessity for a comprehensive approach that harmonizes economic, social, and environmental objectives (Gu et al., 2023; Roh et al., 2021). The concept of sustainability originates from the concept of “sustainable development”, defined by the World Commission on Environment and Development (1987) as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Built on three pillars – economic, social, and environmental – sustainable development seeks to achieve, in a balanced manner, economic development, social development, and environmental protection (Elkington, 1998; Karimpour, 2024; Loviscek, 2020).

This three-pillar approach, commonly known as the “Triple Bottom Line” (TBL), emphasizes the necessity for businesses and industries to evaluate their performance not only in terms of economic profitability (profit) but also in terms of their environmental impact (planet) and social impact (people) (Elkington, 1998).

This concept has gained increasing relevance across various industries, including the seaport industry, which plays a critical role in global trade but also generates significant environmental and social externalities (Acciaro, 2015).

Indeed, although seaports play a crucial role in the global economy, serving as critical nodes for the transportation of goods and people, generating significant wealth, fostering investments, and supporting the logistics and supply chain industries, they have considerable environmental and social costs (Notteboom et al., 2022).

Maritime transport and port-related activities pose serious risks to both human health and the environment, as they involve the use of diesel-fueled machinery, which releases airborne pollutants such as GHGs, including carbon dioxide (CO_2) and nitrogen oxides (NO_x), and sulfur oxides (SO_x), and particulate matter (PM) (Ducruet et al., 2024; Gu et al., 2023; Sadiq et al., 2021).

In 2018, GHG emissions from European maritime transport accounted for 13.5% of the total emissions from the EU transport sector (Transport & Environment, 2022). Additionally, maritime activities in European ports generated approximately 140 million tonnes of CO_2, accounting for around 3-4% of the EU's total emissions (European Environment Agency, 2021). In 2019, ships calling at European ports released approximately 1.63 million tons of SO_2 (Transport & Environment, 2022; ESPO, 2024).

Due to the increasing volume of maritime trade and the rising demand for port services and associated land transportation, emissions are expected to grow, thereby exacerbating climate change and global warming. The resulting environmental consequences include more frequent extreme weather events such as flooding, hurricanes, and droughts, as well as rising sea levels and disruptions to ocean circulation patterns (Alamoush et al., 2022; Benamara et al., 2019; Del Giudice et al., 2021).

In addition to air pollution, port activities also contribute to noise pollution, odor emissions, waste accumulation, and water contamination (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2020; Peris-Mora et al., 2005; Široka et al., 2021).

The need to reduce port-related environmental externalities, drive economic growth, and address social concerns is encapsulated in the concept of "Port Sustainability" (Alamoush et al., 2021b; Serra et al., 2023).

Port Sustainability encompasses three different dimensions: environment, economy, and society (Lim et al., 2019; Stein & Acciaro, 2020). These three dimensions are interdependent, as illustrated in Figure 5.

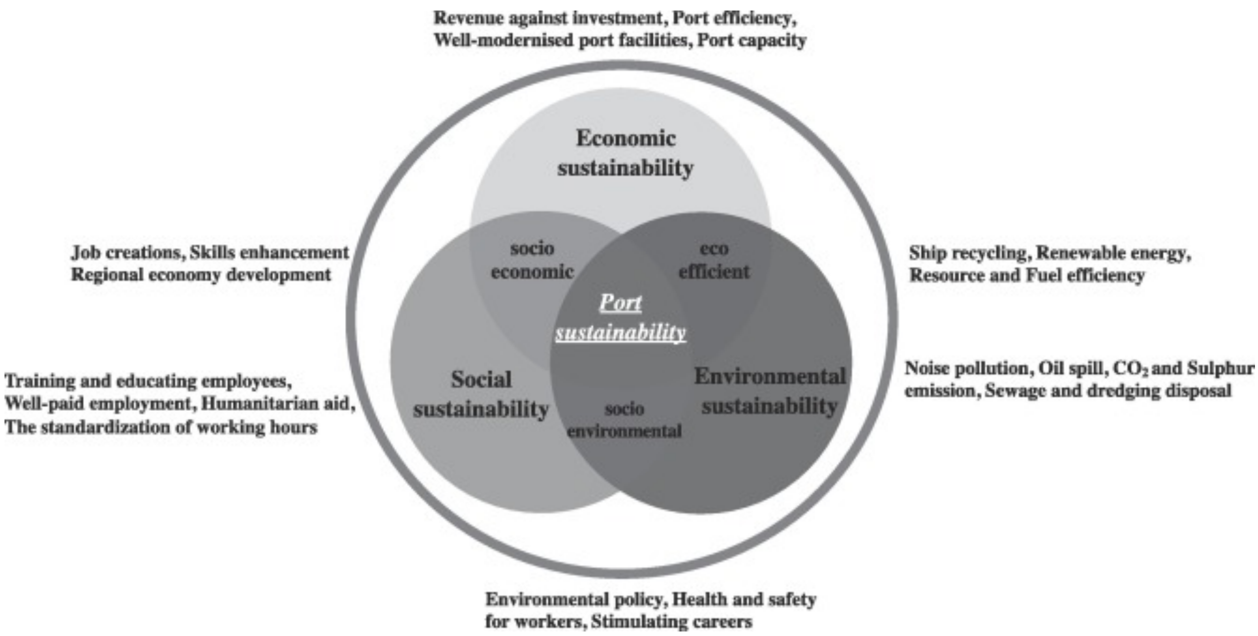

Figure 5. Interaction of port sustainability three bottom lines (pillars)

Source: Lim et al. (2019).

Environmental sustainability focuses on mitigating the negative impacts of port activities, including emissions from ships and vehicles, waste management, and energy consumption, all of which have a direct impact on the ecosystem and local communities. By improving energy efficiency, seaports can play a crucial role in reducing GHG emissions, thereby contributing to climate action and supporting global efforts to mitigate climate change (Alamoush et al., 2020, 2022; Narula, 2014). The integration of renewable energy sources, such as solar and wind power, can further enhance the sustainability of port operations (Fadiga et al., 2024).

Social sustainability refers to the safety and security of port operations. This dimension is strengthened through the monitoring, control, and minimization of accidents and incidents, as well as ensuring the safe and secure navigation of ships. Additionally, social sustainability encompasses employee welfare, including occupational health and safety, the provision of continuous training and education, as well as support for local employment and community well-being (Alamoush et al., 2021b; Narula, 2014; Serra et al., 2023).

Lastly, economic sustainability refers to the port's economic performance. Its primary objectives include maximizing revenue in relation to investments, modernizing port infrastructure, and enhancing operational capacity. As key facilitators of global trade and economic development, as discussed in Section 1.3, ports must maintain their competitiveness. However, this must be achieved by integrating sustainable practices that promote long-term resilience and stability (Lim et al., 2019).

The intersections among these three dimensions generate the following synergies (Martins et al., 2024):

- Economic-social: job creation and skills development;
- Economic-environmental: efficient resource and fuel management;
- Social-environmental: implementation of environmental policies and protection of workers' health.

Port efficiency is achieved by balancing these three pillars, fostering sustainable and integrated port management (Alamoush et al., 2021a; Lim et al., 2019; Martins et al., 2024; Roh et al., 2016).

1.5.2 Sustainable Development Goals (SDGs) and Environmental, Social, and Governance (ESG)

In 2015, the United Nations (UN) introduced seventeen SDGs to promote sustainable development globally. The 17 SDGs form the core of the Agenda for Sustainable Development, a plan of action for people, planet, and prosperity (United Nations, 2015).

Figure 6. The 17 Sustainable Development Goals (SDGs)

Source: United Nations, 2015.

The SDGs aim to address key global challenges, including climate change, environmental degradation, economic inequality, and social inclusion. In the maritime sector, these objectives emphasize the promotion of a circular economy, the protection of marine ecosystems, the enhancement of energy efficiency, and the reduction of pollutant emissions (United Nations, 2015).

As key nodes in international trade and maritime transport, ports play a significant role in advancing the SDGs, as highlighted by several studies (Alamoush et al., 2021a; Caliskan, 2022; Di Vaio et al., 2021; International Association of Ports and Harbors, 2020; Lighthouse, 2023). Specifically, ports contribute to:

- SDG 3 – Good Health and Well-being: Promoting the health and well-being of local communities by reducing pollution and improving environmental quality;
- SDG 7 – Affordable and Clean Energy: Ensuring access to affordable, reliable, sustainable, and modern energy;
- SDG 8 – Decent Work and Economic Growth: Creating sustainable employment opportunities and fostering economic development;
- SDG 9 – Industry, Innovation, and Infrastructure: Developing resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation;

- SDG 11 – Sustainable Cities and Communities: Enhancing urban sustainability and resilience;
- SDG 13 – Climate Action: Mitigating climate change and its impacts through sustainable practices;
- SDG 14 – Life Below Water: Protecting marine ecosystems and promoting the sustainable use of ocean resources;
- SDG 15 – Life on Land: Preserving terrestrial ecosystems and biodiversity;
- SDG 17 – Partnerships for the Goals: Strengthening strategic cooperation to support sustainable development initiatives.

To effectively support the achievement of the UN SDGs, many AdSPs have increasingly prioritized sustainability by integrating ESG principles into their operational and strategic frameworks. The ESG framework helps align port operations with sustainable development objectives established at international, national, and local levels.

The concept of ESG stems from the broader concept of sustainable development, emphasizing corporate responsibility in balancing economic, social, and environmental factors. It formalizes the principles of responsible investment and corporate social responsibility (CSR) (Gu et al., 2023).

Growing concerns about environmental accountability have led the port industry to assume greater ESG responsibilities, aligning with the principles of sustainable port development.

ESG initiatives aim to enhance sustainability, accountability, and resilience within the seaport sector (CarbonBetter, 2024; International Association of Ports and Harbors, 2020), including:

- Innovative environmental initiatives, such as renewable energy adoption, emission reduction strategies, and climate resilience measures;
- Community engagement, fostering social inclusion and local economic development;
- Technological advancements aimed at improving sustainability monitoring and operational efficiency;
- Sustainability reporting to measure, track, and communicate sustainability performance, ensuring transparency, ethical conduct, and regulatory compliance (Valenza & Damiano, 2023).

This strategic alignment with the UN SDGs enables ports to balance economic growth with environmental sustainability, facilitating a transition toward more sustainable management models.

The integration of ESG principles ensures that ports remain economically viable while also acting responsibly toward environmental conservation and community development. By

aligning their strategies with the UN SDGs, ports can establish themselves as leaders in sustainable maritime transport, setting industry standards for future growth.
This approach not only strengthens global sustainability efforts but also enhances the role of ports as key drivers of economic and social development. Moreover, ports that operate sustainably are more likely to gain support from governments, local communities, and the public, as well as attract potential investors in the maritime industry (Gu et al., 2023; Safuan et al., 2023; UNCTAD, 2015).

1.5.3 Tools and technologies for sustainable ports

In recent years, technology and digitalization have become fundamental to the maritime transport sector, reinforcing the growing emphasis on sustainability. In the digital era, advanced technologies have become key enablers of the transition toward energy efficiency and sustainable port management (Bjerkan & Seter, 2019; Enel X & Legambiente, 2021; Garrido Salsas et al., 2022; Notteboom et al., 2022; Othman et al., 2022).
Considering the challenges related to port sustainability and the rapid development of new technologies, this section examines the key initiatives, strategies, and innovations implemented to enhance sustainable port management, improve energy efficiency, and integrate ESG principles into port governance.
The increasing focus on sustainability has prompted port authorities worldwide to implement strategies that enhance port performance through digitalization and automation, reduce environmental impact by adopting renewable energy, electrification, and emission control measures, and improve climate resilience through adaptive infrastructure and eco-friendly practices.
European seaport authorities have prioritized sustainability by aligning their strategies with climate change mitigation policies and regulatory frameworks, ensuring compliance with international sustainability goals. To reduce GHG emissions and strengthen resilience against extreme climate events, ports are adopting various environmental and technological measures to transition toward greener and more sustainable models (ESPO, 2024).
A key strategy to enhance sustainability in seaports is the progressive electrification of port operations and the integration of renewable energy sources such as solar and wind power. These measures can significantly contribute to creating long-term, sustainable value (Enel X & Legambiente, 2021).
Several ports have taken decisive steps to lower CO_2 emissions by expanding the use of renewable energy and gradually phasing out coal-based energy sources. Others have prioritized

reducing overall energy consumption by modernizing heating systems, installing LED lighting, and deploying solar power infrastructure within port areas (Sadiq et al., 2021).

Closely related to these efforts is the focus on energy efficiency, which has become an essential aspect of port sustainability. As seaports are significant consumers of energy – particularly electricity and diesel fuel – it is crucial to implement effective energy management strategies (Acciaro et al., 2014; Sadiq et al., 2021).

A growing number of ports are installing OPS systems, commonly known as cold ironing, enabling vessels to connect to the electrical grid while docked, thereby eliminating the need to run onboard engines (Glavinović et al., 2023). When powered by renewable energy, these systems can significantly reduce or even eliminate local port emissions (Enel X & Legambiente, 2021).

According to the ESPO (2024) report, approximately 58% of surveyed ports have adopted OPS, while 48% are implementing LNG bunkering as a transition measure toward cleaner fuel use. Additionally, 85% of ports have introduced electric vehicle charging stations, facilitating a shift toward more sustainable transport options (ESPO, 2024). These measures are part of a broader transition to cleaner energy and greener practices within the industry.

In Italy, several AdSPs are already promoting the transition toward greener ports by installing OPS systems, using alternative fuels such as LNG, implementing digitalization initiatives to improve logistics efficiency, and investing in climate-resilient infrastructure. (Enel X & Legambiente, 2021).

In this context, technological advancements are further accelerating the transition toward sustainable port management. The adoption of advanced technologies, including Internet of Things (IoT)-based monitoring systems, energy management techniques, automated container tracking, and predictive analytics, plays a crucial role in optimizing resource use, reducing emissions, and improving operational efficiency (Notteboom et al., 2022).

Advancements in vessel design, alternative fuels, and engine technologies can reduce fuel consumption and facilitate the adoption of renewable energy sources, thereby lowering greenhouse gas emissions and improving air quality. Meanwhile, advancements in Information and Communication Technology (ICT), such as the implementation of 5G networks and cloud computing, enable digital transformation through faster data transmission. These technologies support the deployment of the IoT and the Internet of Vehicles (IoV), increasing operational efficiency and providing real-time data to address environmental challenges and reduce costs. Additionally, blockchain technology enhances documentation storage and transfer, increasing process transparency, minimizing human errors, and reducing waste. In summary, these innovations contribute to sustainable development by balancing economic, environmental, and social considerations, thereby supporting long-term economic success while protecting natural resources and enhancing the quality of life (Mudronja et al., 2022).

Bjerkan and Seter (2019) have identified several tools and technologies that foster port sustainability, as summarized in Table 1. These innovations play a crucial role in accelerating the transition toward energy efficiency and sustainable port operations, reinforcing the integration of economic, environmental, and social dimensions in port management. Among the various tools employed, environmental monitoring of air and water plays a crucial role in this process. Through monitoring and measurement, particularly of GHG emissions, port authorities can enhance sustainability strategies and improve sustainability reporting activities (Lam & Notteboom, 2014).

Port management and policies (30)	Power and fuels (36)	Sea activities (19)	Land activities (19)
Port plans (6)	Wind energy (4)	Speed reduction (17)	Technological shift: trucks and drayage (8)
Management of environment and energy (10)	Solar energy (6)	Efficient vessel handling (7)	Modal shift (12)
Monitoring (10)	Wave and tidal energy (4)	Other (2)	Efficient truck operations (8)
Concession agreements (9)	Geothermal energy (1)		Efficient loading/unloading (3)
Modal split (12)	Electrification (30)		Automation and intelligence (6)
Port dues (10)	LNG (10)		Clean industrial activity (1)
Collaboration (7)	Biofuels (4)		
Other managerial policies (4)	Methanol and hydrogen (2)		
	Low sulfur fuels (4)		

Table 1. Categories and subcategories of tools and technologies for sustainable ports
Source: Bjerkan & Seter (2019, p. 246)

The adoption of sustainability initiatives and tools demonstrates a growing commitment to reducing the environmental impact of ports and strengthening their resilience. These efforts encompass digitalization, the adoption of innovative technologies, and the promotion of green infrastructure and sustainable management practices.

When integrated into strategic planning and performance management systems and supported by continuous regulatory adaptation and collaboration across local, national, and international levels, these initiatives can drive the transition toward more efficient and sustainable ports.

Despite the significant progress achieved so far, critical challenges remain. Addressing these issues requires ongoing commitment and increased investment in innovation and research.

Furthermore, adopting integrated and multidimensional strategic managerial frameworks is essential to ensuring that the port sector continues to play its key role in the global economy while simultaneously protecting the environment and enhancing the well-being of local communities.

As the maritime sector evolves, it is becoming increasingly evident that sustainability cannot be considered an isolated goal but must instead be systematically embedded into business models, governance frameworks, and operational strategies (Garrido Salsas et al., 2022; Geissdoerfer et al., 2018).

As traditional business models are no longer adequate to address the complexities of global sustainable development, Knudson (2023) argues that seaports must adopt innovative strategic frameworks that integrate environmental, economic, and social dimensions, ensuring long-term sustainable growth while remaining competitive in the evolving global trade landscape. However, implementing these innovative frameworks requires a deep understanding of the complexities of seaport performance management systems, a topic that will be further explored in the next section.

1.6 Complexity in performance management systems

As highlighted in the previous sections, AdSPs are complex organizations that manage a wide range of resources, activities, and processes. They are responsible not only for ensuring the efficient operation of maritime transport but also for strategically integrating sustainability objectives into their operations. These organizations exhibit a high degree of organizational complexity, as they must balance economic, environmental, and social goals within a highly dynamic and interconnected environment. AdSPs operate within a multifaceted ecosystem where numerous variables interact, including port infrastructure, operations, regulatory frameworks, and socio-economic aspects. They coordinate port and logistics services by engaging an extensive network of actors, including shipping companies, customs agencies, local authorities, and regulatory bodies, which operate at different levels of the value chain. In this context, effective internal management and close collaboration with external stakeholders, including logistics operators, local authorities, and investors, are crucial. This complexity has a direct impact on performance management, which must consider not only operational and financial efficiency but also the environmental and social impact of port activities. Pursuing sustainability objectives in this context is challenging, as AdSPs must navigate complex organizational and inter-organizational interconnections (Bergantino et al., 2013; Ensslin et al., 2018; Lim et al., 2019; Parola & Maugeri, 2013; Notteboom et al., 2022).

AdSPs must balance competitiveness, innovation, and sustainability, embedding a long-term vision where sustainability is not merely an accessory element but a fundamental pillar of strategic decision-making (UNCTAD, 2022). However, AdSPs often operate with a business-oriented approach, primarily focusing on financial balance and operational efficiency, maintaining the status quo and prioritizing short-term economic profits over long-term sustainable planning (Becker & Caldwell, 2015; Bjerkan & Seter, 2019). Traditional performance management systems are essentially based on financial models and static reporting, with a focus on the organization's internal dynamics. This approach results in a lack of connection between outputs (i.e., the results of activities) and outcomes (i.e., long-term impacts) (Bianchi, 2016).

Performance management systems should focus on the long-term impacts of port operations, adopting a holistic and adaptive approach that balances operational requirements with long-term sustainability objectives. Integrating the three dimensions of sustainability – economic, environmental, and social – is crucial in addressing global challenges such as market fluctuations, geopolitical tensions, regulatory changes, and socio-environmental issues. To ensure that sustainability efforts are effective and not isolated, careful strategic planning is required. This planning must align with international and national policies, regional economic objectives, stakeholder needs, and global trade trends. In this context, successful port management must be based on a solid strategic process that includes infrastructure development, the adoption of innovative technologies, and the expansion of operational capacities (Virtual Maritime Academy, 2024).

AdSPs must balance their core mission – such as ensuring the competitiveness of the port system, facilitating international trade, and improving the quality of logistics services – with financial sustainability goals and the need to mitigate the environmental and social impacts of their operations. This alignment must be consistent with the UN's SDGs.

Other challenges are the measurement and evaluation of sustainability, which require defining metrics that encompass both quantitative aspects – such as emission reduction, energy efficiency, and traffic volumes – and qualitative variables, including quality of life, community well-being, overall environmental impact, and public perception of port activities (UNCTAD, 2023a; UNCTAD, 2024, p.109).

Furthermore, identifying effective and relevant indicators is crucial for analyzing, assessing, and monitoring port sustainability initiatives (Di Vaio et al., 2018) and their contribution to the Sustainable Development Goals (SDGs) established by the United Nations (UNCTAD, 2023a).

For this reason, measuring and evaluating sustainable performance requires the implementation of robust management systems capable of monitoring and assessing economic, social, and environmental performance. These systems must provide accurate data to support decision-making and ensure continuous improvement. However, in a highly dynamic and complex environment such as the port sector, considering all the variables that influence performance remains particularly challenging (Ensslin et al., 2018; Lim et al., 2019; Peris-Mora et al., 2005). To address these challenges, strategic planning, and performance management tools are needed to integrate sustainable value creation across the three dimensions of sustainability – economic, social, and environmental – as analyzed in Section 1.5 of this chapter. Only a holistic approach can ensure truly sustainable port management (Martins et al., 2024).

The unpredictability of interconnections highlights the dynamic complexity that characterizes complex systems, resulting from delays, nonlinearity, and multiple feedback loops (Bianchi, 2009, 2016). Thus, a dynamic approach is essential to capture the interconnections between inputs, implemented processes, outputs, and the long-term impacts of port activities. A dynamic and systemic perspective enables AdSPs to continuously monitor the progress of implemented strategies and take timely action if sustainability objectives are not met. Performance management, therefore, goes beyond ex-post measurement, becoming a proactive and adaptive process that is essential for ensuring the long-term competitiveness and sustainability of the port sector. To effectively address and manage the complexity of performance management systems, AdSPs must adopt innovative tools, ensuring they achieve their strategic objectives while contributing to environmental and community well-being.

1.7 Research objectives and questions

Despite the growing emphasis on sustainability in national and international policies, its systematic integration into port strategies remains limited. While AdSPs have adopted sustainable practices and new technologies to respond to regulatory pressures and environmental challenges – as discussed in the previous sections – these efforts are often fragmented and lack a structured and integrated management framework. A review of the literature further reveals that many studies focus exclusively on specific aspects of sustainability, particularly its environmental dimension, neglecting a holistic approach that also incorporates social and economic dimensions. These aspects underscore the need to develop integrated methodological frameworks that can support sustainability planning and management in ports. These frameworks should enable the implementation and monitoring of sustainability strategies while ensuring a balance between economic competitiveness and environmental and social requirements (Ashrafi et al., 2019; Bucak et al., 2020; Caliskan, 2022; Di Vaio & Varriale, 2018; Gavalas, 2024; Martins et al., 2024).

To address these gaps, this study proposes the adoption of the DBMfS (Cosenz et al., 2020). This model serves as an effective tool for integrating the principles of economic, social, and environmental sustainability into the strategic planning and management of maritime ports.

Based on this objective, the research aims to answer the following questions:

- **RSQ1:** How can AdSPs effectively integrate economic, social, and environmental sustainability into their business models? How does the DBMfS address the limitations of existing approaches and enhance the long-term integration of sustainability?
- **RSQ2:** How can the DBMfS support AdSPs in strategic planning and sustainable performance management, enhancing operational efficiency and fostering long-term environmental, social, and economic sustainability?
- **RSQ3:** What are the advantages of adopting a dynamic perspective in the sustainable performance management of AdSPs? How can this approach enhance decision-making, performance measurement, and evaluation through the use of sustainable key performance indicators (KPIs)?

By answering these questions, the research aims to provide a dual contribution:

- Theoretical contribution: enrich the academic debate on sustainable port performance management by proposing a structured methodological framework that integrates the three dimensions of sustainability – economic, social, and environmental – while adopting a long-term perspective;
- Practical contribution: provide an operational, strategic framework that can effectively guide Port Authority managers in strategic planning and managing sustainable performance.

To concretely demonstrate how the DBMfS can be applied to the port sector, it will be implemented in a case study: the Western Sicily Seaport Authority (AdSP MSO). The case study analysis will provide practical evidence of the effectiveness of the DBMfS, offering a replicable methodological framework for other port contexts.

Based on these research objectives, the following chapter will present the proposed methodology, detailing the structure and key features of the DBMfS. This framework aims to provide a comprehensive approach to integrating and pursuing sustainability in port management, addressing the challenges identified in this chapter.

1.8 Concluding remarks

The chapter provides a critical and comprehensive analysis of the seaport sector, emphasizing its central role in global trade and regional development, while also underscoring the profound complexity and challenges associated with its management (Notteboom et al., 2022). Modern ports are no longer simple transit and logistical nodes, but function as strategic platforms for sustainable development, where economic performance, environmental protection, and social well-being are deeply interconnected and must be carefully aligned and balanced.

After analyzing the historical evolution of seaport management, and highlighting the transformation of ports from basic operational infrastructures into intermodal hubs integrated within global value chains, this chapter has examined the European and Italian port contexts, characterized by high traffic volumes, significant economic relevance, complex and often heterogeneous governance structures, and a multi-level regulatory framework increasingly aligned with the objectives of the ecological transition.

The growing awareness of port externalities, together with regulatory and societal pressures to mitigate them, has brought to the forefront the concept of port sustainability, structured around the TBL approach (Elkington, 1998; Lim et al., 2019) – economic, environmental, and social – and linked to the UN's SDGs (United Nations, 2015). In this perspective, ports are increasingly expected not only to ensure operational efficiency and economic competitiveness but also to actively contribute to environmental protection, social inclusion, and the long-term resilience of the territories in which they operate. Within this framework, the adoption of green and digital technologies – such as dock electrification, renewable energy integration, and advanced digital solutions – emerges as a key lever to achieve sustainability goals, reduce negative externalities, and enhance systemic resilience (Bjerkan & Seter, 2019; Garrido Salsas et al., 2022).

However, the analysis has also highlighted the complexity of performance management systems in the port context, where multiple stakeholders, interdependent processes, and diverse objectives converge. Traditional approaches, often based on static indicators or fragmented initiatives, prove inadequate to capture the dynamic interactions among economic, social, and environmental dimensions. This underscores the need for innovative and dynamic tools capable of mapping feedback structures, identifying causal relationships, and aligning short-term actions with long-term objectives (Bianchi, 2009, 2016).

To address these challenges, this study advocates the adoption of the DBMfS (Cosenz et al., 2020). As both a conceptual and operational framework, the DBMfS is designed to embed the three pillars of sustainability into strategic and performance management. By adopting a systemic and dynamic perspective, the model enables AdSPs to continuously monitor key drivers, anticipate emerging bottlenecks, and strategically intervene when objectives are not achieved. Moreover, its adaptive nature allows ports to remain resilient in the face of evolving pressures, including global trade shifts, regulatory changes, and the ecological transition.

In summary, this chapter lays the theoretical foundation for the development of a sustainable and dynamic performance management model for seaports, highlighting the limitations of existing approaches and the need for integrated frameworks that balance competitiveness, efficiency, and sustainability.

The following chapter presents the proposed methodological framework, illustrating its structure, theoretical underpinnings, and practical functioning, to provide AdSPs with a replicable and adaptable methodology to guide their transition toward more sustainable, resilient, and strategically oriented management practices across different port contexts.

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2 Methodology: the Dynamic Business Model for Sustainability

2.1 Introduction

This chapter presents a conceptual and methodological framework for integrating sustainability – encompassing environmental, social, and economic aspects – into strategic planning and performance management within seaport contexts. Although sustainability has gained increasing attention in recent years, its practical implementation in port governance remains fragmented. Many port authorities continue to address the three pillars of sustainability in isolation, lacking a coherent and long-term strategy (UNCTAD, 2022). Moreover, the academic literature has predominantly focused on environmental performance – often measured through indicators such as emissions, air quality, and energy consumption (Di Vaio et al., 2018; Peris-Mora et al., 2005; Puig et al., 2014; Puig et al., 2015) – while the economic and social dimensions remain underexplored (Styliadis et al., 2022). This fragmented approach highlights the need for integrated frameworks that can capture the interconnections among the three pillars of sustainability and support long-term value creation. In response, a growing body of literature advocates for holistic and dynamic approaches that promote a balanced integration of competitiveness and sustainability (Bucak et al., 2020; Caliskan, 2022; Di Vaio & Varriale, 2018; Martins et al., 2024), thereby emphasizing the importance of aligning performance management systems with sustainability objectives, especially in increasingly complex port environments. Within this evolving landscape, the business model concept has gained renewed relevance as a valuable lens for analyzing and guiding sustainable value creation. Sustainability-oriented business models offer a broader perspective, focusing not only on economic value but also on the generation and preservation of environmental and social value over time (Geissdoerfer et al., 2018; Schaltegger et al., 2016). However, traditional business models often prove too static to reflect the adaptive and systemic nature of port ecosystems, which are shaped by shifting regulatory frameworks, environmental constraints, and the interaction of diverse stakeholders. To address these limitations, recent contributions have advocated the use of systemic and dynamic modeling approaches capable of capturing the evolving interactions among strategic variables (Haezendonck, 2021). As modern seaports are complex systems marked by interdependencies among actors, inputs, processes, external variables, and outcomes, such approaches are essential for supporting adaptive, forward-looking decision-making and for embedding sustainability into both governance structures and business model design.

In line with this perspective, this research adopts the DBMfS. This methodological framework combines the Business Model Canvas (BMC) with the principles of System Dynamics (SD). This integration enables the DBMfS to surpass conventional models by offering a visual and systemic framework that can dynamically track the flow of resources, map causal relationships, and assess both short-term and long-term sustainability impacts. The model is particularly relevant in the port sector, where decision-makers must continuously balance economic competitiveness with environmental and social responsibilities. The DBMfS enables port authorities to rethink their strategy design by explicitly incorporating the three pillars of sustainability: economic performance, environmental stewardship, and social well-being. By integrating System Dynamics, the DBMfS facilitates a deeper understanding of how sustainability-oriented decisions unfold over time and affect the broader port ecosystem. This chapter is structured as follows:

- Section 2.2 provides a comprehensive literature review of the business model concept, offering an in-depth overview of its evolution and increasing importance in strategic management. It also highlights the limitations of traditional, static approaches in addressing complexity and sustainability.
- Section 2.3 explores the evolution of sustainable business models, emphasizing the need for frameworks that integrate social and environmental dimensions alongside economic value creation.
- Section 2.4 provides an in-depth presentation of the DBMfS, illustrating its theoretical underpinnings, structural components, and methodological foundations. The section traces the conceptual and methodological path that led to the development of the DBMfS. This integrated framework combines the strengths of the Business Model Canvas with the dynamic and systemic perspective offered by System Dynamics. The discussion unfolds across four subsections: 2.4.1 examines the strengths and limitations of the traditional Business Model Canvas; 2.4.2 introduces the core principles of System Dynamics as a modeling methodology; 2.4.3 outlines the transition toward the Dynamic Business Model as an intermediate step; and 2.4.4 presents the final configuration of the DBMfS, focusing on its sustainability-oriented structure, causal interconnections, and feedback loops.
- Section 2.5 discusses the relevance of the Dynamic Business Model for Sustainability in the context of seaport management, with a focus on its applicability to strategic sustainability planning and performance management in seaport systems.
- Section 2.6 presents concluding remarks on the methodological approach and its potential implications for seaport management.

Through the proposed methodological framework, this research aims to make both theoretical and practical contributions to the field of sustainable port management, providing a tool that can be adapted to various port contexts and applied to the development, implementation, and monitoring of sustainability strategies.

2.2 The concept of business model

The concept of business model has gained increasing relevance in economic and managerial literature since the 1990s, particularly with the advent of digital technologies and the rise of internet-based firms (DaSilva & Trkman, 2014). In recent years, it has attracted significant attention from researchers, becoming a widely investigated and debated topic (Cosenz et al., 2020).

In light of this growing interest, this section aims to retrace the conceptual origins of the business model, clarify its general meaning, and review the main interpretative perspectives that have emerged in the literature.

The term "business model" was first mentioned in an academic article written by Bellman et al. in 1957, where it was used to refer to a representation of reality, essentially a simulation of the real world through a model.

At a general and intuitive level, a business model can be understood as a description of an organization and how it functions to achieve its goals (e.g., profitability, growth, social impact) (Massa et al., 2017). However, beyond this intuitive understanding, there is a lack of consensus among scholars regarding more operational and precise definitions of the term (Zott et al., 2011). This definitional ambiguity has prompted various interpretative frameworks, which will be explored in detail in this section.

Over the past few decades, the literature on business models has produced a wide range of definitions, often heterogeneous and, at times, even divergent. To systematize this conceptual variety, Massa et al. (2017) propose a classification that identifies three main interpretative perspectives, each offering a different lens through which the business model can be understood:

1. The business model as an attribute of real firms;
2. The business model as a cognitive and linguistic schema;
3. The business model as a formal conceptual representation.

According to the first interpretation, the business model represents a concrete and observable attribute of firms, encompassing the strategic choices, operational activities, and organizational resources through which an organization creates and captures value. From this perspective, the business model reflects the actions the firm takes to achieve its objectives.

Within this view, Zott and Amit (2010) define a business model as “a system of interdependent activities that transcends the focal firm and spans its boundaries.” According to these authors, the business model emphasizes how a company creates value and revenue streams for customers, serving as a fundamental tool for analyzing key strategic choices and understanding how the firm is managed and how it performs.

Similarly, Casadesus-Masanell and Zhu (2010) describe the business model as a coherent set of contingent choices and consequences that determine the behavior and performance of the organization, highlighting the dynamic and competitive nature of managerial decisions.

Other scholars adopt a functional or pragmatic approach. Chesbrough (2010) defines the business model in terms of its ability to articulate the value proposition, identify a target market, outline a revenue model, and position the firm within a value network. Likewise, Birkinshaw and Goddard (2009) simply define the business model as “how a company makes money”, while Bocken et al. (2015) describe it as a framework for mapping the firm's purpose and value creation opportunities across its network.

Gambardella and McGahan (2010) define the business model as the organization of activities that enables a firm to generate profits in a sustainable way. Similarly, Hienerth et al. (2011) describe it as “the logic of how a business creates and delivers value to users and converts payments received into profits”. San Roman et al. (2011) further argue that a business model “describes how a product or service is provided, including the perceived value creation of a certain product for a final customer”, emphasizing its role in linking suppliers, customers, and competitive strategy.

A more comprehensive interpretation is provided by Smith et al. (2010) who define the business model as a strategic design that integrates firm choices related to markets, customers, resources, and value propositions through an organizational architecture composed of people, processes, and capabilities. Along similar lines, Nielsen and Lund (2014) conceptualize the business model as a platform that connects resources, processes, and service offerings while ensuring long-term profitability.

Despite their differences, all these definitions share a common understanding of the business model as an empirical description of how firms operate. It serves both as a conceptual tool for analyzing organizational logic and as a practical guide for aligning strategic intent with operational activities.

The second interpretative category proposed by Massa et al. (2017) views the business model as a cognitive and linguistic schema, a mental and communicative representation through which managers and entrepreneurs understand, interpret, and communicate how the firm operates. From this perspective, the business model serves as a lens through which organizational reality is understood and strategic decision-making processes are guided.

Aspara et al. (2013), for instance, argue that the business model represents managers' perceived logic of how a business unit creates value, concerning both the market and the internal organizational context. Similarly, Baden-Fuller and Morgan (2010) suggest conceiving business models as conceptual models useful not only for describing, classifying, and comparing firms, but also for supporting managerial innovation.

Doganova and Eyquem-Renault (2009) emphasize the narrative nature of the business model, which functions as a tool for exploring new markets and transforming an innovative idea into a concrete project.

Magretta (2002) offers a narrative and intuitive definition of the business model, describing it as "a story that explains how an enterprise works – who its customers are, what they value, and how the company intends to deliver value to them in a profitable way". According to the author, telling the story of the business model means making explicit who the customers are, what they value, and how the company intends to offer them value in an economically sustainable manner. In this sense, the business model becomes a narrative device that guides managerial action and communicates strategy.

Martins et al. (2015) consider the business model as a system of activities that reflects managers' mental models, while Velu and Stiles (2013) describe it as a synthesis of the firm's architecture and logic, useful for top management to make decisions and manage change.

In summary, the cognitive-linguistic approach interprets the business model as a dynamic mental representation, enabling decision-makers to navigate, innovate, and communicate within a continuously evolving competitive environment.

According to the third interpretative perspective, the business model is conceived as a formal conceptual representation – an explicit and structured description of how the firm operates. This view emphasizes the business model's function as a cognitive and communicative tool for representing, analyzing, and sharing how value is created, delivered, and captured.

According to Osterwalder et al. (2005), the business model serves as a blueprint that enables a coherent and integrated visualization of key activities, customer segments, revenue streams, and value creation mechanisms. From this perspective, business models are not merely narratives or metaphors but formal tools that facilitate the understanding, measurement, and communication of a firm's operational and strategic logic.

Several scholars adopt this interpretive stance. Baden-Fuller and Haefliger (2013), for example, define the business model as a system that enables firms to identify customers,

understand their needs, offer value, and monetize it, thus highlighting its managerial function. Similarly, Casadesus-Masanell and Ricart (2010) describe the business model as the representation of the logic through which the firm creates and delivers value to stakeholders.
Teece (2010) emphasizes that the business model is a crucial tool for articulating an effective and sustainable value proposition, making it a fundamental lever for achieving competitive advantage.
McGrath (2010) underscores the strategic intentionality of the model, conceived as a coherent set of choices that allows the firm to adapt dynamically to environmental changes. Abdelkafi and Täuscher (2016) further expand this view by including the social and environmental dimensions of value creation. They describe the business model as part of a feedback cycle between value created, captured, and returned to the system.
Similarly, Upward and Jones (2015) offer a sustainability-oriented interpretation, suggesting that the business model becomes a strategic structure for defining and achieving long-term success by integrating economic, environmental, and social objectives.
Overall, this body of literature positions the business model, understood as a formal conceptual representation, as more than a descriptive artifact. It serves as an analytical tool for strategic and organizational design. It simplifies organizational complexity, reveals the interdependencies among key components, and enables the exploration of alternative configurations aligned with specific goals. Its function extends beyond merely representing the status quo to actively supporting the design and innovation of new value creation models.
The classification proposed by Massa et al. (2017) highlights the multidimensional nature of the business model and its multiple functions: as a descriptive tool, a decision-making guide, and a design instrument. In sum, the business model is now recognized as a key element for

understanding, representing, and innovating organizational logic, assuming a central role in strategic management.

As the discussion makes evident, there is still no universally accepted definition of the business model. Nevertheless, most authors agree that it is a tool that describes how a company operates and how it creates and captures value (Osterwalder & Pigneur, 2010; Zott et al., 2011).

Traditionally, business models have focused on value creation through economic benefits (Chesbrough & Rosenbloom, 2002), often neglecting environmental and social concerns (Cardeal et al., 2020).

A commonly accepted framework structures the business model around three core components – value proposition, value creation and delivery, and value capture (Chesbrough, 2010; Osterwalder & Pigneur, 2010; Richardson, 2005), as illustrated in figure 7 (Bocken et al., 2014).

Figure 7. Conceptual business model framework

Source: Bocken et al. (2014)

The value proposition refers to an organization's product or service offering and the value it delivers. It defines what the company offers to its customers, why they are willing to pay for it, and the competitive advantage underlying the offer. It also includes the target market and the company's strategic positioning (Richardson, 2005).

Value creation and delivery involve the organization's activities, resources, suppliers, partners, and distribution channels (Bocken et al., 2014; Knudson, 2023). This component describes how the company generates and delivers value to customers by identifying the resources and capabilities that underpin its competitive advantage. It includes distinctive competencies, internal structures such as the value chain, activity systems, and operational processes, as well as the relationships with suppliers, partners, and customers that shape the firm's role within the broader value network (Richardson, 2005).

Value capture refers to how the company converts the value it has created into economic returns, including revenues and sustainable profits (Richardson, 2005).

In practical terms, the business model serves as a strategic tool to outline and conceptualize an organization's value-related activities, their interactions, and their impact on customers and stakeholders.

According to Osterwalder and Pigneur (2010), it is a structured and logical model that enables organizations to identify and articulate a value proposition for the customer, while simultaneously defining a value structure for the company's partners.

Likewise, Chesbrough (2006) argues that a business model fulfills two fundamental functions: value creation and value capture. It delineates a set of coordinated activities that lead to the development of products or services, ultimately generating net value. Part of this value is then captured for the benefit of the organization that implements the model.

Teece (2010) further reinforces this point by defining the business model as a mechanism that "*demonstrates how a business creates and delivers value to customers and outlines the architecture of revenues, costs, and profits associated with (..) delivering that value*".

Numerous authors have emphasized the critical distinction between business model and strategy (Magretta, 2002; Mansfield & Fourie, 2004). Although the two terms are often used interchangeably, the business model is generally considered much more generic than strategy (Teece, 2010). One of the key strengths of the business model as a planning tool lies in its focus on how all the components of an enterprise fit together into a functioning system. While business models describe the logical foundations on which a company creates and delivers value to customers, they do not address the critical competitive dimension of performance, which is instead the primary concern of strategy.

Strategy, therefore, deals with how to compete successfully, while the business model helps to think systemically and coherently about how all the organizational elements connect (Magretta, 2002).

According to Shafer et al. (2005), although a business model facilitates the analysis, experimentation, and validation of a firm's strategic choices, it does not constitute a strategy in itself. Indeed, as observed by Mintzberg (1987), strategy can be interpreted in five distinct ways: as a pattern, a ploy, a plan, a position, or a perspective. In a retrospective view, strategy is conceived as a sequence of decisions taken over time. More commonly, however, it is understood prospectively as a plan, that is, a set of intended choices and actions. It may also reflect a positional approach to market offerings or serve as a cognitive lens through which the organization is perceived and managed.

Despite the diversity of perspectives, the literature consistently highlights the central role of decision-making. Strategy is fundamentally based on choices, while the business model reflects these choices by translating them into concrete operational elements. It serves as a tool for analyzing, testing, and communicating strategic decisions, ensuring coherence and long-term sustainability.

As the literature reveals, the business model is a multifaceted and dynamic concept, not merely a structural description of the firm. It provides a conceptual framework for understanding how an organization creates and captures value. Although different theoretical contributions emphasize distinct aspects, they converge in recognizing the business model as a key mechanism for linking strategic intentions with operational implementation.

In this sense, the business model acts as an interface between strategy, organizational structure, and context. It provides a shared language for designing, managing, and communicating the logic of value creation, enabling the alignment of strategic decisions with the resources, activities, and stakeholder relationships that support the organization's functioning.

Therefore, the business model enables the translation of strategic decisions into concrete operational elements, such as the activities to be undertaken, the resources to be allocated, the relationships to be managed, and the revenue streams to be generated. By making strategy understandable, implementable, and measurable, a well-designed business model becomes an essential tool for the strategic management of any successful organization (Teece, 2010).

In summary, the concept of the business model has emerged as a fundamental lens through which to interpret and design the functioning of organizations, coherently linking strategic choices with operational elements. However, in an increasingly unstable, complex, and interconnected context – characterized by rapid technological transformations, growing environmental pressures, and evolving social expectations – traditional business models appear limited and are rarely oriented toward sustainable value creation (Cosenz et al., 2020; Evans et al., 2017; Zott & Amit, 2010). Their static and linear configuration struggles to capture interdependencies among variables, evolving processes over time, and the systemic effects of strategic decisions.

In light of these challenges, there is a growing need to move beyond simplified and fragmented perspectives toward a systemic, dynamic, and sustainability-oriented approach. Such an approach should be able to capture the complexity of contemporary environments and guide strategic innovation aligned with stakeholder expectations. It is no longer sufficient for a business model to describe how an organization creates and captures value in purely economic

terms; it must also be capable of representing and guiding processes of shared value creation, explicitly including environmental and social dimensions alongside the economic one.
The growing emphasis on sustainability has led both scholars and practitioners to reconsider and expand the concept of the business model, developing conceptual and operational tools that integrate economic, environmental, and social objectives within a unified framework. In this context, the notion of the Sustainable Business Model (SBM) has emerged as one of the most significant developments in recent management literature, and it forms the focus of the following section.

2.3 Sustainable business models

The growing prominence of sustainability in academic and managerial discourse has led to increasing efforts to integrate sustainability into business models. This trend has given rise to Sustainable Business Models (SBMs), which are receiving growing scholarly attention, as demonstrated by the expanding literature on the subject (Abdelkafi & Taeuscher, 2016; Bocken et al., 2014; Schaltegger et al., 2016; Stubbs & Cocklin, 2008).
Numerous studies have proposed varying definitions and interpretations of SBMs, highlighting different dimensions and characteristics that integrate sustainability within entrepreneurial logic. The concept of a sustainable business model has emerged as a strategic response, encouraging firms to actively contribute to the transition toward a more sustainable economic system by structurally integrating environmental and social concerns into the core of their corporate strategy (Geissdoerfer et al., 2018).
According to Stubbs and Cocklin (2008), a SBM is one in which sustainability becomes the primary driver of the firm, shaping its decision-making processes. In this perspective, the business model is reconfigured to reflect and prioritize social and environmental goals alongside economic performance.
Schaltegger et al. (2012) define SBMs as models that create value for both customers and society by integrating economic, social, and environmental activities. Similarly, Bocken et al. (2013) emphasize the ability of SBMs to go beyond economic value generation by including other forms of value relevant to a broader range of stakeholders.
Boons and Lüdeke-Freund (2013) offer a more nuanced characterization of sustainable business models, identifying four key aspects. First, the value proposition should aim to generate not only economic but also environmental and social benefits. Second, the supply chain should include partners who act in socially and environmentally responsible ways. Third, the customer interface should be designed to promote sustainable consumption patterns. Ultimately, the

financial model should ensure an equitable distribution of costs and benefits, while also considering the social and environmental impacts.

Other authors have emphasized complementary aspects. Abdelkafi and Täuscher (2016), for instance, emphasize the importance of integrating sustainability into both the value proposition and the underlying logic of value creation.

Geissdoerfer et al. (2018) adopt a systemic view, defining a SBM as a representation of the elements, relationships, and interactions that an organization uses to create, deliver, capture, and exchange sustainable value in collaboration with a broad range of stakeholders.

Evans et al. (2017) identify five fundamental propositions that underpin the concept of a sustainable business model, including the internalization of externalities, the integration of economic, social, and environmental benefits, and the development of sustainability-oriented value networks.

A sustainable business model is thus recognized as a tool for systematically incorporating goals, principles, and mechanisms that maximize benefits and minimize harm across the triple bottom line (Youli et al., 2023).

According to Schaltegger et al. (2016) a business model for sustainability helps describe, analyze, manage, and communicate a company's sustainable value proposition to its customers, and all other stakeholders, how it creates and delivers this value, and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries.

Incorporating sustainability issues into business models enables the adoption of a comprehensive perspective of the strategy design and associated organizational dynamics driving the success (or failure) of organizations. (Cosenz et al., 2020).

Creating value across economic, social, and environmental domains is the ultimate goal of sustainable business models, which can effectively contribute to reducing the harmful effects of business activities on the environment and society by providing solutions that help companies meet their economic and sustainability goals simultaneously (Nosratabadi et al., 2019).

The Business Model for Sustainability extends traditional frameworks by explicitly and proactively considering stakeholders, as well as environmental, social, and economic capital and encouraging organizations to look beyond their boundaries and adopt a long-term perspective (Geissdoerfer et al., 2018; Schaltegger et al., 2016).

In particular, a sustainable business model requires organizations to develop a systemic understanding of the interactions between activities, resources, and relationships, placing at the center not only the provision of products or services but also the perceived value for stakeholders and the broader context in which the firm operates (Bocken et al., 2014; Boons & Lüdeke-Freund, 2013).

From this perspective, the value proposition is no longer exclusively focused on economic return but instead reflects broader needs and preferences, such as reducing environmental impact or generating positive social outcomes. Value creation and delivery processes span the entire value chain, including responsible sourcing, sustainable production, and collaborative partnerships. Value capture assumes a broader meaning, encompassing not only monetary profit but also the social and environmental benefits that the organization generates and internalizes.

Recent literature further emphasizes the importance of generating sustainable value, underlining the need for firms to achieve economic success while simultaneously delivering environmental and social benefits. According to Hart and Milstein (2003), this concept refers to the creation of sustainable value for shareholders. Morioka et al. (2017) define sustainable value as the fulfillment of economic, social, and environmental needs of both current and future generations.

From a sustainability perspective, a firm's value creation logic should therefore integrate social and environmental objectives into a broader and more holistic conception of value (Schaltegger et al., 2016). The notion of sustainable value thus emerges as an integrated synthesis of environmental, social, and economic dimensions (Ueda et al., 2009).

Although the literature does not provide a single, universally accepted definition, sustainable value is recognized as a multidimensional concept aligned with the triple bottom line principle (Elkington, 1994; Stubbs & Cocklin, 2008).

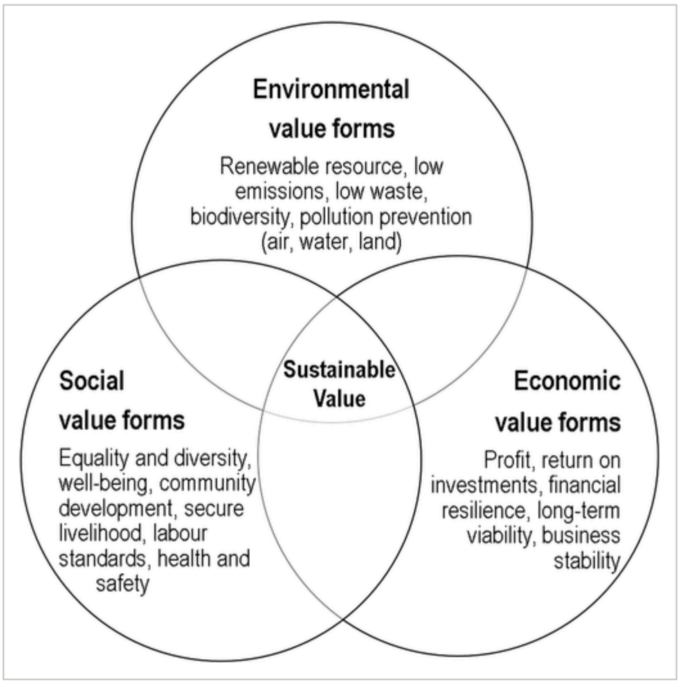

Figure 8. Sustainable value

Source: Evans et al. (2017)

Figure 8 illustrates a holistic view of sustainable value, encompassing economic, environmental, and social dimensions. Each of these components contributes in a distinct yet complementary way to the construction of a truly sustainable business model (Cosenz et al., 2020; Evans et al., 2017).

Economic value includes elements such as profit, return on investment, financial resilience, long-term profitability, and organizational stability. While these dimensions reflect traditional business performance objectives, within a sustainability context, they are reinterpreted in light of the firm's ability to generate enduring value over time.

Environmental value refers to goals such as reducing emissions, utilizing renewable resources, minimizing waste, conserving biodiversity, and preventing pollution in air, water, and soil. These aspects emphasize the importance of designing and implementing production and logistics processes that minimize ecological impact.

Social value includes variables such as equality and diversity, community well-being and development, workplace safety, adherence to labor standards, and employee health and welfare. This dimension underscores the importance of ensuring fair and inclusive conditions for all stakeholders, both internal and external to the organization.

The intersection of these three domains is defined as *sustainable value* and represents the ultimate goal of a SBM. This approach recognizes that sustainability cannot be achieved through isolated initiatives or sectoral interventions, but rather requires the systemic integration of different forms of capital – economic, social, and environmental – throughout the business model.

Adopting a sustainable value logic not only enables organizations to better meet stakeholder expectations, but also serves as a powerful driver of innovation and long-term strategic resilience.

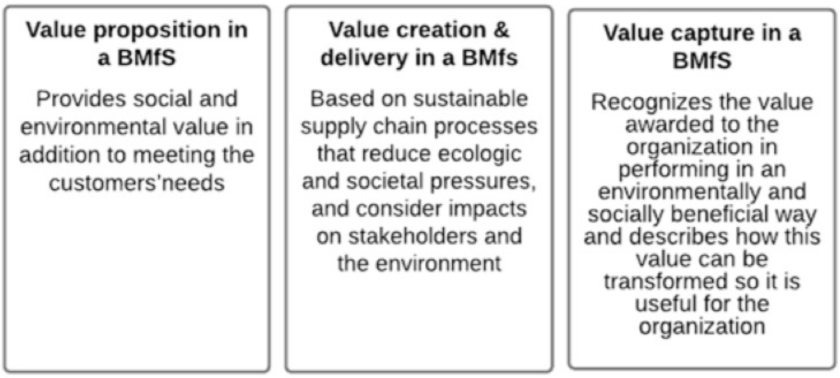

Figure 9. Sustainable business model archetypes

Sources: Knudson (2023) adapted from Bocken et al. (2014).

Figure 9 illustrates a conceptual framework that identifies the three core components around which a Business Model for Sustainability can be designed: value proposition, value creation and delivery, and value capture.

In sustainability-oriented models, the value proposition is not limited to economic offerings but also encompasses environmental and social benefits, such as minimizing ecological impact, promoting social inclusion, or enhancing quality of life.

Value creation and delivery refer to the organizational processes, resources, capabilities, and stakeholder relationships that enable the firm to generate and distribute value. This encompasses the adoption of sustainable production practices, the integration of responsible suppliers, and the formation of partnerships aimed at reducing environmental and social externalities along the value chain.

Finally, value capture refers to how the firm retains a portion of the value it generates. While traditionally associated with revenue and profit, in SBMs, this component also includes intangible and long-term returns, such as an improved reputation, increased stakeholder trust, and access to emerging markets that prioritize sustainability (Bocken et al., 2014; Knudson, 2023).

From this perspective, Bocken et al. (2014) propose eight sustainable business model archetypes, identifying recurring configurations through which companies can contribute to environmental and social sustainability while maintaining economic competitiveness.

These archetypes are grouped into three main categories:

- Technological, such as maximizing resource efficiency and valorizing waste;
- Social, promoting new forms of value through the shift from ownership to usage, the adoption of social and environmental responsibility by firms, and the encouragement of more conscious and sufficient consumption behaviors;
- Organizational, fostering new ownership models, inter-organizational collaboration, open innovation, and entrepreneurial approaches oriented toward generating positive impacts for both society and the environment.

These archetypes serve as a useful guide for innovating existing business models or developing new ones, offering concrete solutions for integrating sustainability into the processes of value creation, delivery, and capture. They help systematize emerging practices and serve as a reference for firms and researchers seeking to design models oriented toward a sustainable transition. The analysis of the three core components – value proposition, value creation and delivery, and value capture – highlights the increasing complexity and interconnectedness that characterize sustainable business models. Integrating the economic, social, and environmental dimensions into the logic of value creation requires a systemic perspective that considers not only immediate performance but also indirect effects and long-term dynamics. In this context, a static representation of the business model is no longer sufficient. A dynamic approach is needed – one that can capture interdependencies, anticipate environmental shifts, and assess the non-linear consequences of strategic decisions.

To effectively support the transition toward more sustainable development models, firms must be equipped with advanced operational tools that go beyond merely describing organizational structures or value propositions. Such tools should enable the capture and understanding of the dynamic complexity of interconnected systems, facilitate the identification of trade-offs among different objectives, and support adaptive and informed decision-making processes.
It is in this direction that the DBMfS (Cosenz et al., 2020) emerges as a suitable framework. It represents a methodological evolution of the traditional business model, combining the logic of the Sustainable Business Model Canvas with the principles of SD, to offer a dynamic, feedback-

based framework for managing complexity. The DBMfS enables the structured representation of causal relationships among resources, activities, stakeholders, and outcomes, modeling the feedback mechanisms that support (or hinder) the generation of sustainable value over time. Through tools such as causal loop diagrams and stock-and-flow models, it becomes possible to explore how changes in one part of the system can produce ripple effects across the entire business ecosystem, influencing not only economic performance but also environmental and social impacts. This approach makes the DBMfS particularly suitable for complex, multi-actor organizational contexts, such as port systems, where sustainability cannot be managed through linear logic or standardized solutions. On the contrary, the ability to govern sustainability depends on the capacity to continuously learn from systemic dynamics, adapt strategies to evolving external conditions, and promote a shared vision of value among all stakeholders involved. In summary, the DBMfS stands out as both a theoretical and practical tool to address sustainability challenges in an integrated, dynamic, and forward-looking manner. It enables organizations not only to align their activities with the principles of the TBL, but also to develop business models that can evolve, generate positive impacts, and enhance their strategic resilience. The next section discusses the structure and functioning of the DBMfS, highlighting its practical application in the field of port management.

2.4 The methodological framework: the Dynamic Business Model for Sustainability

In a context marked by increasing complexity, uncertainty, and the acceleration of economic, social, and environmental change, traditional business models exhibit significant limitations in supporting organizations in strategic decision-making processes oriented toward sustainability. In particular, tools such as the Business Model Canvas (BMC) (Osterwalder & Pigneur, 2010) offer a concise and accessible representation of value creation logic; however, they are overly static and ill-suited to capture the dynamic and interdependent nature of contemporary organizational systems. The lack of a temporal dimension and the absence of causal relationship modeling significantly undermine the BMC's ability to effectively support strategic planning and control in volatile, sustainability-oriented environments. To address these limitations, this research proposes the adoption of the DBMfS, a framework developed by Cosenz et al. (2020), which aims to explicitly integrate the three sustainability pillars into the business models of port authorities. The DBMfS emerges from the combination of an adapted version of the Sustainable Business Model Canvas (Osterwalder & Pigneur, 2010) and the methodological approach of System Dynamics (Cosenz, 2017; Cosenz & Noto, 2018). It provides a theoretical and operational tool capable of overcoming the rigidity of static models and capturing the evolutionary and feedback-driven dynamics that characterize complex business systems. Through a causal and temporal representation of the relationships between key processes, strategic resources, stakeholders, performance drivers, and outcomes, the DBMfS enables decision-makers to explore future scenarios, simulate alternative policies, and assess the consequences of strategic choices across economic, environmental, and social dimensions. In doing so, it strengthens the alignment between strategic vision, organizational structure, and sustainability goals, promoting continuous organizational learning and the development of more resilient and adaptive business models.

The following sections will provide a detailed account of the methodological evolution that led to the development of the DBMfS. First, the original formulation of the Business Model Canvas will be analyzed, highlighting both its strengths and its main limitations in addressing sustainability and systemic complexity. Then, the foundations of System Dynamics – a methodology for understanding and modeling complex systems that can represent feedback loops, time delays, and nonlinear dynamics – will be introduced. Finally, the chapter will illustrate the evolution from the Dynamic Business Model Canvas to the Dynamic Business Model for Sustainability, with particular emphasis on its application in the field of sustainable port governance.

2.4.1 The Business Model Canvas

The Business Model Canvas (BMC), developed by Osterwalder and Pigneur (2010), is a widely adopted strategic management tool that provides a visual and practical framework for describing both the internal and external dynamics of a business. It is one of the most commonly used archetypes and proves particularly effective in communicating business strategies in a clear and structured manner. The BMC is divided into nine "building blocks", each representing a fundamental component of the value creation process. These blocks are as follows:

1. **Key Partners**: This block identifies the primary external stakeholders involved in value creation, particularly those essential to the execution of business activities (e.g., suppliers, financiers, and strategic alliances).
2. **Key Activities**: This building block outlines the most critical actions an organization must take to ensure the functionality of its business model. It describes the core activities and processes that enable the company to deliver its value proposition such as production, marketing, research and development.
3. **Key Resources**: This section outlines the most critical assets necessary for a business model to succeed. These include both tangible and intangible resources linked to critical

success factors. Key resources can be physical, financial, intellectual, or human in nature. Moreover, they may be acquired from the market or developed internally through organizational routines and are used in the value creation process.

4. **Value Proposition**: This building block describes the bundle of products and services that create value for a specific Customer Segment. It illustrates how the company's offering meets customer needs and defines the strategic positioning of the business in terms of differentiation and value delivered.
5. **Customer Relationships**: This section outlines how the organization engages with its customer base to acquire new customers and retain existing ones.
6. **Channels**: This section describes how a company communicates with and reaches its Customer Segments to deliver a Value Proposition. It outlines the means through which products or services are delivered to customers, including distribution, sales, and communication channels.
7. **Customer Segments**: This section identifies the specific groups of people or organizations the business aims to serve, distinguishing between different types of customers based on their needs and characteristics.
8. **Cost Structure**: This block highlights the major costs associated with operating the business, with a focus on resource acquisition, operational activities, and key partnerships.
9. **Revenue Streams**: It details how the business earns income from its customer segments, including pricing mechanisms and expected sales volumes.

The nine building blocks form the basis for the BMC, whose structure – originally developed by Osterwalder and Pigneur (2010) – is illustrated in the figure below.

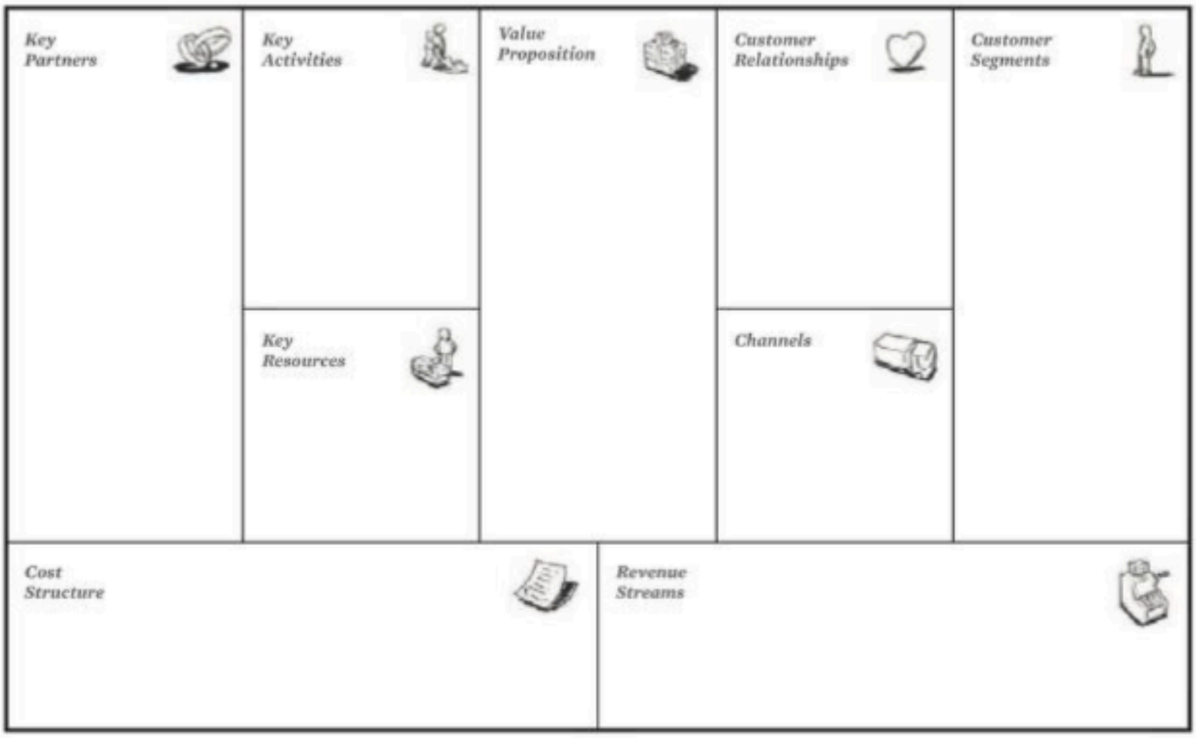

Figure 10. Business Model Canvas

Source: Osterwalder and Pigneur (2010)

These elements capture the core aspects of how a business creates, delivers, and captures value, providing a comprehensive snapshot of the organization's operational structure. The internal blocks represent the drivers of business value, while the external ones reflect the elements that influence and are influenced by the company's operations.

Although it is widely used and recognized by academics and companies, BMC provides only a static approach. Without a dynamic perspective, decision-makers cannot understand the interconnections within complex systems and the unintended outcomes of decisions, operations, and activities (Bordoli et al., 2023).

Modern markets are indeed characterized by high uncertainty, dynamic complexity, and unpredictability. In such complex contexts, the absence of a systemic perspective renders the BMC incapable of clearly representing the causal relationships among its elements, leaving fundamental questions unanswered regarding the interactions between resources, key activities, customers, costs, and revenues. Moreover, the BMC does not distinguish between linear and non-linear relationships, nor does it permit the analysis of trade-offs among efficiency, competitiveness, and sustainability. Another critical issue concerns the static nature of the model, which makes it unsuitable for capturing the evolving dynamics of both the competitive and organizational environment (Chesbrough, 2010; Demil & Lecocq, 2010).

To overcome the excessive rigidity typical of traditional business models, this research proposes the adoption of the Dynamic Business Model Canvas for Sustainability. This framework integrates the three dimensions of sustainability. It adopts a dynamic and systemic perspective to understand and evaluate the interactions among key variables in the business model by combining the BMC with the System Dynamics (SD) approach (Cosenz & Noto, 2018; Cosenz, 2017).

The adoption of the System Dynamics approach represents an effective response to the limitations of the traditional BMC. It enables the capture and modeling of causal relationships among business model components, the simulation of alternative scenarios, and the analysis of the consequences of strategic decisions.

In summary, the limitations of traditional business models underscore the need for a conceptual and methodological evolution that can effectively address the challenges posed by increasingly complex, dynamic, and interdependent organizational contexts. The lack of a systemic perspective, the insufficient focus on causal relationships between model components, and the inability to represent evolving dynamics reduce the business model's effectiveness as a tool for strategic planning and performance management. While traditional models, such as the BMC, are useful for the concise representation and communication of value creation logics, they exhibit significant limitations in supporting strategic management in complex, uncertain, and dynamic environments. The absence of a systemic perspective, the static nature of the model, and the difficulty in capturing causal relationships among strategic variables make these models partial and, at times, inadequate for decision-making processes oriented toward sustainability.

In this context, System Dynamics emerges as a theoretically and operationally grounded response, offering a dynamic and systemic perspective that enriches and strengthens business model design with a dynamic, integrated, and learning-oriented approach. The following section explores the foundational principles and practical applications of this methodology.

2.4.2 System Dynamics modeling

In light of the critical issues discussed in the previous sections, it becomes increasingly evident that there is a need to adopt an approach that goes beyond the rigidity and static nature of traditional business models. Contemporary contexts – characterized by rapidly changing environmental dynamics, increased interdependence among stakeholders, and global challenges such as climate change – require both conceptual and operational tools capable of capturing systemic complexity and the temporal evolution of organizations. In this regard, System Dynamics (SD) emerges as a methodology particularly suited for addressing the inherent complexity and dynamism of modern economic, social, and organizational systems. Originally developed by Jay W. Forrester in the late 1950s at the Massachusetts Institute of Technology, SD was initially designed to model urban and industrial systems. It can be defined as "a perspective and a set of conceptual tools that enable us to understand the structure and dynamics of complex systems" (Sterman, 2000). Over the decades, its applications have expanded to several domains, including strategic management, organizational change, innovation, and, more recently, sustainability. SD is especially useful for analyzing the interactions between variables within a system, highlighting how decisions, processes, and organizational structures influence broader outcomes. It adopts a holistic perspective, enabling the mapping and interpretation of intricate interdependencies and feedback mechanisms in systems characterized by high levels of complexity. SD models are grounded in a cause-and-effect logic, which enables researchers and practitioners to interpret and simulate system behavior concerning a specific issue or phenomenon. This is made possible through the construction of causal relationship chains – known as feedback loops – and their visual representation using two core tools: Causal Loop Diagrams (CLDs) and Stock-and-Flow Diagrams (SFDs).

CLDs are qualitative tools that depict the causal structure of a system, emphasizing the feedback loops and relationships among key variables. In contrast, SFDs provide a quantitative depiction of the physical structure and dynamics of a system, enabling the measurement and simulation of stocks (accumulations) and flows (rates of change). The concept of CLDs was first introduced by Forrester (1961) and further elaborated by scholars such as Rosnay (1979), Richardson and Pugh (1981), Senge (1990), Sterman (2000), and Morecroft (2015). Their primary function is to map a system's structure and feedback to uncover its underlying behavioral mechanisms. Feedback loops are closed chains of causal relationships that can be either reinforcing or balancing (Sterman, 2000).

The polarity of a loop is determined by multiplying the algebraic signs of each causal link: a direct relationship is denoted by a positive sign (+), and an inverse relationship by a negative sign (−).

In particular, a reinforcing loop (R) has a positive polarity and produces exponential growth or decline in the behavior of the affected variable, often resulting in instability. These are also known as positive feedback loops, where the interactions among variables amplify change.

Importantly, the term “positive” refers to the polarity of the relationship, not to its desirability or impact (Bianchi, 2016).

A balancing loop (B), by contrast, has a negative polarity and acts to counter deviations from a desired condition, thereby fostering system stability. These are also known as negative feedback loops, which dampen fluctuations and maintain the system in equilibrium (Bianchi, 2009).
Understanding these feedback mechanisms is essential for predicting system behavior and managing complexity, particularly in organizational and business environments (Sterman, 2000; Forrester, 1961). By adopting the SD perspective, it becomes possible to identify and simulate the interdependencies and feedback structures within business models, enabling a more nuanced understanding of how various components influence one another (Cosenz & Noto, 2017).

The following figure synthesizes the fundamental characteristics of feedback loops and illustrates the concept of causal loops.

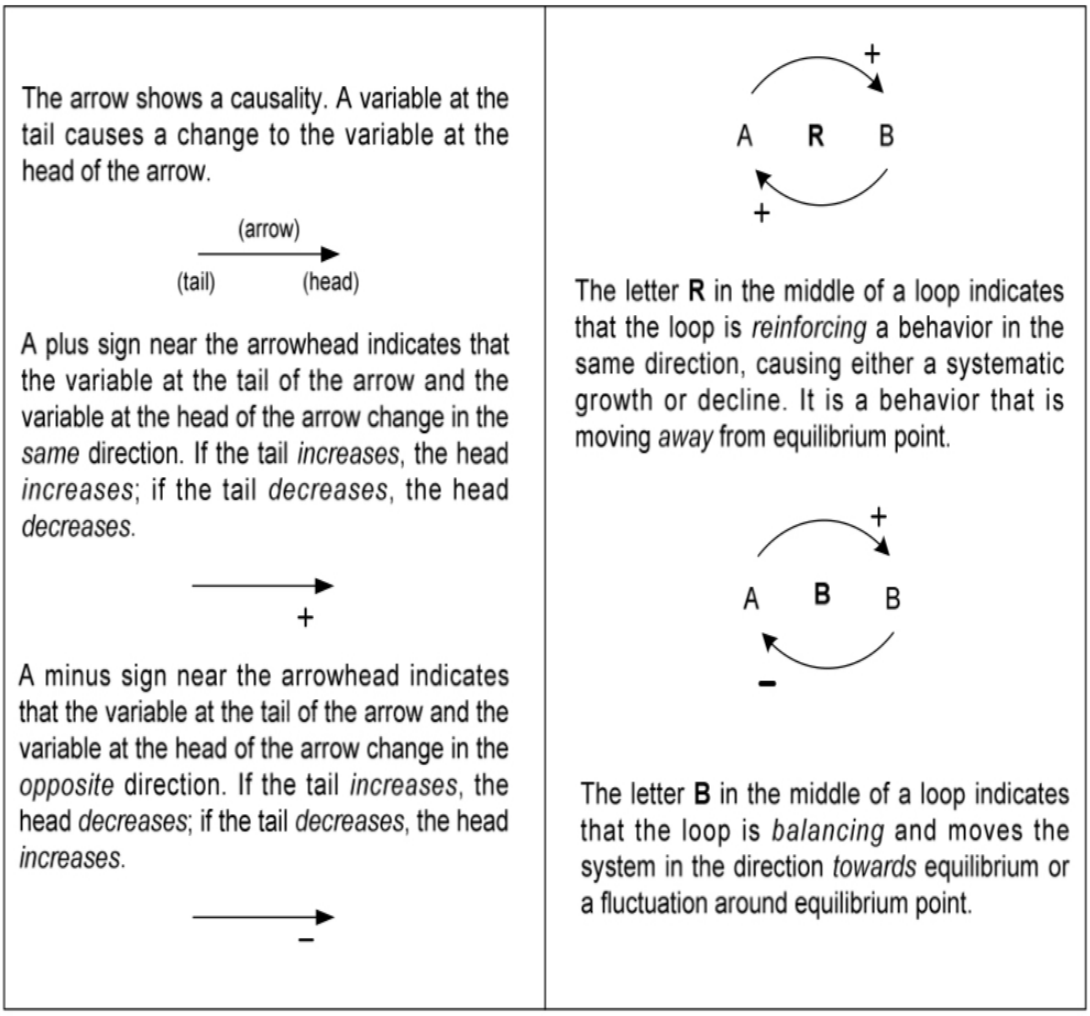

Figure 11. The Causal Loop concept explained

Source: Adapted from Roberts et al. (1983) in Haraldsson (2004).

A reinforcing loop represents a self-reinforcing system in which the interaction among variables leads to accelerated growth or decline. Feedback in such systems amplifies the direction of change, resulting in a compounding effect over time. Typical examples include compound interest, population growth, and the spread of information through viral channels. This behavior is typically visualized through an upward or downward curve over time, as illustrated in Figure 12, which depicts the dynamic behavior of a reinforcing loop (Haraldsson, 2004).

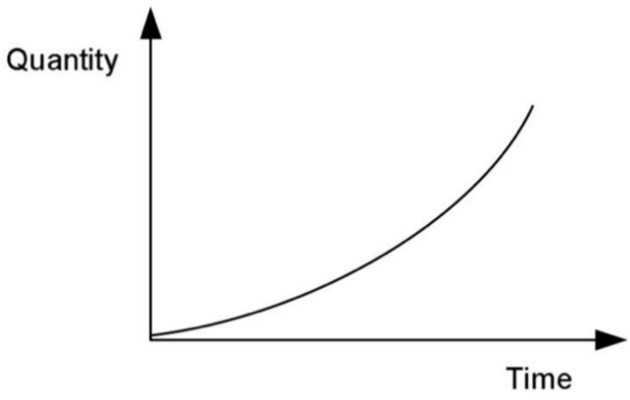

Figure 12. Behavior over Time of a Reinforcing Loop

Source: Adapted from Haraldsson (2004)

In contrast, a balancing loop describes a self-regulating system that tends to stabilize around a target value. These systems incorporate variables that counteract deviations and maintain equilibrium. A classic example is the act of filling a glass with water: once the glass reaches its capacity, the inflow stops, demonstrating how the system maintains a stable state. The behavior over time of a balancing loop is shown in Figure 13, where the curve initially increases and then levels off, indicating system stabilization (Haraldsson, 2004).

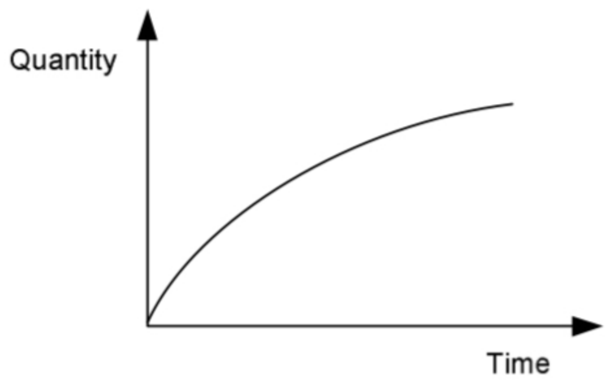

Figure 13. Behavior over Time of a Balancing Loop

Source: Adapted from Haraldsson (2004)

In addition to CLDs, a fundamental modeling tool in SD is the Stock-and-Flow Diagram (SFD), which provides a quantitative and structural representation of how accumulations (stocks) and movements (flows) of resources evolve over time.
While CLDs are primarily qualitative, focusing on the identification of causal feedback loops,

SFDs provide a more formal and detailed representation of a system's physical and informational architecture, thereby enabling the simulation of its dynamic behavior. Stocks represent quantities that build up or deplete over time – such as the amount of inventory in a warehouse or the level of financial reserves. Flows, by contrast, represent the rates at which these stocks change, such as production rates, customer arrivals, or cash inflows and outflows. The interplay between stocks and flows determines the system's dynamic state and reflects its responsiveness to internal decisions or external stimuli.

A key advantage of SFDs lies in their ability to model time delays and nonlinear behaviors, both of which are common in real-world systems. Time delays – such as those associated with recruiting personnel, shipping goods, or procuring raw materials – can have significant effects on system stability and performance. Additionally, nonlinearities, including threshold effects, capacity constraints, and diminishing returns, can also be effectively represented and analyzed using this modeling framework.

By integrating stock-and-flow structures with the feedback loops previously mapped through CLDs, SD enables the development of simulation models that are both conceptually sound and operationally useful. These models enable decision-makers to test alternative strategies, explore long-term consequences, identify leverage points, and better manage the inherent complexity of strategic and operational planning (Bianchi, 2009; Bianchi, 2016; Forrester, 1961; Sterman, 2000).

The following figure presents a basic structure of a Stock-and-Flow Diagram, summarizing the core elements and relationships used in dynamic modeling.

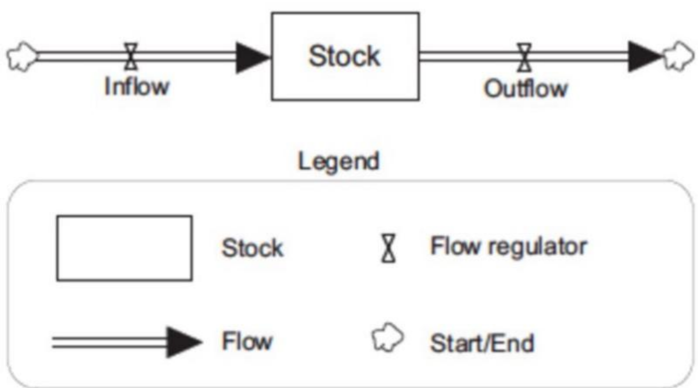

Figure 14. Stock and Flow Notation

Source: Sterman (2000)

The typical tools of System Dynamics are essential for adopting a truly dynamic and systemic perspective when analyzing complex systems. Their use enables a structured understanding and visualization of the interactions among economic, social, and environmental variables, which are often difficult to capture with static analytical approaches. Specifically, CLDs help identify feedback mechanisms that shape the emergent behavior of the system. At the same time, SFDs convert these qualitative relationships into quantitative models, allowing for the simulation of the system's temporal evolution. Overall, SD offers an integrated and operational framework for decision-making, as it facilitates the analysis of strategic levers, the detection of bottlenecks, and the evaluation of potential system trajectories in response to internal decisions or external shocks. In doing so, it supports strategic analysis and performance management (Bianchi, 2016; Morecroft, 2007, 2015).

Moreover, adopting a System Dynamics perspective is crucial in complex governance contexts, where strategic decisions, expected outcomes, and environmental conditions continuously co-evolve and influence one another over time. In such settings, the Dynamic Performance Governance (DPG) approach – grounded in System Dynamics principles – provides a robust conceptual framework to link strategic choices with feedback mechanisms, time delays, and resource accumulation processes that shape the evolution of socio-economic systems. By embedding these elements into the decision-making process, DPG supports the design of more adaptive governance frameworks capable of learning from experience, anticipating unintended consequences, and fostering the long-term creation of sustainable public value (Bianchi et al., 2019; Bianchi, 2021, 2022; Bianchi & Grippi, 2025).

Due to its characteristics, SD modeling can provide valuable methodological support for the design of Business Models (BMs) (Cosenz, 2017; Cosenz & Noto, 2018; Groesser & Jovy, 2016), including those oriented toward sustainability (Abdelkafi & Täuscher, 2016; Täuscher & Abdelkafi, 2017), as it satisfies the need to adopt a systemic approach to business model design. This allows for the identification of causal relationships among key elements of the model, overcoming the limitations of traditional static frameworks and supporting a more integrated and dynamic understanding of business behavior (Casadesus-Masanell & Ricart, 2010; Sanchez & Ricart, 2010).

In light of these insights, the next section introduces the Dynamic Business Model (DBM), a framework that integrates System Dynamics principles into the architecture of business models. This approach lays the foundation for more advanced applications, such as the Dynamic

Business Model for Sustainability, which will be explored subsequently to illustrate the integration of sustainability into strategic planning and management.

2.4.3 The Dynamic Business Model Canvas

In light of the previous reflections, it becomes clear that the System Dynamics approach offers a deeper understanding of the dynamics that characterize complex systems. However, to effectively translate this systemic perspective into managerial practice and support strategic design, it is necessary to rethink traditional business model frameworks. In response to this need, the Dynamic Business Model Canvas (DBMC) was developed as an evolution of the traditional Business Model Canvas. This enhanced version integrates the principles of System Dynamics to more effectively represent and simulate the interconnections among the various components of the business model (Cosenz, 2017; Cosenz & Noto, 2017).

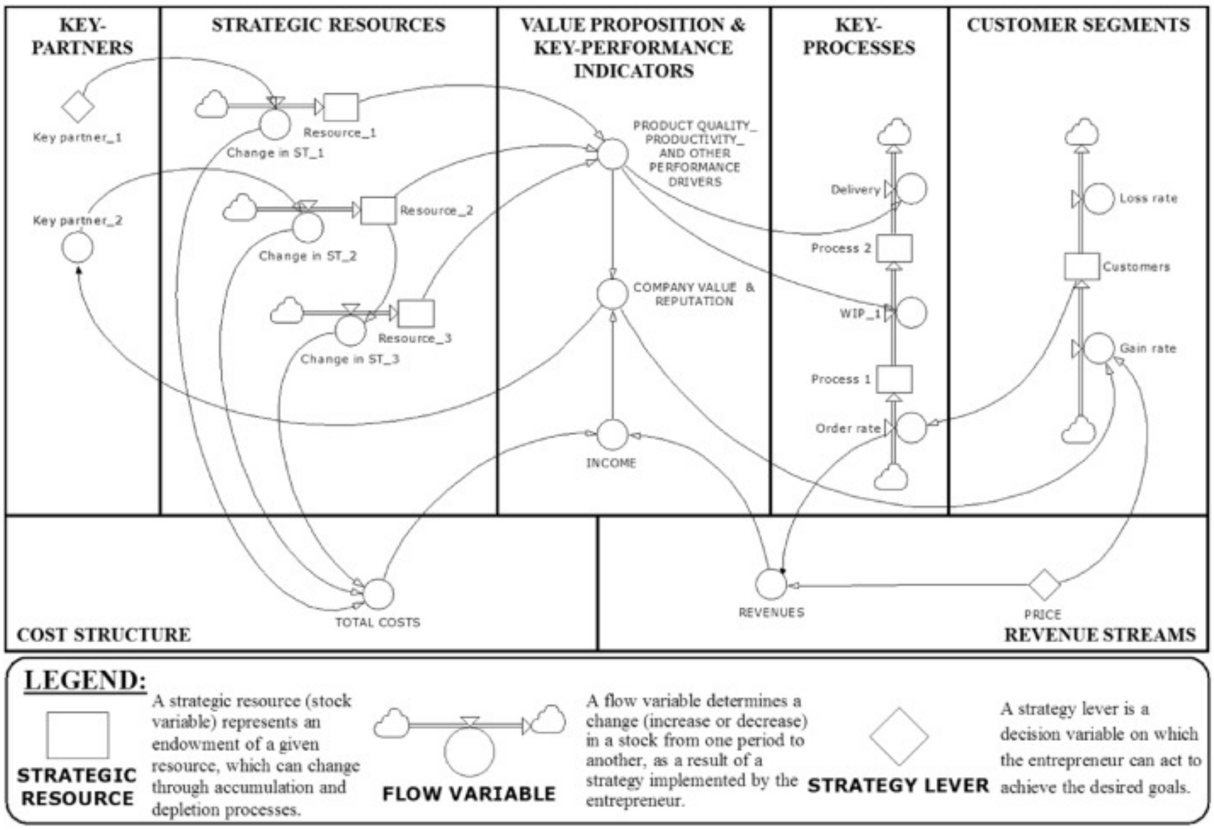

Figure 15. The DBMC framework structure

Source: Cosenz & Noto (2017).

Within the framework structure of the Dynamic Business Model Canvas (DBMC) proposed by Cosenz and Noto (2017), the arrows represent causal connections among the critical elements of the business model, which are distributed across various functional blocks. These links highlight dependencies and dynamic mechanisms that shape the evolution of the business system over time. For instance, in figure 15, pricing and order rate directly influence revenue, which – together with the costs related to the acquisition of strategic resources – determines profit. In turn, profit affects the firm's value and reputation in the medium to long term, which subsequently influences the behavior of key partners. Strategic alliances with key partners may therefore lead to changes in strategic resources, whose allocation impacts performance drivers such as product quality, productivity, and other key factors. These drivers affect business processes as well as the company's reputation and value, ultimately influencing new customer acquisition (Cosenz & Noto, 2018).

The value proposition occupies a central position within the DBMC framework, serving as the point of convergence between strategic decisions and expected performance. It includes a set of indicators (or value drivers) to measure and assess firm performance over time. These indicators may refer to competitiveness, profitability, and social satisfaction, and are expressed in relative terms – that is, by comparing actual results to a benchmark, often linked to a competitor's performance.

Each variable in the DBMC structure can be simulated to observe its behavior over a specific time horizon. Notably, the ability to simulate business system behavior over time allows entrepreneurs to experiment with alternative strategies, assess the effectiveness of specific business choices, and manage potential trade-offs in performance between the short and long term. Therefore, beyond the initial design phase, the DBMC can also serve as a lean managerial tool for measuring and managing performance, as well as for innovating the current business model. As a result, having a holistic view of the business system and the ability to simulate its dynamics over time facilitates strategic learning processes, enhancing the organization's capacity to adapt resiliently and proactively to contextual changes.

The integration of System Dynamics within the BMC allows practitioners to overcome the analytical limitations of traditional models, providing a dynamic framework that realistically depicts interactions among economic, social, and environmental factors. Incorporating SD into the BMC enables the modeling and simulation of causal relationships that link resources, key activities, value propositions, and outcomes over time. This supports decision-makers in anticipating the long-term implications of strategic choices (Cosenz & Noto, 2018; Sterman, 2000). Such an approach enables firms to identify leverage points for intervention, explore alternative scenarios, and address the complexity arising from the need to balance business goals with sustainability objectives (Bocken et al., 2014).
In summary, the systemic and dynamic perspective of System Dynamics enables the

transformation of the business model from a predominantly descriptive and static tool into a predictive and adaptive managerial instrument. The Dynamic Business Model Canvas represents an advanced framework that enables the simulation of the impact of strategic decisions over time, highlighting feedback loops, delays, and trade-offs between short-term and long-term performance (Bianchi, 2016; Cosenz & Noto, 2018). Thanks to its dynamic approach, the DBMC can support more informed and resilient decision-making processes, fostering continuous strategic learning and the sustainable innovation of business models. This approach is particularly effective in complex, rapidly changing contexts characterized by ecological and digital transitions, including those affecting port authorities. The evolution toward a sustainability-oriented business model requires a further step beyond the configuration proposed by the Dynamic Business Model (DBM). In this context, adopting a dynamic and systemic perspective becomes essential to address the growing complexity of contemporary organizational contexts, increasingly influenced by global challenges such as climate change, energy transition, and pressure for responsible resource use. In response to such needs, the DBMfS represents a methodological evolution that explicitly integrates sustainability objectives into the systemic-dynamic logic. This approach, developed by Cosenz et al. (2020), utilizes System Dynamics to map and capture causal relationships among the structural and strategic components of the business model, aiming to gain a deeper understanding of how the system as a whole responds to the implementation of sustainable practices. When sustainability goals are embedded within the business model structure, System Dynamics enables the explicit analysis of interdependencies and feedback mechanisms that link actions, performance, and both short- and long-term impacts. Specifically, changes in one part of the system – such as the adoption of low-impact technologies or inclusive governance practices – can generate nonlinear and often counterintuitive effects on other elements of the model, influencing critical aspects such as reputation, operating costs, stakeholder value, or organizational resilience (Bianchi, 2016; Sterman, 2000).

Through this lens, the DBMfS offers both an analytical and operational framework that enables organizations – including port authorities – to assess to what extent sustainability-oriented strategies can generate long-term value, balancing economic goals with environmental and social objectives. The added value of this approach lies in its ability to support decision-making through dynamic simulations, which help to forecast the systemic effects of strategic decisions and to identify effective and coherent levers for action aligned with the principles of integrated sustainability (Cosenz & Noto, 2018; Bocken et al., 2014; Schaltegger et al., 2016).

2.4.4 The Dynamic Business Model for Sustainability

The DBMfS represents a significant evolution of the traditional BMC, specifically designed to integrate sustainability principles into the strategic structure and operational dynamics of organizations. Originally developed in line with the seventeen Sustainable Development Goals (SDGs) proposed by the United Nations (2015), the DBMfS was elaborated by Cosenz et al. (2020, 2024) to address the growing need for a dynamic, systemic, and sustainability-oriented framework for business modeling.

In particular, the DBMfS is conceptually based on the structure shown in figure 16, which illustrates a Sustainable Business Model Canvas as interpreted by Bocken et al. (2015, 2018). This model represents one of the most significant adaptations of the original BMC developed by Osterwalder and Pigneur (2010), rethought from a sustainability perspective. The Sustainable Business Model Canvas maintains the basic logic of the traditional BMC but incorporates additional elements that reflect the environmental and social dimensions of value creation. It includes, for example, the role of natural resources, the involvement of environmental and social stakeholders, and value capture mechanisms aligned with the "People, Planet, Profit" paradigm.

This version of the canvas allows for a systemic understanding of how an organization creates, delivers, and captures value in a sustainable way. It also helps identify opportunities for innovation and supports strategic decisions aligned with long-term sustainability goals.

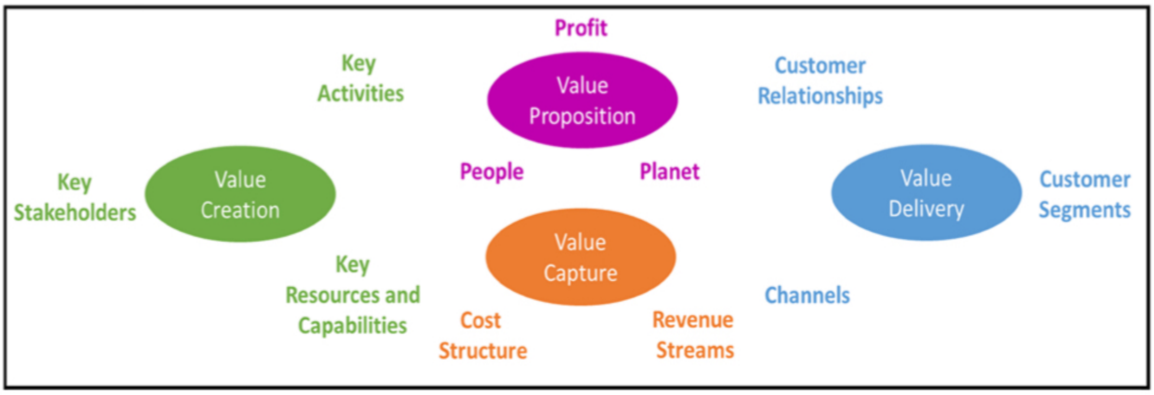

Figure 16. The Sustainable Business Model Canvas

Source: Cosenz et al. (2020), adapted from Bocken (2015) and Bocken et al. (2018)

The DBMfS builds upon the framework in Figure 16 by introducing a dynamic perspective that highlights feedback loops, delays, and interdependencies among key components of the business model, thus enabling a more comprehensive and forward-looking approach to sustainable management. As illustrated in Figure 17, the DBMfS is structured around seven key building blocks, each representing a fundamental dimension of the business architecture (Cosenz et al., 2024):

1. **Key Stakeholders:** Identifies both internal and external actors that influence or are influenced by the organization's activities.
2. **Strategic Resources:** Includes tangible and intangible assets necessary for creating and delivering sustainable value.
3. **Key Processes**: Encompasses core operational, relational, and innovation activities that support sustainable value creation.
4. **User Segments:** Replaces the “customer segments” block from the traditional BMC with a broader perspective on the users of value, including non-market actors such as communities, institutions, and ecosystems.
5. **Sustainable Value Proposition:** Articulates the organization's promise of sustainable value creation across the three pillars of the Triple Bottom Line.
6. **Cost Structure:** Identifies the main cost drivers and financial commitments necessary to support the delivery of long-term environmental, social, and economic value.
7. **Revenue Streams:** this block captures both traditional financial returns and broader benefits or savings generated through sustainable practices.

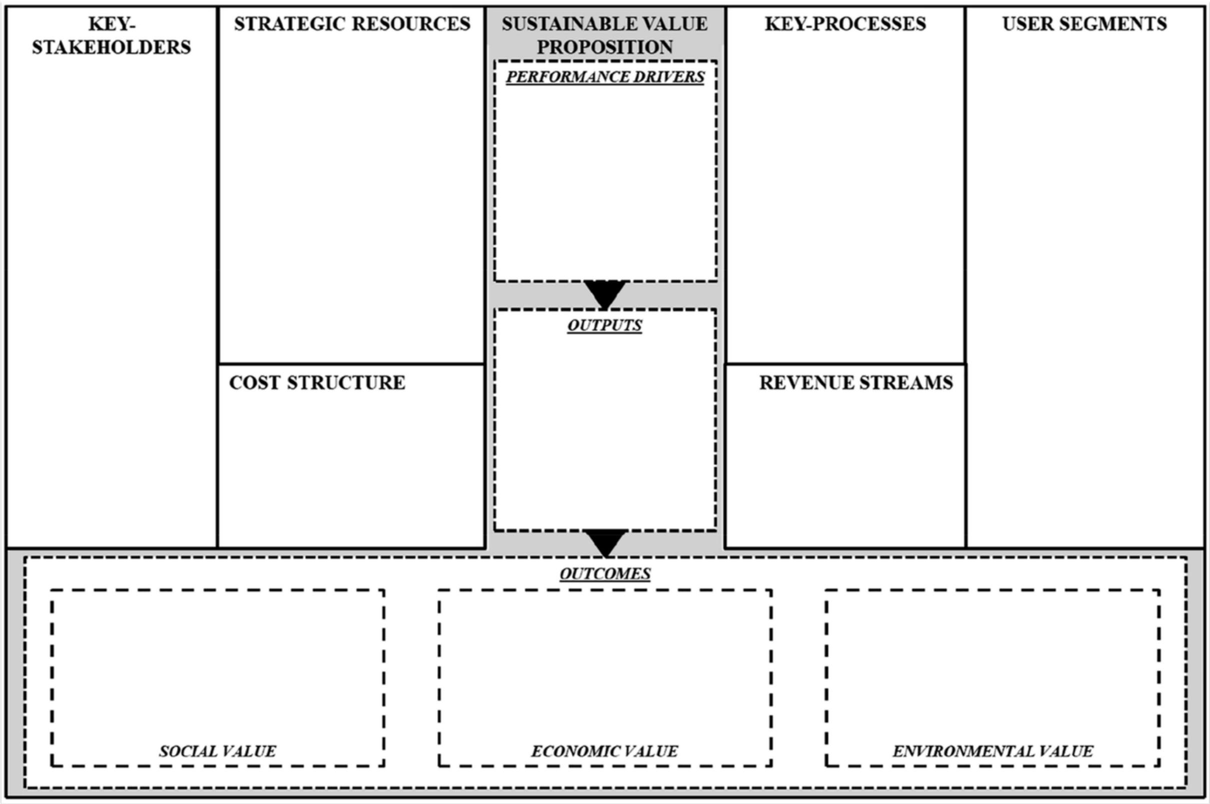

Figure 17. The Dynamic Business Model for Sustainability structure

Source: Cosenz et al. (2020)

Unlike the traditional BMC proposed by Osterwalder and Pigneur (2010), which focuses on customer segmentation and value creation in primarily economic terms, the DBMfS introduces significant structural and conceptual innovations. One of the most notable is the substitution of the conventional customer segments block with a more inclusive and systemic user segments section. This modification reflects a paradigmatic shift from a narrow market-driven logic to a broader stakeholder-oriented perspective. The user segments encompass not only clients in the strict sense but also a range of relevant actors who either benefit from or contribute to the organization’s activities and impacts. In the context of a port authority, for example, user segments may include shipping companies, terminal operators, logistic service providers, cruise lines, ferry passengers, cargo owners, port workers, and local communities. This reconceptualization of “users” reinforces the model’s embeddedness within its territorial and socio-economic environment, aligning with stakeholder theory and the growing emphasis on inclusive governance in public infrastructure systems.

Moreover, the DBMfS reconfigures the internal architecture of the business model by grouping the traditionally separate blocks of customer relationships, distribution channels, and key activities into a unified component called key processes (Cosenz et al., 2020). This aggregation not only reflects a process-oriented logic but also emphasizes the integration and orchestration of critical operations that support the creation, delivery, and co-creation of sustainable value. Within a port ecosystem, key processes may include vessel traffic management, cargo handling, intermodal coordination, environmental monitoring, stakeholder engagement, and innovation partnerships. These processes are not viewed as isolated actions but as interdependent and dynamically evolving flows of value, knowledge, and resources that contribute to the overall systemic performance of the port.

The most profound transformation, however, occurs within the value proposition block, which in the DBMfS assumes a central and expanded role. While in the original BMC, the value proposition focuses primarily on the product or service benefits offered to customers, in the DBMfS, it is redefined as the organization's multi-dimensional promise to society, articulated along the three interconnected pillars of sustainability: economic, social, and environmental. This reframing aligns with the TBL logic (Elkington, 1998), which urges organizations to generate not only financial returns but also social equity and ecological integrity. The sustainable value proposition is expressed through a series of key performance indicators and is further structured into three analytical subcomponents: performance drivers, outputs, and outcomes.

Performance drivers refer to the strategic levers and operational enablers that influence the creation of value. Outputs are the short-term, measurable results of business activities. At the same time, outcomes represent the long-term effects and systemic changes generated by those activities, including regional economic growth, social cohesion, improved public health, biodiversity protection, and climate resilience. Outcomes are further categorized into social, economic, and environmental value according to the TBL of Port Sustainability. Each component of the value proposition includes a specific set of indicators designed to measure the firm's performance from a multidimensional sustainable value perspective (Cosenz et al., 2020).

In summary, the DBMfS provides a robust framework for integrating the three dimensions of sustainability into the strategic planning and management of complex organizations. Through a systemic and dynamic perspective, it enables organizations to map, monitor, and enhance sustainable value creation across three sustainability domains. By making explicit the causal mechanisms that drive sustainable performance, the DBMfS supports more informed decision-making and a better alignment of strategies with long-term sustainability goals. Given its capacity to capture and analyze interdependencies and feedback loops within complex systems, the DBMfS is particularly well-suited for organizations operating in dynamic and multifaceted environments such as seaports. The next section explores its relevance and potential in supporting sustainable governance in the port system.

2.5 Relevance of the Dynamic Business Model for Sustainability in seaport management

As introduced in Chapter 1, seaports function as inherently complex systems, shaped by the interplay of economic, environmental, and social dimensions. Their strategic role as global trade and logistics hubs places them at the core of contemporary sustainability challenges, including emissions reduction, economic resilience, social inclusion, and climate adaptation (Acciaro et al., 2014). The environment in which port authorities operate is characterized by high levels of uncertainty and continuous interaction between multiple actors, resources, and decision-making processes (Ensslin et al., 2018; Parola & Maugeri, 2013; Notteboom et al., 2022). This dynamic complexity (Duncan, 1972) makes it difficult to predict the long-term effects of strategic actions and requires flexible, adaptive tools.

In complex contexts, traditional business models and static performance management tools often fall short, as they are not designed to address the dynamic interdependencies and feedback mechanisms that characterize these contexts. Static or reductionist approaches prove inadequate, as they neglect key systemic features such as time delays, feedback loops, and non-linear interactions (Bianchi, 2016).

In contrast, dynamic approaches based on System Dynamics are better suited to understanding and managing such complexity, helping port authorities achieve operational efficiency while advancing sustainable development objectives (Senge & Sterman, 1992; Sterman, 2002). In this light, the DBMfS (Cosenz et al., 2020) provides a comprehensive framework that integrates System Dynamics with business model logic. It supports long-term planning, strategy design, and performance evaluation across the three sustainability dimensions. The model responds to the growing need for holistic approaches in port governance (Lam & Notteboom, 2014; Martins et al., 2024), driven by increasing awareness of ports' negative externalities – such as emissions, pollution, and energy consumption – and by rising regulatory pressures (Beleya et al., 2015; Roh et al., 2016).
The demand for new strategic frameworks is closely linked to the evolution that seaports have undergone in recent years. Modern ports are no longer merely logistical nodes; they now play an active role in the energy transition, supporting the deployment of renewable infrastructure and promoting the adoption of low-carbon solutions, such as green shipping corridors.
At the same time, ports are embracing digital innovation through the implementation of smart

technologies, such as the IoT, blockchain, AI, and digital twins – tools that enhance predictive maintenance, real-time monitoring, and integrated cargo tracking. Increasingly, ports also serve as innovation hubs, collaborating with universities, startups, and technology providers to develop autonomous navigation systems, circular economy practices, and smart logistics solutions (Garrido Salsas et al., 2022).
These transformations are redefining the concept of port value, which must now encompass not only operational efficiency and cargo throughput, but also social well-being and environmental protection.
Within this new scenario, the DBMfS emerges as a robust framework capable of supporting ports in navigating complexity and designing sustainability-oriented strategies. One of its most distinctive contributions lies in the explicit identification and visualization of causal relationships between strategic drivers, outputs, and long-term outcomes. These interconnections can be formalized using System Dynamics tools, which enable a deeper understanding of feedback mechanisms and systemic behaviors over time (Sterman, 2000). By illustrating how these variables interact within feedback loops, the model enhances evidence-based and adaptive decision-making, while also facilitating the alignment of port strategies with global frameworks such as the United Nations Sustainable Development Goals (Nyenno & Nitsenko, 2017).

A key strength of the DBMfS lies in its sustainable value proposition, which incorporates a comprehensive set of tailored KPIs specifically designed to measure and assess seaport sustainability performance. These indicators are structured around three categories – performance drivers, outputs, and outcomes – and capture value creation across the economic, environmental, and social dimensions of sustainability (Di Vaio et al., 2018; UNCTAD, 2023).

By supporting the evaluation, monitoring, and simulation of a port's contribution to strategic sustainability objectives, these KPIs provide a solid foundation for performance management. They assist managers in tracking progress toward long-term goals, identifying performance gaps and their underlying causes, and implementing timely and effective corrective actions. Moreover, the use of these indicators enhances the transparency and legitimacy of strategic decisions, while promoting stakeholder engagement through clear and accountable reporting practices.
The DBMfS provides port authorities with an integrated and flexible framework for embedding sustainability into their strategic planning and decision-making processes. By integrating social, environmental, and economic indicators into decision-making dashboards, the model enables a comprehensive assessment of port performance and supports the formulation and evaluation of

strategic initiatives. This capability enables decision-makers to anticipate results, critically assess potential trade-offs, and make informed adjustments to implemented strategies. The DBMfS also facilitates the identification of feedback loops and systemic risks associated with managerial choices, while allowing for continuous monitoring of the dynamic evolution of key value drivers. A distinctive feature of the model is its capacity to promote organizational learning and stakeholder engagement through iterative model refinement. This process promotes a shared understanding of complex interdependencies, enhances collaboration among internal and external stakeholders, and cultivates a culture of continuous improvement. Its adaptability makes it suitable for a wide range of port types – commercial, industrial, passenger, or mixed-use – and for various governance levels, from port authorities to terminal operators. Its systemic structure not only ensures strategic alignment but also enables the co-creation of sustainable value across the entire port ecosystem.

Ultimately, the DBMfS offers both theoretical and practical contributions to the governance of sustainable seaports. By embedding sustainability into the design, implementation, and evaluation of business models, it reinforces the role of ports as key drivers of sustainable development, capable of strengthening their resilience, competitiveness, and long-term legitimacy. In light of these advantages, this study adopts the DBMfS framework to analyze the case of the Western Sicily Seaport Authority (AdSP MSO), which has shown a strong and ongoing commitment to sustainability practices (AdSP MSO, 2022).

2.6 Concluding remarks

This chapter presents a conceptual and methodological framework for embedding sustainability into strategic planning and performance management within port authorities. Starting from a critical reflection on the limitations of traditional business models in dynamic and complex organizations, and in light of the modern and multifaceted challenges related to sustainability, the chapter introduces the DBMfS. This integrated approach combines the BMC with the principles and tools of System Dynamics (SD).

This integration constitutes a significant advancement in the conceptualization and management of business models, especially in complex, evolving, and sustainability-oriented settings such as seaport systems.

Port ecosystems are inherently complex, involving a multitude of stakeholders, infrastructural constraints, environmental pressures, and growing social expectations. Managing such complexity requires a methodological approach that is not only analytically rigorous, but also capable of adapting to uncertainty and continuous change.

The DBMfS responds to this need by providing a dynamic and systemic structure capable of capturing feedback loops, causal relationships, and the temporal impacts of strategic choices, thereby enhancing the understanding of how sustainable value is dynamically created, distributed, and captured over time.

A distinctive feature of the DBMfS lies in its sustainable value proposition, which includes a set of KPIs aligned with the TBL and the UN SDGs. These KPIs, organized across three levels (performance drivers, outputs, and outcomes), facilitate performance monitoring, enable managers to identify gaps, and support timely and strategic evidence-based interventions. In doing so, the model contributes not only to strategy design but also to performance control, reinforcing accountability and continuous improvement.

From an academic standpoint, the DBMfS contributes to the growing literature on sustainability and performance management in the maritime and logistics sectors. It advances a systemic understanding of how sustainable value is generated over time, offering a dynamic representation of seaport governance challenges.

From a managerial perspective, it provides a concrete tool for informed and transparent decision-making, efficient resource allocation, and the effective integration of sustainability into daily operations.

In an increasingly volatile, uncertain, complex, and sustainability-driven context, port authorities can no longer rely on linear and static planning models. The DBMfS introduces a new approach to strategic thinking – systemic, dynamic, and sustainability-focused – that enables port organizations to better interpret dynamic complexity, anticipate change, and actively shape their future trajectories.

To assess the applicability and effectiveness of the proposed framework, this study adopts a qualitative approach, employing a single-case study design (Yin, 2014). The following chapter presents the empirical implementation of the DBMfS within the Western Sicily Seaport Authority, selected for its demonstrated commitment to sustainable development. This case study highlights how the framework can support the design, implementation, and assessment of sustainability-oriented strategies in port governance, while also discussing its limitations and its contributions to managerial practice, academic theory, and future research.

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3 Case study: the Western Sicily Seaport Authority

3.1 Introduction

This third and final chapter applies the methodological framework introduced in Chapter 2 - the Dynamic Business Model for Sustainability (DBMfS) - to the case of the Western Sicily Seaport Authority (AdSP MSO), one of the sixteen AdSPs established by the Italian port reform of 2016. These institutions were designed to modernize the national port system, enhance its competitiveness, and foster integrated and sustainable development strategies across port infrastructure and related activities (Figueroa, 2016; Governo della Repubblica Italiana, 2016). In recent years, AdSPs have faced increasingly complex and interconnected challenges, arising from the urgent need to balance economic performance with environmental protection and social well-being (Alamoush et al., 2021; Lim et al., 2019; Shen et al., 2024).
The growing pressures from climate change, energy transition, and digital transformation - coupled with heightened stakeholder expectations - have reshaped the strategic landscape in which AdSPs operate. These dynamics underscore the need for AdSPs to integrate sustainability into their strategic planning and performance management systems.
Within this evolving scenario, AdSPs must navigate a multifaceted and constantly shifting regulatory framework, while simultaneously addressing crucial issues such as decarbonization, digitalization, and competitiveness in global maritime markets (Alamoush et al., 2023; Song, 2024; Tan Huynh, 2024; Wan et al., 2025).
These challenges require not only technical and infrastructural adaptations, but also new approaches to strategic planning and decision-making that place sustainability at the core of port governance.
In this context, the adoption of sustainability-oriented tools for performance planning, measurement, evaluation, and management becomes essential to enhance the long-term decision-making capacity of Port Authorities (Alamoush et al., 2021; Brunila et al., 2023; Gu et al., 2023; Martins et al., 2024; Shabib et al., 2025).
However, although sustainability has become a central theme in the maritime domain, existing approaches often remain fragmented, predominantly focused on environmental aspects, and rarely provide an integrated tool for governance and decision-making (Alamoush et al., 2021; Bucak et al., 2020; Martins et al., 2024).
To address this gap in the literature and practice, this chapter aims to demonstrate how the DBMfS can serve as an innovative methodological tool to support the sustainable governance of Port Authorities. Through its systemic and dynamic approach, the model enables the

identification and analysis of the interconnections among resources, processes, and outcomes across the three pillars of sustainability – i.e., economic, social, and environmental - offering an integrated and unified strategic vision. As such, it provides a methodological and operational framework that can guide managerial decisions towards the long-term creation of sustainable public value.

To pursue these objectives, the chapter is structured as follows:

- Section 3.2 introduces the AdSP MSO, outlining its institutional profile and territorial jurisdiction, presenting the characteristics of the port network under its management, and its role within the broader regional and national port systems.
- Section 3.3 describes the Authority's governance model and internal organizational structure, focusing on the configuration of its governing bodies, operational areas, and technical offices as defined in the main official planning documents.
- Section 3.4 provides a comprehensive overview of the operational scale and complexity of the Western Sicily port system. It highlights the multifunctional nature of the Authority, which manages cargo, Ro-Ro, vessel movements, passenger, and cruise traffic. The data portray a resilient and diversified network, confirming the system's strategic weight within Mediterranean trade flows and underscoring the need for integrated governance tools oriented toward sustainability.
- Section 3.5 examines the sustainability strategies and initiatives implemented by the AdSP MSO in recent years, including waterfront regeneration projects, energy transition initiatives, and decarbonization measures.
- Section 3.6 illustrates the application of the DBMfS to the case study, showing how the model enables a systemic and dynamic representation of the interconnections among resources, processes, performance drivers, and end-results across the three dimensions of sustainability. Based on the structure and logic of the business model, a set of tailored indicators is introduced to assess and monitor the Authority's sustainability performance over time. These indicators aim to provide port management with a structured and practical information system that supports decision-making, facilitates continuous monitoring and improvement, and contributes to the generation of long-term public value. Furthermore, the DBMfS and the associated indicators may serve as a strategic framework to support sustainability and performance management systems, the formulation of the AdSP's sustainability strategy, and institutional reporting activities.
- Section 3.7 concludes the chapter by summarizing the key findings of the case study and reflecting on the added value of adopting a systemic and dynamic modeling approach, with particular emphasis on the role of the DBMfS in strengthening the Authority's strategic

and operational capacity to address environmental, social, and economic challenges in an integrated and forward-looking manner.

3.2 The Western Sicily Seaport Authority: origins and main developmental stages

The AdSP MSO is a national non-economic public body, entrusted with guidance, planning, and coordination of operations and services in the ports under its jurisdiction. The Ministry of Infrastructure and Transport (MIT) established the Authority within the framework of the Italian port governance reform introduced by Legislative Decree No. 169 of August 4, 2016 (Reorganization, Rationalization, and Simplification of the Legislation concerning Port Authorities, pursuant to Law No. 84 of January 28, 1994). Under this reform, the AdSP MSO absorbed the functions of the former Port Authority of Palermo, which had originally been established under Law No. 84/1994 and was subsequently dissolved (Corte dei Conti, 2024).
The main objective of the 2016 reform was to establish a unified management model for territorially integrated ports, capable of overcoming administrative fragmentation and strengthening the competitiveness and strategic role of the national port system, in line with European guidelines for the Trans-European Transport Network (TEN-T) networks and the sustainable development of infrastructure (Governo della Repubblica Italiana, 2016).

Following its formal establishment in 2017, the AdSP MSO expanded its jurisdiction to include the ports of Palermo and Termini Imerese, which had previously been under the jurisdiction of the suppressed Port Authority of Palermo. It subsequently incorporated the ports of Trapani and Porto Empedocle. In 2021, its territorial scope was further expanded to include the ports of Gela and Licata, and, more recently, the port of Sciacca was also incorporated into the system.

Figure 18 shows the seven ports currently under the jurisdiction of the AdSP MSO.

Figure 18. The seven ports under the jurisdiction of the Western Sicily Seaport Authority (Palermo, Termini Imerese, Trapani, Porto Empedocle, Gela, Licata, and Sciacca). *Source: Author's elaboration. Adapted from AdSP MSO (2022d, November 16). Official Facebook page. https://www.facebook.com/AdSPmarediSiciliaOccidentale*

The AdSP MSO operates under the supervision of the MIT and enjoys administrative, organizational, regulatory, budgetary, and financial autonomy. Its responsibilities include the ordinary and extraordinary maintenance of common areas and seabeds, the supervision of services of general interest, the exclusive administration of maritime state property within the Authority's jurisdiction, and the planning of port area development. The Authority also coordinates administrative activities carried out by other public bodies in port areas and promotes integration with hinterland and inland logistics systems.
In line with the principle of separation between operational roles, entrusted to private operators, and supervisory and regulatory functions, reserved for the AdSPs, the AdSP MSO is prohibited from directly performing port operations or ancillary activities, either independently or through its subsidiaries. This institutional arrangement aims to safeguard managerial neutrality while promoting fair competition and transparency within the port services market (Corte dei Conti, 2024). As a result of its regulatory and territorial evolution, the AdSP MSO currently exercises jurisdiction over a wide and diverse area comprising seven ports: Palermo, Termini Imerese, Trapani, Porto Empedocle, Gela, Licata, and Sciacca (AdSP MSO, 2024a, 2025a). This multi-port configuration embodies the systemic logic introduced by the legislator, according to which ports with different characteristics, functions, and capacities are managed

in a unified and coordinated manner. Such an approach enables the maximization of overall efficiency, fosters functional specialization among ports, optimizes resource allocation, and promotes a balanced development of infrastructure and economic activities across the territory. In line with the regulatory framework - and in particular Article 6 of Law No. 84/94 (Reorganization of port legislation) (Governo della Repubblica Italiana, 1994) - the AdSP is entrusted with a set of institutional functions of both strategic and operational nature (AdSP MSO, 2022a, 2024a, 2025a), including:

- Guidance, planning, coordination, regulation, promotion, and control of port operations and services, including commercial and industrial activities carried out in the ports; exercise of ordinance powers regarding workplace safety and hygiene.
- Ordinary and extraordinary maintenance of common port areas, including seabed management and dredging.
- Assignment and supervision of activities aimed at providing, for a fee, services of general interest to port users.
- Coordination of administrative activities carried out by public entities and organizations within port areas.
- Exclusive administration of maritime state property within the Authority’s jurisdiction.
- Promotion of integration with hinterland and inland logistics systems.

The institutional mission of the Authority is therefore based on the objective of ensuring the integrated and sustainable management of port infrastructure and services, fostering long-term strategic planning, the efficient allocation of resources, and leveraging synergies among ports with different specializations. In this regard, the AdSP MSO does not limit itself to considering ports as autonomous operational entities. Still, it integrates them into a single logistics and production network designed to generate economic, social, and environmental value in a systemic and coordinated manner (AdSP MSO, 2022c, 2024b).

As highlighted in several of the Authority’s key institutional documents (AdSP MSO, 2022a, 2022c, 2024b), the ports of Western Sicily are no longer conceived as isolated entities but as interconnected nodes of a multipurpose system capable of attracting both commercial and tourist flows. They function not only as fundamental logistics hubs but also as strategic drivers of regional economic growth.

In particular, the port of Palermo, the main hub of the system and the Authority’s headquarters, plays a central role thanks to its high functional diversification, which includes cargo traffic, passenger and cruise services, shipbuilding, and integrated logistics activities. Moreover, its urban location requires careful management of the port–city relationship, through waterfront redevelopment initiatives and the integration of port functions into the urban context.

The port of Termini Imerese, located about 30 km from Palermo, acts as a complementary logistics and industrial hub, designed to decongest cargo flows from the capital and to attract new industrial settlements, thanks to the availability of extensive hinterland areas and intermodal connections (AdSP MSO, 2021).

The port of Trapani, situated at the westernmost tip of Sicily, is characterized by a strong passenger vocation, with regular connections to the minor islands, Ro-Ro services, and tourist activities, including cruise traffic and yachting.

Porto Empedocle, Gela, Licata, and Sciacca, although smaller in size and traffic volumes, play a strategic role in supporting local economies, short-sea shipping, fishing, and coastal tourism, thereby contributing to territorial cohesion and the overall connectivity of Western Sicily.

This heterogeneous territorial configuration requires the AdSP to exercise a strategic coordinating function, balancing local needs with broader system-wide objectives. In particular, the Authority is responsible for coordinating infrastructure investments, defining development priorities that align with national and European plans, promoting environmental sustainability, and modernizing port operations through the adoption of advanced digital systems, thereby reducing the environmental impact of port activities.

In this perspective, the governance of the AdSP aims to transform the port system into an integrated, competitive, and resilient logistics infrastructure. The system is designed to sustain regional economic growth, create high-quality employment, and contribute to achieving decarbonization and sustainability objectives in line with national and international ecological and digital transition strategies.

Accordingly, the ports of Western Sicily must be configured as an integrated infrastructure for mobility, logistics, and energy, open to the territory and oriented toward sustainability, with programming focused on decarbonization, digitalization of processes, energy efficiency, and the urban regeneration of waterfront areas. Within this framework, the Authority is no longer limited to acting as an infrastructure and maritime traffic manager, but also operates as an ecosystem-oriented policy-maker and promoter of inclusive and resilient territorial development. In this role, it combines international competitiveness with the creation of public value, playing a transformative role in advancing the green and digital transition of port cities (AdSP MSO, 2022c, 2024b; González-Laxe et al., 2025; Tijan et al., 2021).

3.3 Governance and organizational structure

The governance of the AdSP MSO is based on a multi-level framework in which decision-making processes are distributed across various institutional and territorial levels, involving public, private, and civil society actors.

Port systems operate at the intersection of European, national, regional, and local interests, combining regulatory, economic, and community dimensions (AdSP MSO, 2022b).

At the European level, regulations and policies on transport, competition, and sustainability define the strategic framework of reference. At the national level, the MIT plays a central role, with formal powers concerning the appointment of the President of the AdSP and the approval of key planning instruments. At the regional and municipal levels, the Sicilian Region and its relevant municipalities actively participate through territorial planning functions, land-use regulation, and the involvement of local stakeholders.

The governance and organizational structure of the AdSP - comprising the President, Management Committee, Board of Auditors, Secretary General, and functional areas - ensures the effective implementation of strategies. Within this institutional framework lies a diversified stakeholder system that includes:

- Public sector, represented by port governance bodies, relevant ministries, and territorial entities;
- Private sector, consisting of port and logistics operators, shipping companies, concessionaires of state-owned areas, and firms located in the hinterland;
- Civil society, including local communities, employees, non-governmental organizations, environmental groups, research bodies, universities, media, as well as new actors of the digital communication ecosystem (e.g., bloggers and influencers).

This multi-level architecture facilitates the integration of institutional, economic, and social interests, harmonizing national development objectives with territorial and urban needs, while reinforcing the legitimacy of decisions through participatory processes and tools for planning, monitoring, and accountability (AdSP MSO, 2022b).

The current institutional structure of the AdSP MSO, as established by the applicable legislation (Article 7 of Law No. 84/1994, later amended by Legislative Decree 169/2016), is organized into three political-administrative bodies (AdSP MSO, 2022a; Corte dei Conti, 2024; Governo della Repubblica Italiana, 1994, 2016):

- The President of the AdSP;
- The Management Committee;

- The Board of Auditors.

The President of the AdSP, as the top governing authority with both political and technical functions, exercises the legal representation of the Authority and holds powers of ordinary and extraordinary administration, except for those reserved for the other bodies. According to Article 8 of Law No. 84/1994 and subsequent amendments, the appointment is made by the Minister of Infrastructure and Sustainable Mobility, in agreement with the President(s) of the Region(s) concerned, and may only be conferred on citizens of European Union member states with proven experience and qualifications in the fields of transport economics and port management. The mandate has a duration of four years and may be renewed once. Among the responsibilities of the President are the management of financial resources in line with the POT, the functions of guidance, coordination, and supervision of the Authority’s activities, as well as the granting of authorizations and concessions lasting less than four years. The complexity of the role requires not only advanced technical expertise but also a strategic vision oriented toward the development of the port system as a whole, enhancing its competitiveness beyond purely bureaucratic logic. This demands managerial skills, the ability to engage in dialogue and interaction with different categories of operators, and competencies in economic forecasting, tariff, and logistics strategy formulation, as well as the capacity to build alliances with other ports and attract new operators.

The President must also be able to adapt the Authority’s policies to stakeholder needs, balancing public interest with market demands.

The Management Committee, pursuant to Article 9 of Law No. 84/1994, is the collegiate body responsible for approving the planning and management acts submitted by the President (including the POT, the Port System Strategic Planning Document (DPSS), the Budget, and the DEASP). It is composed of the President of the AdSP and four additional members representing the Sicilian Region, the municipalities included in the port system (the City of Palermo and the Municipality of Trapani), and the competent maritime authority (the Maritime Director of Western Sicily and the Harbor Master of Palermo) (AdSP MSO, 2022a; Corte dei Conti, 2024). The Board of Auditors of the AdSP was established by Ministerial Decree No. 426 of 28 October 2021 for a four-year term starting on 15 November 2021. It is responsible for auditing tasks required by law, including verifying accounting records, performing cash audits, drafting reports, and attending Management Committee meetings. The Board may also request information from the President of the AdSP and report any irregularities to the Ministry. Furthermore, the Independent Evaluation Body, appointed by the political–administrative governing body, performs functions established by Legislative Decree No. 150/2009 and Law No. 190/2012 in the fields of performance evaluation, transparency, and anti-corruption, to foster a culture of accountability and transparency within public administration (AdSP MSO , 2022a; Corte dei Conti, 2024). To support the work of the Management Committee, the Partnership Body for Maritime Resource was established under Article 11-bis of Law No. 84/1994. This representative collegial body has consultative functions, and its opinions on the organization and development of the port system may be disregarded by the Committee only with proper justification. The President of the AdSP chairs it and includes the Maritime Director as well as members designated by trade associations representing port companies and other operators in the sector, who serve on an unpaid basis, except for possible reimbursements covered by their respective associations (Corte dei Conti, 2024).

In addition, for its administrative functions, the AdSP relies on a General Secretariat, composed of the Secretary General and a Technical–Operational Secretariat, which oversees the four main functional areas of the Authority's institutional activities (State Property and Assets, Finance, Operations and Security, and the Technical area). These are complemented by the Legal Affairs and Monitoring and Control units, which report directly to the President (Corte dei Conti, 2024).

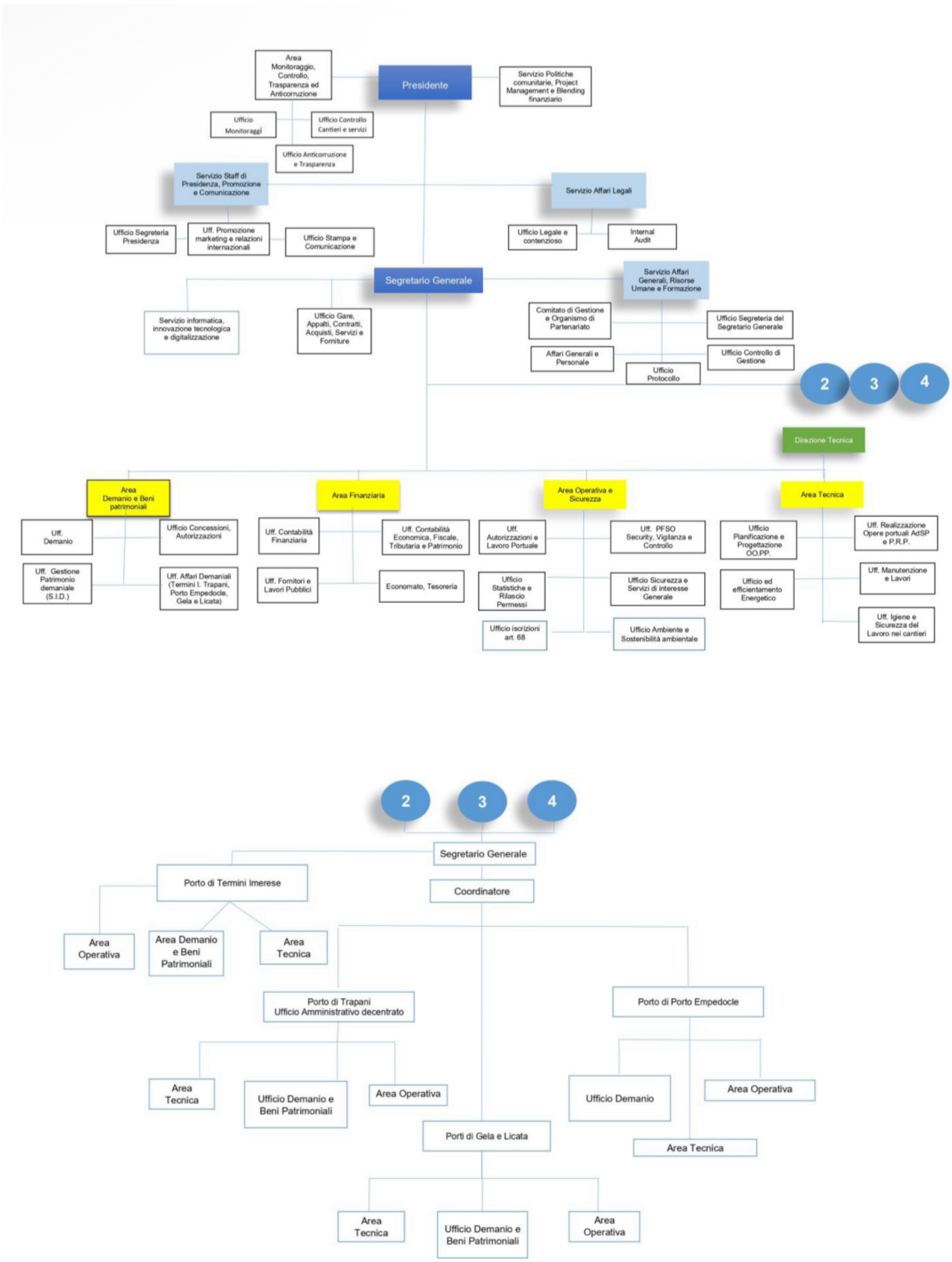

Figure 19. Official organizational chart of the Western Sicily Port System Authority

Source: AdSP MSO *(2024e).*

As illustrated in the official organizational chart of the AdSP MSO, the Authority is structured into Areas, Services, and Offices, some of which report directly to the President and others to the Secretary General. Specifically, the President is responsible for the Area for Monitoring, Control, Transparency, and Anti-Corruption; the Office for EU Policies, Project Management, and Financial Blending; the Presidential Staff Service for Promotion and Communication; and the Legal Affairs Service. The Secretary General, instead, oversees the General Affairs, Human Resources, and Training Service; the IT and Digitalization Office; the Procurement and Contracts Office; the State Property and Assets Area; the Financial Area; the Operational and Security Area; and the Technical Area. Each unit is headed by a Director or Senior Responsible Officer, supported by a dedicated staff (AdSP MSO, 2025b).

The governance of the AdSP reflects the inherent complexity of port systems, which stems from the wide range of tasks, rules, functions, stakeholders, and expectations that must be managed simultaneously. This complexity requires the Authority to act not only as an administrative body but also as a managerial entity, supported by advanced frameworks - such as the DBMfS - that enable it to address strategic and operational challenges systemically and dynamically. It is likewise reflected in the multidimensional nature of port performance, which encompasses port traffic and economic, social, and environmental dimensions. The following sections will analyze these performance dimensions in detail, starting with port traffic flows, which represent the Authority's core business activity.

3.4 Port traffic performance

The Western Sicily Seaport Authority plays a strategic role in the Mediterranean, managing a diversified network of ports with complementary specializations, including container and Ro-Ro traffic, bulk cargo, passenger traffic, and cruise activities. This diversification enhances the system's resilience and adaptability to the dynamics of maritime trade, while also integrating logistics, industrial, and tourism functions. Within this framework, Palermo has consolidated its position as the main hub for cargo and passengers, Termini Imerese has experienced significant growth in the Ro-Ro segment, Trapani and Porto Empedocle perform complementary functions with distinct specializations. At the same time, Gela confirms its strong energy-related vocation (AdSP MSO, 2022c, 2024b).
Overall, these dynamics confirm the progressive consolidation of the AdSP's role within the national and European port network, consistently with the strategic objectives outlined in its institutional planning documents, which emphasize the need to balance competitiveness with environmental and social sustainability (Assoporti, 2025; AdSP MSO, 2022c, 2024b).

This section analyzes traffic-related performance within the port network of Western Sicily, with a focus on the operational dimension of port performance. As traffic flows represent the core activities of the Port Authority, their examination is key to understanding the scale of the network, the complexity of its governance, and the Authority's strategic role.

3.4.1 Cargo traffic

Cargo traffic represents one of the core activities of the AdSP MSO. In recent years, the system has shown an overall stable trend, reflecting both the strong attractiveness of the ports and the strategic geographical position, which ensures resilience to external shocks, as evidenced by the pandemic, which had a limited impact on trade flows.
In 2021, cargo traffic consisted largely of general cargo, accounting for approximately 86% of the total handled, almost entirely originating from the Ro-Ro segment. Most volumes were concentrated in Palermo, with a smaller contribution from Termini Imerese, while Trapani and Porto Empedocle reported marginal figures. Liquid bulk represented around 5% of total traffic, mainly in Palermo and linked to refined oil products, while solid bulk, amounting to around 9%, was more evenly distributed across the ports, with a slightly stronger role for Termini Imerese and Porto Empedocle (AdSP MSO, 2022a). In subsequent years, the system experienced overall growth, consolidating its role within the regional and national landscape.

In 2023, the ports of the AdSP handled approximately 10.8 million tons of cargo, representing a more than 4% increase compared to the previous year. General cargo remained the dominant component, at 9.26 million tons (+9.1%), confirming its role as the primary driver of port traffic.

Liquid bulk rose by 18.4% (494,482 tons), mainly due to the growth in refined oil products handled at Gela and, to a lesser extent, Palermo. Conversely, solid bulk fell sharply by 27.6%, totaling 1.04 million tons (AdSP MSO, 2024f).

Looking at individual ports, in 2023, Palermo handled 8.27 million tons (+7.0% compared to 2022), confirming its role as the main port of the AdSP MSO. General cargo accounted for 7.67 million tons (+10.1%), largely driven by the Ro-Ro segment (7.50 million tons, +9.9%), alongside growth in container traffic (+16.3%). Liquid bulk rose by 22.6% (472,000 tons), while solid bulk experienced a sharp decline (–67.2%).

This trend highlights a growing specialization of Palermo in high-value-added and intermodal traffic, at the expense of traditional bulk commodities. Termini Imerese handled 1.4 million tons, of which more than 1.17 million tons came from the Ro-Ro segment. Trapani recorded 605,000 tons, while Porto Empedocle handled nearly 484,000 tons (AdSP MSO, 2024g, 2024h, 2024i, 2024j).

In 2024, total volumes recorded a slight decline. Palermo confirmed its role as the main hub (8.07 million tons, –2.5%). Liquid bulk increased significantly (+37.3%), while general cargo declined (–4.6%). Trapani and Porto Empedocle registered contractions of –10.2% and –9.7%, respectively, while Gela confirmed its strong energy-related specialization (1.49 million tons) (AdSP MSO, 2025e, 2025g, 2025h, 2025i, 2025j).

In the first half of 2025, data showed a diversified trend: Palermo maintained its leading position (3.88 million tons, +0.5%), Termini Imerese recorded strong growth (+34.0%), Trapani increased by 18.1%, and Porto Empedocle consolidated positively (+4.0%), while Gela experienced a sharp decline (–28.4%) linked to the reduction in refined oil products (AdSP MSO, 2025k, 2025m, 2025n, 2025o, 2025p).

3.4.2 Ro-Ro traffic and vehicles

Ro-Ro traffic represents a strategic segment for the port system of Western Sicily, as it combines the handling of cargo units with the flows of private and commercial vehicles connected to tourism and logistics.

In 2023, the port network recorded significant results. Heavy units transported reached 415,273 (+4.5% compared to 2022), private vehicles 590,904 (+4.5%), and new commercial vehicles 56,882 (+31.9%) (AdSP MSO, 2024f). In 2024, Termini Imerese and Palermo confirmed their roles as the main Ro-Ro gateways. However, Palermo registered a slight decrease (–4.9%) (AdSP MSO, 2025g, 2025h).

In the first half of 2025, Termini Imerese further strengthened its position in the Ro-Ro segment, followed by Trapani (+64.6%), while Palermo experienced a moderate decline (–3.7%). The handling of private vehicles continued to grow across the network, with particularly significant increases in Termini Imerese (+38.9%) and Trapani (+11.1%) (AdSP MSO, 2025m, 2025n, 2025p).

3.4.3 Vessel traffic

Vessel traffic, measured by the number of ship movements, completes the picture of the operational performance of the AdSP ports, complementing the analysis of cargo, Ro-Ro, and passenger volumes. This indicator enables the capture of the frequency and intensity of routes, the specialization of individual ports, and the overall contribution of the port network to the system's competitiveness and sustainability.

In 2023, the ports of the AdSP MSO recorded a total of 15,506 ship movements (+3.8% compared to 2022). This result confirms the progressive centrality of the Western Sicilian port system in Mediterranean maritime flows, supported by both passenger and cargo traffic (AdSP MSO, 2024f). The 2024 trends highlight differentiated dynamics across the various ports. Palermo consolidated its leadership with 6,766 ship movements (+3.0% compared to 2023), strengthening its role as the main hub of the network. Termini Imerese, with 586 movements, confirmed its role as a complementary port, primarily serving Ro-Ro and scheduled services. Trapani achieved a significant result with 4,534 movements, maintaining high levels and confirming its importance both as a passenger port and as a support node for cargo flows. Conversely, Porto Empedocle recorded 1,074 movements (–24.4% compared to 2023), reflecting difficulties in the dry bulk sector. Finally, Gela confirmed its specialization in the energy sector, with 280 movements, a limited number but consistent with its specific role (AdSP MSO, 2025e, 2025g, 2025h, 2025i, 2025j).

In the first half of 2025, vessel traffic across the AdSP ports of Western Sicily showed differentiated dynamics, reflecting the operational specificities of each port. Palermo, despite a slight contraction (–5.1%), confirmed its central role thanks to the high frequency and variety of services offered. Termini Imerese recorded significant growth (+12.7%), reinforcing its logistics and commercial support function, while Trapani remained essentially stable with over 2,200 movements. Porto Empedocle showed a stable trend (+0.4%), though on lower volumes, while Gela, with an increase compared to 2024, confirmed its energy-related vocation. Overall, the data confirm Palermo's centrality, Termini Imerese's expansion, Trapani's continuity, and the more limited but specialized role of Porto Empedocle and Gela, outlining a complementary and resilient port system (AdSP MSO, 2025k, 2025m, 2025n, 2025o, 2025p).

3.4.4 Passenger and cruise traffic

The passenger sector represents one of the most dynamic and steadily growing segments of the Western Sicily port system. In recent years, the ports managed by the AdSP have experienced a significant increase in passenger traffic, driven by both scheduled ferry services and the cruise segment. The latter, in particular, has established itself as a strategic driver for tourism development and economic value generation, serving as a fundamental lever for the growth of Western Sicily (Parigi, 2024). Following the sharp contraction caused by the global pandemic, which in 2020 led to a nationwide collapse in passenger traffic, the Western Sicilian port system demonstrated remarkable resilience (AdSP MSO, 2021).

In 2023, total passenger movements reached 3.89 million (+20.5% compared to 2022), mainly driven by the cruise sector, which recorded over 952,000 cruise passengers (+68.9%) (AdSP MSO, 2024f).

In 2024, the Port of Palermo consolidated its position as the main hub with 2.59 million passengers (+2.3%), while Trapani and Porto Empedocle showed divergent trends (–2.3% and –20.3% respectively). Termini Imerese experienced a sharp contraction in passenger flows between 2023 and 2024, with ferry movements decreasing from 62,715 to 37,239 (–40.6%), marking a particularly significant reduction in scheduled passenger traffic (AdSP MSO, 2025g, 2025h, 2025i, 2025j).

In the first half of 2025, passenger traffic expanded significantly: Palermo (+7.5%), Termini Imerese (+70.4%), Trapani (+14.8%, with cruise passengers up by +314.7%), and Porto Empedocle (+36.8%, cruise traffic +79.4%). Cruise operations were also extended to Licata, which received its first transit call, with 47 cruise passengers (AdSP MSO, 2025l, 2025m, 2025n, 2025o, 2025p).

3.4.5 Concluding insights on port traffic

The analysis of port traffic provides a comprehensive overview of the operational dimension of the AdSP MSO, highlighting both strengths and challenges. The data confirm Palermo's centrality as the main hub, the growing role of Termini Imerese in the Ro-Ro and general cargo segments, Trapani's dynamism in container and cruise traffic, the regional profile of Porto Empedocle, and the specialization of Gela and Licata in energy and bulk cargo.

Overall, the findings outline a polycentric, multipurpose, and resilient system that is also complex to govern. The diversification of traffic flows represents both a strategic asset and a managerial challenge, requiring coordinated and forward-looking governance. The analysis also highlights the growing complexity of the port system, where diversified traffic flows enhance competitiveness but also require governance that balances economic performance with environmental and social considerations (AdSP MSO, 2022c, 2024b).

3.5 Sustainability strategies of the Western Sicily Seaport Authority

In recent years, the Western Sicily Seaport Authority has progressively consolidated a sustainability-oriented approach, conceived not merely as a compliance exercise or a managerial requirement but as a genuine strategic lever for the growth and transformation of the port system.

This orientation is formalized in the Authority's key official documents, particularly in the Sustainability Report, which was voluntarily adopted in 2022. The AdSP defines it as "a project of transparency and dialogue, aimed at designing, measuring, evaluating, and disseminating its activities from a sustainability perspective. It represents a demonstration of responsibility towards stakeholders directly affected by the impact of port activities" (AdSP MSO, 2022a).

The drafting of this document, in addition to fulfilling the need for sustainability reporting, constitutes a concrete commitment to responsible and participatory governance, which is capable of strengthening trust and engagement among the community, economic operators, and various stakeholders involved. This orientation is further demonstrated by the achievement of ISO 9001 (quality management) and ISO 14001 (environmental management) certifications, which attest to the quality of the Authority's managerial processes and its environmental responsibility (Shipmag, 2025).

The Authority's tangible commitment to sustainability is framed within the concept of public value, which provides the interpretative lens for its strategies and initiatives. From this perspective, the AdSP does not limit itself to pursuing economic or infrastructural objectives; rather, it aims to generate tangible benefits for the community. Creating public value entails using resources efficiently, enhancing internal capabilities, developing collaborative networks, and strengthening organizational capacity.

At the same time, it requires addressing the needs of stakeholders and local communities, integrating economic growth, environmental sustainability, and social well-being within a unified vision (AdSP MSO, 2024a, 2025a).

This vision translates into a broad portfolio of strategies, designed to achieve the main strategic objectives set out in the Authority's planning documents, namely the Port System Strategic Planning Document (DPSS) (AdSP MSO, 2022b), the Energy and Environmental Planning Document of the Port System (DEASP) (AdSP MSO, 2021), and the Integrated Plan of Activities and Organization (PIAO) (AdSP MSO, 2024a, 2025a). Among the most relevant objectives are:

- Upgrading and modernizing port infrastructures (DPSS, PIAO)
- Managing traffic and goods (DPSS) efficiently, safely, and sustainably (DEASP)
- Fostering the integration between the city and the port (DPSS)
- Implementing network economies within the port system (DPSS)
- Promoting energy transition and environmental sustainability (DEASP, PIAO)

- Reducing CO_2 emissions through renewable energy, energy efficiency, and low-impact technologies (DEASP)
- Developing and activating smart services and innovative solutions (DEASP)
- Ensuring continuous monitoring of environmental performance (DEASP)
- Strengthening labour protection, occupational safety, and port security (PIAO, DEASP)
- Improving quality of life for local communities and stakeholders (DEASP)
- Guaranteeing transparency, anti-corruption practices, and process digitalization (PIAO)
- Enhancing the Authority's economic and human resources (PIAO)
- Promoting the ports of the system and attracting European funding opportunities (PIAO).

These strategic objectives provide the overall framework within which the Authority develops and implements its sustainability strategies. Collectively, they outline a long-term pathway to transform the ports of Western Sicily from small regional facilities to competitive hubs of international relevance.

These initiatives are consistent with European guidelines on green and digital ports and are coherently structured across the three dimensions of sustainability–environmental, social, and economic (AdSP MSO, 2022a).

In addition to these objectives, the 2022 Sustainability Report identifies several commitments and priorities, such as achieving zero emissions in port operations by 2026, strengthening waste management, protecting biodiversity and marine habitats, improving water quality, and enhancing community engagement and social sustainability in port-related employment (AdSP MSO, 2022a).

To better prioritize both objectives and commitments, the AdSP conducted a materiality analysis aimed at identifying the most relevant aspects guiding its sustainability policies. This analysis graphically represented the relative importance of different issues by linking the Authority's internal priorities with the expectations of external stakeholders.

The development of the matrix followed a three-stage process: first, consultations with internal actors identified an initial set of issues; second, additional topics were incorporated following discussions with external stakeholders; and third, top management validated the process to ensure consistency between the organizational perspective and the demands of the broader context (AdSP MSO, 2022a).

The resulting materiality matrix, shown in Figure 20, highlights the issues considered most relevant by both the AdSP and external stakeholders. The topics located in the upper-right quadrant represent the strategic priorities, as they are deemed highly important by both parties. These include waste management, reduction of energy consumption, abatement of emissions and pollution, transparency and accountability, the use of sustainable materials for infrastructure, and the social sustainability of port-related employment. Other key aspects include community engagement, enhancement of the local socio-economic fabric, workers' health and safety, and the Authority's economic and financial performance. Although located in intermediate areas of the matrix, additional issues still play a meaningful role - such as biodiversity and marine habitat protection, water quality, and the social sustainability of the supply chain.

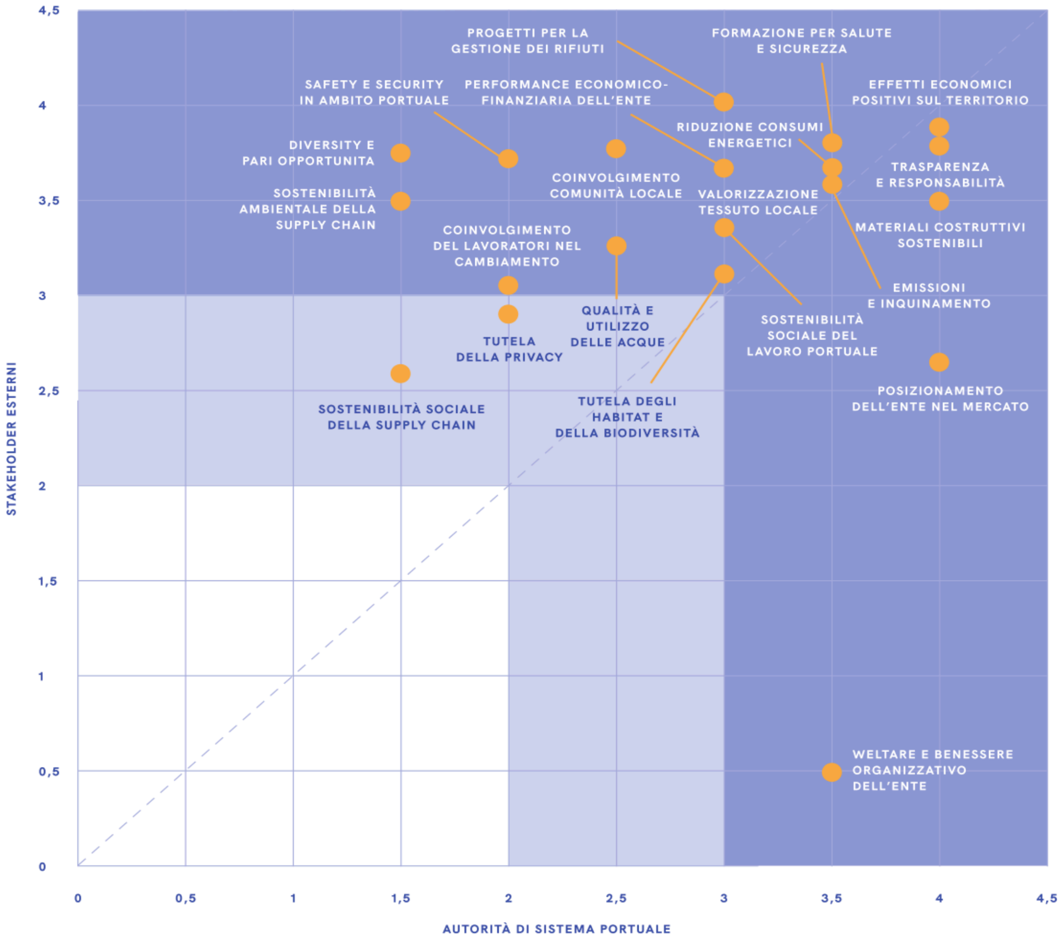

Figure 20. Sustainability Matrix

Source: (AdSP MSO, 2022a)

Based on the priorities identified in the materiality matrix, the AdSP defines and reports its strategies, which are discussed in the following sections.

3.5.1 Economic sustainability

The economic sustainability of an organization is rooted in its ability to generate long-term income and create employment opportunities. For the Western Sicily Port System Authority, this capacity is reflected in balanced budget management and in the monitoring of key accounting indicators, in accordance with the regulatory and managerial principles governing non-economic public entities. As a national body operating under a special legal framework, the AdSP enjoys administrative, organizational, regulatory, accounting, and financial autonomy (AdSP MSO, 2025c).

As outlined in the Authority's performance reports (AdSP MSO, 2025b, 2025c, 2025d), in 2024 the institution maintained a solid financial and economic position.

Overall, total revenues amounted to about €94.6 million, while total expenditures were approximately €80.1 million. After financial adjustments and accruals, the Authority closed the year with a net profit of €5.68 million.

On the revenue side, current revenues were mainly driven by concession and state property fees, idle berth charges, and port security-related services. Capital revenues originated primarily from state transfers for infrastructure development, as well as financing projects such as dredging operations, quay redevelopment, the Port Community System (PCS) digitalization program, and cyber-resilience initiatives.

On the expenditure side, resources were allocated to personnel, ordinary maintenance of port infrastructure, provision of port security services, and general operations. These included lighting, water supply, cleaning, and shuttle bus services in Palermo, Termini Imerese, Trapani, and Porto Empedocle.

Additional funds were devoted to promotional activities, publicity, and support for port-related initiatives.

Capital expenditures reached €15.15 million, directed towards strategic infrastructure projects, including the completion of breakwaters at Termini Imerese, dredging works, the redevelopment of the Trapezoidal Quay, the full implementation of the PCS, and improvements in cyber-resilience. Many of these projects were supported by national programs such as the Fondo Adeguamento Prezzi and other strategic development funds (AdSP MSO, 2025b, 2025d).

From a strategic perspective, the Authority's initiatives aim to enhance the competitiveness of the port system through infrastructure investments, technological innovation, and digitalization of processes. The implementation of large-scale projects and the development of green and digital ports represent fundamental levers for positioning the ports of Western Sicily along the main international trade routes, improving the Authority's economic and financial performance while simultaneously generating positive spillover effects on the regional economy (AdSP MSO, 2022b).

These benefits emerge not only in direct terms but also through indirect economic impacts observable over the medium to long term.

Among the most significant projects are dredging operations, which increase seabed depth and enable access for larger vessels. In particular, the dredging of the Crispi Basin at the Port of Palermo has increased the port's capacity to accommodate next-generation vessels, boosting the number of calls and consolidating its competitive position in both passenger and cargo traffic. At the same time, the redevelopment of quays and maritime works, along with the completion of breakwaters and coastal defenses, has enhanced infrastructure resilience and operational regularity in adverse weather and sea conditions, thereby reducing indirect costs and ensuring greater service continuity.
Another strategic area concerns the enhancement of the port–city interface. The requalification of the waterfront of Palermo provides a significant example of urban regeneration, improving the livability of the area, increasing its attractiveness for tourism, and enhancing the net economic well-being of residents. Similarly, in the Port of Trapani, the construction of the passenger terminal and the hydrofoil station has strengthened accessibility and supported the growth of passenger flows to the islands, with positive spillovers on the tourism and hospitality sector and the creation of new local businesses, also facilitated by the activation of national and international connections (AdSP MSO, 2022b).

3.5.2 Social sustainability

From a social perspective, the AdSP has prioritized strengthening the port–city relationship by launching several initiatives aimed at improving coexistence with local communities, while also mitigating the environmental and noise impacts generated by port traffic. Among the most significant interventions are the redevelopment of the Sant'Erasmo marina, transformed into a recreational and cultural space for citizens; the recovery of the Trapezoidal Quay, redesigned with pedestrian areas, green spaces, and leisure zones for cultural and commercial activities; and the Core Port Interface project of Palermo, co-financed by the CEF program, which includes pedestrian walkways, new parking areas, and public spaces to reconnect the waterfront with the city. Similar regeneration projects have also been carried out in Trapani and Porto Empedocle, involving the construction of new passenger terminals. In Termini Imerese, interventions on the breakwaters have improved both infrastructure protection and the quality of urban life (AdSP MSO, 2022a). Attention to the social dimension is also reflected in the promotion of occupational safety, continuous training, and inclusion practices, aimed at enhancing human capital and reinforcing organizational belonging. The AdSP of Western Sicily currently employs 87 staff members, in addition to the Secretary General, who are distributed among executives, officers, and administrative personnel. In recent years, the Authority has steadily increased its investment in staff training, considered a strategic lever to strengthen skills and professional profiles in line with European and international standards. The training program, planned on both an annual and multi-year basis, goes beyond updating technical knowledge and pursues a dual objective: to enhance human capital while creating public value by improving the quality of services provided to citizens and businesses. Continuous training, also oriented towards cross-cutting fields, is therefore a key element of the Authority's social sustainability, fostering innovation, transparency, and organizational integrity. Particular attention is dedicated to the development of digital and managerial competences, ecological transition, the promotion of ethics and anti-corruption, as well as the strengthening of soft skills (leadership, teamwork, adaptability), all considered essential levers for consolidating administrative capacity and aligning with national and European challenges (AdSP MSO, 2022a, 2025a).

The social strategies also include policies for inclusion, equal opportunities, and welfare, with initiatives aimed at ensuring gender equality, promoting diversity, and supporting staff well-being. These actions strengthen the internal climate of the organization and reinforce its commitment to social responsibility, aligning with national and European frameworks. Regarding safety, the Authority applies the provisions of Legislative Decree 81/2008, preparing Risk Assessment Documents, emergency plans, and a system of health surveillance that ensures the prevention and continuous monitoring of working conditions. These measures were reinforced during the pandemic through the introduction of health protocols, the use of personal protective equipment, and the adoption of remote working arrangements.

Regarding port security, all ports of the system are equipped with Security Plans, manned access gates, and video surveillance systems, integrated with 24/7 operational control rooms (AdSP MSO, 2022a).

A central aspect of the Authority's social sustainability strategy is the process of institutional, territorial, and stakeholder consultation, initiated during the drafting of the Port Master Plan and subsequently consolidated in the Port System's Environmental and Energy Planning Document (DEASP). This process has involved public actors (the Sicilian Region, municipalities, universities, and research institutions) as well as private stakeholders (concessionaires, shipowners, energy and shipbuilding companies), fostering shared governance of planning measures and strengthening the legitimacy of infrastructure and environmental interventions.

The participatory mechanisms activated through these instruments represent a distinctive component of the AdSP's social strategy, reinforcing transparency and inclusiveness in decision-making.
In this way, the initiatives of the AdSP are aligned with the objectives of the European Green Deal and the SDGs of the UN Agenda 2030 (AdSP MSO, 2021).

Additional relevant instruments include the Sustainability Report and the Transparency Section of the institutional website, which promote stakeholder participation and foster trust through clear and accessible communication. In this context, anti-corruption and integrity policies also play an essential role in ensuring a credible governance model oriented toward social responsibility (AdSP MSO, 2022a).

3.5.3 Environmental sustainability

From an environmental perspective, the Western Sicily Seaport Authority has undertaken numerous initiatives to reduce atmospheric emissions, safeguard marine biodiversity, and constantly monitor the key environmental matrices (air, water, soil, sediments). Particularly relevant are energy efficiency programs, the promotion of renewable energy, and the development of shore power infrastructure, also known as cold ironing (or shore-side electricity) (AdSP MSO, 2024k). These initiatives are framed within the Environmental and Energy Planning Document of the Port System (DEASP), in line with national and European decarbonization strategies and the SDGs.
Overall, these actions demonstrate the Authority's determination to integrate sustainability as a cross-cutting principle in strategic planning and management, strengthening the capacity of the ports of Western Sicily to proactively address the global challenges of ecological and digital transition (AdSP MSO, 2021, 2022a, 2024a, 2025a).

In this perspective, the AdSP has embarked on a progressive green transformation, with policies aimed at reducing greenhouse gas emissions, ensuring efficient energy use and increasing the share of renewable energy. The overarching objective is to achieve port facilities with near-zero emissions and energy costs. Among the most advanced measures is cold ironing, which enables ships at berth to be powered from shore, significantly reducing emissions and improving air quality in surrounding urban areas (AdSP MSO, 2021, 2022b, 2024k; Cosedil, 2025).

A cornerstone of environmental sustainability is the "Smart Port" project, which encompasses various interventions aimed at upgrading the energy efficiency of port sites (Gruppo Free, 2021). A first line of action concerns the installation of renewable energy self-production systems, with a particular focus on solar power. The deployment of photovoltaic plants in areas undergoing redevelopment aims to maximize self-consumption, reduce energy costs, and contribute to the decarbonization of the port system. These measures, in addition to generating tangible environmental benefits, also enhance the economic sustainability of the ports and reflect a public value-oriented approach, consistent with European green port policies. The initiative, embedded in the DEASP, is one of the most significant steps toward achieving zero-emission ports by 2026, in line with EU strategies on green ports (AdSP MSO, 2025a).

Alongside photovoltaic energy, another strategic intervention for the energy upgrading of ports is cogeneration, which involves the simultaneous production of electricity and heat. This process recovers thermal energy that would otherwise be wasted, thereby saving primary fuel. In this perspective, the AdSP has planned the construction of a trigeneration plant at the Port of Palermo, powered by natural gas-fueled generators and designed to supply electricity, thermal energy, and cooling to port users. The plant, also prepared for future developments such as the production of potable water through triple-effect evaporators, is a key component of decarbonization and the transition toward green and digital ports, in line with the DEASP objectives and EU directives on energy efficiency AdSP MSO, 2021).

Another area of intervention concerns the upgrading of port lighting systems through the gradual replacement of traditional installations with LED technologies. This initiative significantly reduces energy consumption and management costs while ensuring higher standards of safety, light quality, and compliance with light pollution regulations. LED relamping is not only a cost-saving measure but also enhances port areas and improves working conditions within them (AdSP MSO, 2021). Complementing this is the Smart Lighting project, which introduces digital functionalities for monitoring and remote control of light points. The system enables real-time adjustment of lighting flows according to traffic, environmental conditions, or specific events, further reducing consumption and optimizing maintenance operations. Thanks to these innovations, the lighting system becomes an integral component of the digital transformation of ports, serving as enabling infrastructure for additional smart services. In this way, the initiative contributes not only to energy efficiency but also to safety, quality of life in port areas, and the creation of public value, aligning with the EU's green and digital transition strategies (AdSP MSO, 2021, 2024k).

In parallel, the AdSP has launched measures for sustainable water management. In particular, a project was developed for the renewal of rainwater and wastewater disposal networks in the Port of Palermo, aimed at upgrading infrastructure to current regulations and reducing environmental impacts. The intervention, with an estimated value of around €50 million, foresees the construction of a new sewerage system to efficiently manage both stormwater and wastewater, thereby improving the overall operational efficiency of commercial and operational areas (AdSP MSO, 2022a).

Special attention is also devoted to marine biodiversity through environmental monitoring activities supporting dredging operations. These activities include continuous monitoring of water quality, the presence of contaminants, and turbidity, in accordance with the guidelines of the Italian Institute for Environmental Protection and Research (ISPRA), the national authority responsible for environmental monitoring and protection. The objective is to prevent the dispersion of harmful substances and safeguard marine habitats, in line with the EU Habitats Directive 92/43/EEC and its national transpositions (AdSP MSO, 2022a).

As regards waste management, the AdSP ensures the collection and disposal of waste through specialized concessionaires (including emergencies) and is developing an environmental management system to strengthen control over the impacts generated by port-related waste (AdSP MSO, 2022a).

Finally, in terms of sustainable mobility, electric vehicle charging stations have been installed in port parking areas for visitors, employees, and operators, contributing to emission reductions and reinforcing the port–city connection (AdSP MSO, 2021).

3.5.4 Technologies for sustainability

Digital transformation today is one of the most relevant strategic axes of the sustainability policies pursued by the Western Sicily Port System Authority, as it enables innovation processes that simultaneously affect the economic, social, and environmental dimensions (AdSP MSO, 2024a). Part of the Smart Port project - already discussed in the environmental section, such as the installation of photovoltaic systems, methane-based trigeneration, LED relamping, and smart lighting - has been specifically aimed at improving energy efficiency and reducing emissions. Alongside these measures, the same program includes actions explicitly oriented toward digitalization and technological innovation, which represent a transversal pillar of the transition toward the smart and green port (AdSP MSO, 2022a). In this perspective, the AdSP has launched a structured pathway of investments in ICT infrastructure, integrated platforms, and digital services to strengthen the competitiveness, safety, and transparency of the port system (AdSP MSO, 2021, 2022a).

A first area of intervention is the intelligent video surveillance system, which, through advanced analytics, enables the detection of intrusions, abandoned or removed objects, abnormal behaviors, and suspicious flows, thereby reinforcing control of sensitive areas and increasing overall security. Alongside this system, the Authority has introduced innovative solutions for the automation of access gates, parking management, and digital services for passengers and visitors (e.g., wayfinding and digital signage systems) to support hospitality and strengthen the port–city connection (AdSP MSO, 2021, 2022a).

Another important area concerns the development of high-coverage LAN and Wi-Fi networks, conceived as enabling infrastructure for the deployment of innovative services for operators, passengers, and logistics processes. Compared to traditional cabling, wireless coverage provides flexible access, enabling applications based on the Internet of Things IoT and big data. Application areas include communication with ships in transit, data exchange for cargo traceability, widespread environmental monitoring, and dynamic management of operational procedures. In this way, connectivity becomes not only a factor of efficiency but also a tool for transparency and inclusion for stakeholders (AdSP MSO, 2022a).

The digitalization pathway has also involved the Authority's internal governance. The Sustainability Report highlights the activation of a platform for the online management of decrees, service orders, and spending authorizations; the launch of an HR portal for personnel management (holidays, leave, overtime, attendance); and the establishment of the Single Administrative Desk (Sportello Unico Amministrativo), introduced under Article 15-bis of Law 84/94, aimed at centralizing and digitalizing administrative procedures. Investments in cloud computing, digital security systems, and the design of a telematic platform for remote embarkation control and vehicle traceability have complemented these interventions (AdSP MSO, 2022a).

Finally, the Port Community System (PCS) plays a key role. This telematic platform enables the integration and standardized exchange of information among various actors in the port logistics chain, including the Port System Authority, customs, terminal operators, freight forwarders, shipping companies, and transport firms. The PCS improves the efficiency and transparency of administrative and operational processes, reduces customs clearance times, and simplifies the management of goods and passengers (Tijan et al., 2021). This tool aligns fully with European policies promoting the digitalization of logistics and the creation of more efficient and sustainable intermodal corridors, positioning itself as enabling infrastructure for the smart port. In this perspective, the PCS is not only a technological innovation but also acts as a driver of competitiveness for the port system, capable of combining sustainability, operational efficiency, and public value creation. Although primarily an instrument for enhancing economic and logistical competitiveness, the PCS also generates positive spillovers in the social dimension (transparency and stakeholder inclusion) and the environmental dimension (reduced processing times and emissions from port operations) (AdSP MSO, 2025a).

Overall, these interventions underscore that digitalization is not merely a technical aspect, but a strategic lever for sustainability and public value creation, fully consistent with the European Green Deal and the SDGs of the 2030 Agenda.

3.5.5 Synthesis of strategies for sustainability

The analysis of the sustainability strategies undertaken by the Western Sicily Seaport Authority reveals a broad range of initiatives, spanning financial management, urban regeneration, energy transition, and process digitization.

On the economic side, the AdSP has strengthened its financial soundness through a balanced budget and the targeted use of private financing as well as national and EU funds. At the same time, major infrastructure investments (dredging, quay redevelopment, and new maritime works) have consolidated operational resilience and enhanced international competitiveness, also thanks to the development of green and digital ports.

On the social side, particular attention has been devoted to the port–city relationship, with urban regeneration initiatives (such as the Palermo waterfront and the Sant'Erasmo marina), cultural and tourism enhancement projects, and the strengthening of human capital through training, inclusion, and workplace safety. Policies promoting transparent governance and anti-corruption, combined with broad institutional and territorial engagement, have reinforced trust and the social legitimacy of the measures implemented.

On the environmental side, the AdSP has embarked on decarbonization through shore power systems (cold ironing), photovoltaic plants, and trigeneration facilities, complemented by energy efficiency measures (LED systems and smart lighting). These actions are accompanied by the sustainable management of water resources, monitoring of environmental matrices (air, water, soil, sediments), protection of marine biodiversity, and advanced waste collection and disposal systems. Sustainable mobility has also been promoted through the development of charging infrastructure and the adoption of low-emission vehicles.

Digitalization plays a pivotal role, enhancing efficiency, transparency, safety, and connectivity through the PCS, intelligent video surveillance, advanced ICT networks, and integrated command and control platforms. This, in turn, generates new opportunities for social and economic sustainability.

Table 2 offers a structured synthesis of the sustainability strategies and instruments adopted by the Western Sicily Port System Authority.

Strategic Area	Strategies/Tools
Economic and financial performance	Balanced budget management; mobilization of state funds and EU transfers; concession and property fees; infrastructure investments.
Energy consumption and emissions reduction	Cold ironing systems, photovoltaic plants, trigeneration, LED systems, smart lighting, energy efficiency measures, deployment of electric charging stations, and promotion of low-emission vehicles aim to reduce CO_2 emissions, improve air quality, and foster cleaner transportation.
Digitalization and ICT systems	Control room, data center, and integrated digital platforms for monitoring and management, along with an ICT management dashboard. The Port Community System (PCS) facilitates logistics efficiency, reduces waiting times and related emissions, promotes transparency, and fosters stakeholder inclusion.
Market positioning of the Authority	Development of green and digital ports, as well as consolidation of freight and passenger routes.
Local community and port–city enhancement	Waterfront regeneration (Palermo, Sant'Erasmo marina); port–city interface projects; cultural events; support for tourism and hospitality.
Social sustainability of port-related work	Port Staffing Plan; continuous training; inclusion and gender equality; workplace safety.
Safety and security	ISPS security plans; intelligent video surveillance; barriers and metal detectors; integrated mobility systems.
Sustainability of the supply chain (environmental and social)	Integration of environmental/social criteria in procurement; monitoring of suppliers; sustainable logistics practices.

Water and wastewater management	Renewal of sewerage networks, wastewater disposal, stormwater management, and monitoring of wastewater and stormwater quality.
Protection of habitats and biodiversity	ISPRA controls; protection of marine biodiversity, marine and coastal water quality monitoring.
Waste management projects	Waste collection, treatment, and disposal; recycling initiatives; environmental risk prevention.
Transparency and accountability	Sustainability reporting, anti-corruption policies, transparency section, materiality analysis, and participatory governance.
Training for health and safety	Training programs for workers; occupational safety measures.

Table 2. Sustainability strategies of the Western Sicily Seaport Authority
Source: Author's elaboration.

The holistic analysis of the sustainability strategies adopted reveals that many interventions, although attributable to a specific sustainability dimension, actually generate cross-cutting and interdependent impacts across the various pillars of sustainability.

This perspective is consistent with the TBL framework integrated into the port context as discussed by Lim et al. (2019), which highlights the existence of intermediate areas resulting from the intersection of different sustainability dimensions: eco-efficient (economic–environmental), socio-economic (economic–social), and socio-environmental (social–environmental). Moreover, the in-depth analysis of the sustainability strategies adopted reveals the multidimensional complexity of sustainability challenges, objectives, and initiatives in the port context, where numerous actors, resources, and processes interact in a dynamic, non-linear, and interdependent manner.

This complexity calls for the development of an effective system for managing and improving sustainability performance.

In particular, sustainability can be strengthened and more fully realized by embedding the Authority's diverse initiatives and tools within a comprehensive sustainable business model that makes explicit the systemic interconnections among resources, processes, drivers, and outcomes, thereby explaining how long-term value is generated and sustained through the integration of the environmental, social, and economic dimensions (Bocken et al., 2014;

Elkington, 1998; Evans et al., 2017; Geissdoerfer et al., 2018; Schaltegger et al., 2016; Stubbs & Cocklin, 2008; Ueda et al., 2009).

The DBMfS (Cosenz et al., 2020), by combining a system dynamics perspective (Sterman, 2000; Morecroft, 2007, 2015) with the sustainable business model lens, provides a robust framework for continuous monitoring, learning, and strategic alignment with the creation of sustainable public value across the three pillars (Abdelkafi & Täuscher, 2016; Täuscher & Abdelkafi, 2018; Cosenz et al., 2020; Cosenz et al., 2024). In this perspective, the next section presents an empirical application of the DBMfS to the case study.

3.6 Applying the DBMfS to the AdSP case study

After analyzing the institutional profile, performance, and sustainability strategies of the Western Sicily Port System Authority, this study applies the DBMfS approach to the selected case study. The objective is to demonstrate how the model enables a systemic and dynamic representation and analysis of the interconnections among resources, processes, and outcomes across the three dimensions of sustainability - economic, social, and environmental.

Through this perspective, the DBMfS highlights the mechanisms of long-term sustainable public value creation and translates the strategies outlined by the AdSP into measurable and monitorable processes over time. In doing so, it provides structured support for strategic decision-making, while enhancing the AdSP's capacity to achieve sustainable performance.

The construction of the model is grounded in a systematic analysis of the Authority's official documentation, as reviewed in the previous sections. In particular, sources include the Sustainability Report (AdSP MSO, 2022a), the Integrated Plans of Activities and Organization (PIAO) 2024–2026 (AdSP MSO, 2024a) and 2025–2027 (AdSP MSO, 2025a), the Budget Forecasts for 2024 (AdSP MSO, 2023) and 2025 (AdSP MSO, 2024c), as well as the 2023 and 2024 Performance Reports (AdSP MSO, 2024d, 2025c).

To capture technical aspects related to the sustainability strategies adopted by the Port Authority - as already highlighted in the previous paragraph - key institutional planning documents were also analyzed, particularly those concerning the ecological, energy, and digital transitions (AdSP MSO, 2021, 2024k) and waterfront regeneration (AdSP MSO, n.d.; Carta, 2024).

These sources were complemented by direct exchanges with AdSP members, which provided valuable insights for defining the processes and variables included in the model.

3.6.1 The DBMfS of the AdSP

The application of the DBMfS to the case of the AdSP is grounded in the analyses presented above. The preliminary work provides the basis for filling the different building blocks of the model, and, through a systemic and dynamic perspective, it illustrates the interconnections among resources, processes, and results.

Three processes emerge as particularly relevant in this context:

1. Waterfront regeneration;
2. Dock electrification through cold ironing systems;
3. Energy efficiency enhancement through renewable sources.

These processes have been selected because they represent strategic projects either already completed or currently underway by the AdSP and are formally reported in key institutional documents. Their selection is also aligned with the AdSP's strategic objectives (paragraph 3.5) and with the materiality matrix (AdSP MSO, 2022a) (Figure 20), which highlights the most relevant sustainability priorities according to both external stakeholders and the Authority itself.

Furthermore, these processes enable the capture and analysis of the combined effects across the three dimensions of the Triple Bottom Line: economic, social, and environmental.

The main stakeholders involved in these processes include public institutions, such as the Italian MIT, the Ministry for Ecological Transition, the Sicilian Region, local municipalities, and the European Union, as well as private investors and potential new partners.

A decisive contribution is provided by public–private partnerships (PPPs), which play a crucial role in securing funding for strategic initiatives. Among private actors, the most significant is the Free Group (Free Energia, Free Energy Saving, Lux Master), which actively promotes innovative solutions to improve energy efficiency and accelerate the transition toward renewable sources.

As for revenue streams, the AdSP relies predominantly on public funding and private investments, with a smaller share derived from revenues generated by port operations.

These resources are mainly allocated to projects supporting the ecological transition, technological innovation, and waterfront regeneration.

The DBMfS in Figure 21 illustrates the specific causal dynamics associated with sustainable value generation in the waterfront regeneration process.

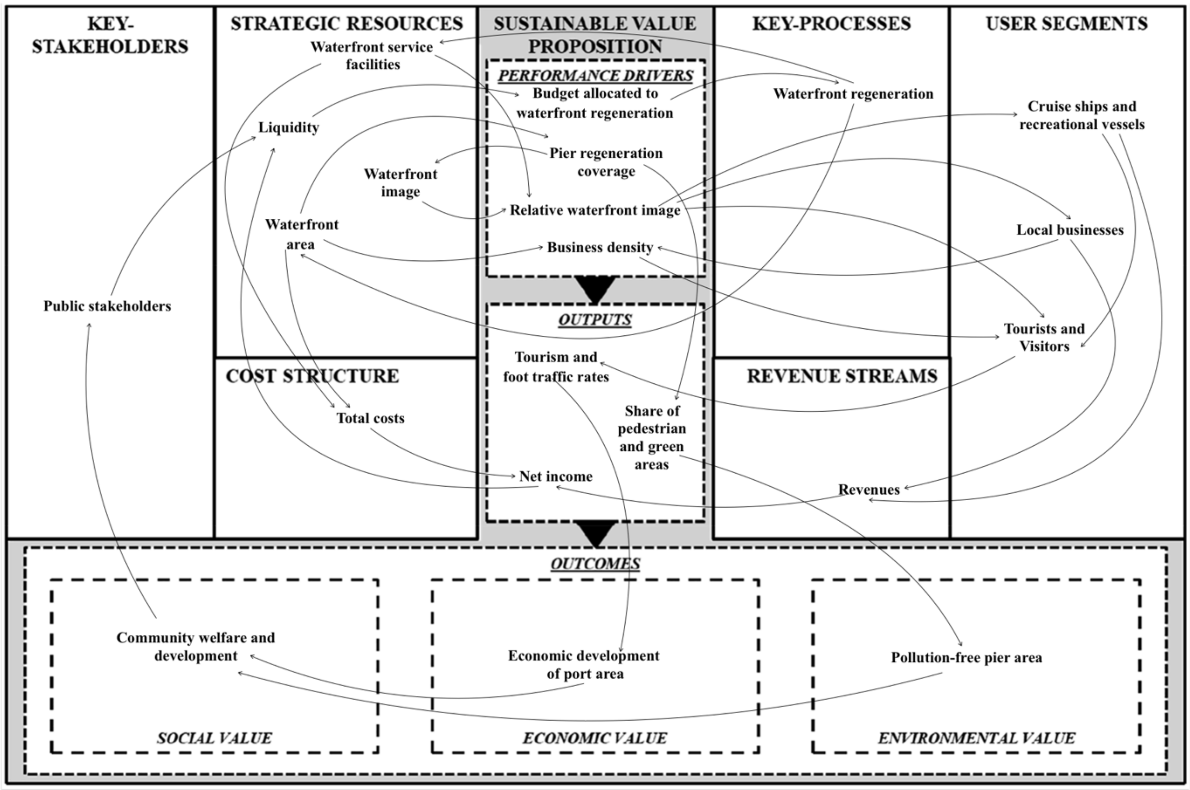

Figure 21. The Dynamic Business Model for Sustainability (DBMfS) canvas applied to the Western Sicily Seaport Authority: the waterfront regeneration process.
Source: Author's elaboration

The requalification of the pier in the port of Palermo required an overall investment of nearly €25.5 million, largely financed through national public funds. Specifically, the MIT allocated these resources as part of a broader plan for port infrastructure development (Corte dei Conti, 2023). In addition to this initial contribution, the AdSP financed and implemented further works necessary for the full realization of the waterfront redevelopment project. Moreover, the Authority sustains the ongoing operational and management costs of the regenerated infrastructure, which include maintenance, personnel, energy consumption, project design, and feasibility studies.

Within this process, the waterfront area represents the strategic physical resource on which regeneration activities are developed. In contrast, the waterfront image constitutes a crucial intangible resource for enhancing both the attractiveness and reputation of the port. The regeneration process increases the "Pier regeneration coverage" - measured as the ratio between the regenerated surface and the total surface of the pier - and also strengthens the waterfront service facilities, such as new parking areas, public spaces such as an 8,000 m^2 urban lake, panoramic terraces, and nautical facilities. The expansion of regenerated areas and the development of service facilities, in turn, positively affect the performance driver "Relative waterfront image".

A more appealing and modernized waterfront significantly enhances the Authority's capacity to attract visitors, tourists, cruise ships, recreational vessels, and local businesses. In particular, the growing number of firms operating in the waterfront area makes the regenerated zone increasingly attractive to tourists and visitors, who represent a crucial user segment of the regeneration process.

This dynamic stimulates the economic development of the port–city area, which in turn contributes directly to community welfare, in line with the expectations of the AdSP's public stakeholders.

Among the strategic objectives of the waterfront regeneration is the creation of pedestrian and green areas, represented in the model as the "Share of pedestrian and green areas". This output reflects the extent to which redeveloped surfaces are converted into spaces that prioritize pedestrian accessibility and green amenities. Its increase provides tangible evidence of reduced vehicular pressure, improved environmental quality, and stronger integration between port and city areas.

Over time, these dynamics converge toward the outcome "Pollution-free pier area", which encapsulates the long-term environmental benefits of regeneration, expressed in terms of reduced CO_2 emissions and improved air quality in the redeveloped zone.

This environmental improvement also generates significant social value, as lower air pollution and improved overall environmental quality contribute to enhanced public health, increased comfort, and higher well-being for residents in the port area.

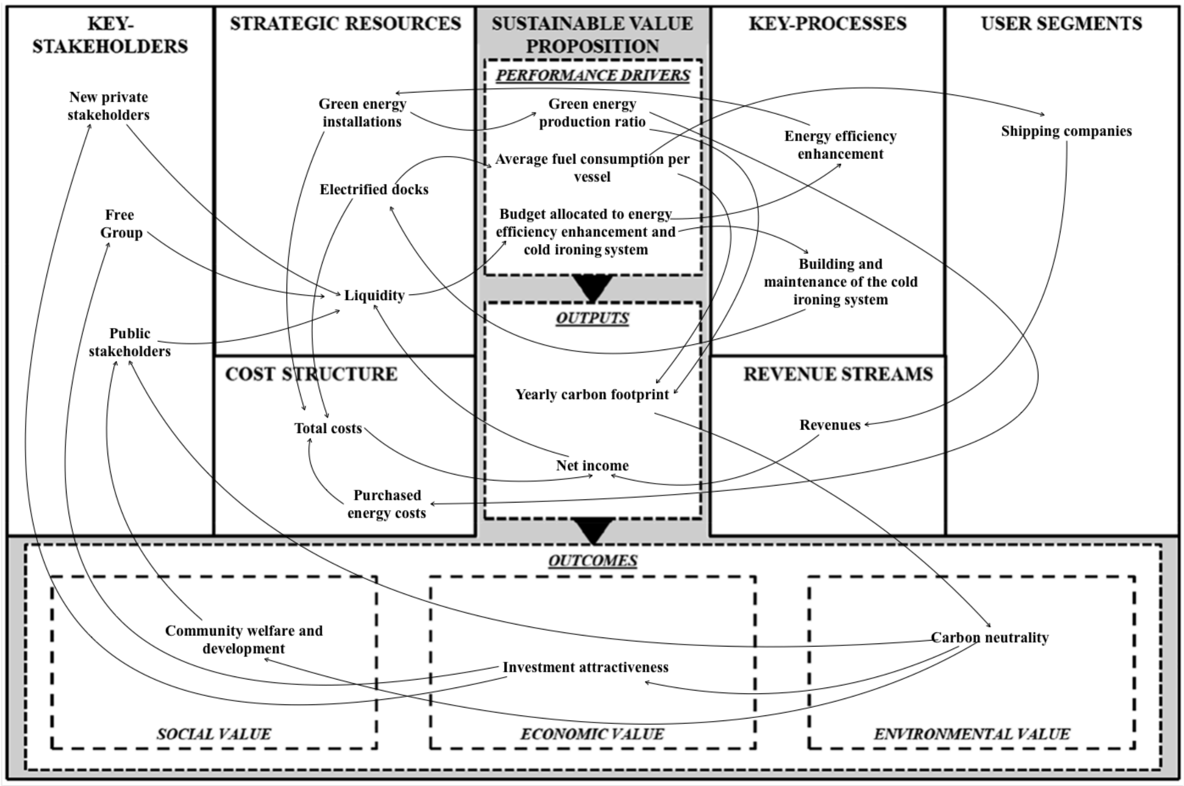

Figure 22. The Dynamic Business Model for Sustainability (DBMfS) canvas applied to the Western Sicily Seaport Authority: dock electrification and energy efficiency enhancement processes.

Source: Author's elaboration

The DBMfS in Figure 22 illustrates the process of sustainable value creation associated with dock electrification through cold ironing and energy efficiency improvements based on renewable sources. These interventions are co-financed by public stakeholders and by the Free Group through public-private partnerships (PPPs). Dock electrification, achieved through the implementation of cold ironing systems, enables vessels to connect to the port's electrical grid and switch off their engines while berthed.

This process directly affects the driver "Average fuel consumption per vessel", thereby reducing the output "Yearly carbon footprint" and, in the long term, supporting the achievement of the outcome "Carbon neutrality".

In this way, the expectations and interests of the main stakeholders are met, while simultaneously generating positive effects on community well-being and on the attractiveness of new investments.

Shipping companies benefit substantially from these interventions through cost savings resulting from reduced fuel consumption.

Moreover, the progressive adoption of cold ironing by shipping companies generates additional revenue for the AdSP, thereby reinforcing the Authority's long-term financial sustainability. Energy efficiency measures, implemented through the installation of renewable energy plants such as photovoltaic systems, increase the driver "Green energy production ratio", thereby raising the share of clean energy used in port operations.

Over time, this transition reduces operating costs, strengthens the Authority's economic sustainability, and contributes to improved air quality and overall quality of life for residents in port–city areas.

The cost structure reflects both the initial investments required for these strategic processes, co-financed by the AdSP, public authorities, and private investors, as well as the recurring expenses related to maintenance, personnel, project design, feasibility studies, and energy consumption. Despite the initial magnitude of these costs, they are expected to decline progressively due to efficiency gains and long-term savings.

In sum, the DBMfS provides a structured framework for representing and analyzing, through a systemic and dynamic perspective, the interconnections among resources, processes, and results. It clarifies the mechanisms through which the Authority's strategies generate sustainable public value.

In addition, thanks to its dynamic perspective, the DBMfS not only enables the analysis of how the strategies adopted by the AdSP generate sustainable value over time, but also highlights their concrete contribution to the UN's SDGs (Cosenz et al., 2024). Building on the sustainable value generated across the three outcome dimensions - economic, social, and environmental - it is possible to associate each with the relevant SDGs, thereby demonstrating the AdSP's tangible contribution to achieving the 2030 Agenda. The main linkages can be summarized as follows:

- Community welfare and development contribute to SDG 3 (Good Health and Well-being), SDG 8 (Decent Work and Economic Growth), and SDG 11 (Sustainable Cities and Communities).
- Economic development of the port area contributes to SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation and Infrastructure).
- Investment attractiveness contributes to SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 17 (Partnerships for the Goals).
- Pollution-free pier area contributes to SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action).
- Carbon neutrality contributes to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

Specifically, by generating social value, the AdSP aligns with SDGs 3, 8, and 11 through improvements in public health, quality of life, and urban livability, as well as the creation of new employment opportunities (a social dimension with economic implications). Economic outcomes are primarily linked to SDGs 8, 9, and 17, underscoring the Authority's role in promoting territorial growth, infrastructural innovation, and investment attractiveness through strategic partnerships with private stakeholders. Finally, the environmental value generated contributes to SDGs 7, 11, and 13, as it reflects the pathway towards decarbonization, sustainable urban regeneration, and climate change mitigation.

Overall, the DBMfS emerges as a valuable framework for capturing the interconnected dynamics that drive long-term sustainable value creation and for demonstrating their contribution to the objectives of the UN 2030 Agenda.

3.6.2 Sustainability-related KPIs

To operationalize the DBMfS and translate its sustainable value proposition into practice, two complementary sets of tailored KPIs were developed. The first set, summarized in Table 3, focuses on performance drivers and outputs. These indicators aim to measure, monitor, and assess the short- to medium-term value generation processes of the Western Sicily Seaport Authority.

They are structured to capture the environmental, economic, and social dimensions of sustainability, in alignment with European guidelines on green ports and port–city integration. For each indicator, a clear description and a transparent measurement structure are provided, ensuring both analytical robustness and practical applicability. By integrating environmental measures, socio-economic impacts, and governance-related dimensions, the framework provides a holistic perspective on how port regeneration and decarbonization strategies contribute to sustainable value generation over time.

Variable name	Description	Measurement
Average fuel consumption per vessel	Assesses the average energy efficiency of ships calling at the port. A lower value indicates higher efficiency and reduced environmental impact of maritime traffic.	Total fuel consumption/number of vessels
Budget allocated to energy efficiency enhancement and the cold ironing system	Indicates the share of financial resources devoted to energy transition measures, such as cold ironing and efficiency upgrades, reflecting the Authority's strategic priority on decarbonization.	Budget allocated to energy efficiency enhancement and cold ironing system/total budget
Budget allocated to waterfront regeneration	Measures the proportion of investments aimed at urban and port interface regeneration, highlighting the commitment to enhancing the port–city relationship and improving livability.	Budget allocated to waterfront regeneration/total budget
Business density	Measures the share of regenerated port space rented and used by businesses, providing evidence of the intensity of economic activity in the redeveloped areas.	m^2 of area rented by businesses/total m^2 regenerated
Green energy production ratio	Represents the share of port energy consumption covered by renewable sources, reflecting the progress of the	Green energy produced/total energy consumed

	Authority in shifting towards sustainable and resilient energy models.	
Pier regeneration coverage	Measures the proportion of the total pier surface that has undergone physical redevelopment, providing evidence of the overall progress of infrastructure modernization.	m^2 of regenerated pier area/total m^2 of pier area
Relative waterfront image	Perception-based indicator assessing the attractiveness of the waterfront against predefined objectives, useful to capture intangible value creation in terms of place branding and city–port integration.	Actual waterfront image/target waterfront image (survey-based)
Tourism and foot traffic rates	Assesses the attractiveness of the waterfront by monitoring tourist flows and general visitor presence, showing how port regeneration contributes to tourism development and community use of the area.	(i)Number of tourists in the waterfront area/year (ii) Number of visitors in the waterfront area/year
Share of pedestrian and green areas	Assesses the proportion of regenerated pier surface that has been converted into pedestrian zones and/or green spaces, providing evidence of improved environmental quality, urban livability, and reduced vehicular pressure in the port–city interface.	(i) m^2 of pedestrian areas within regenerated pier surface/total m^2 of regenerated pier area (ii) m^2 of green areas within regenerated pier surface/total m^2 of regenerated pier area
Yearly carbon footprint	Provides the annual estimate of greenhouse gas emissions generated by port-related activities.	Total tons of CO_2 emissions/year

Net income	Represents the financial sustainability of the Authority, reflecting its capacity to generate surplus resources (net income) that, in line with its role as a non-economic public entity, are reinvested in infrastructure development, sustainability initiatives, and long-term stability.	Revenues – Costs

Table 3. Key performance indicators (KPIs) of performance drivers and outputs of the sustainable value generation processes in the Western Sicily Seaport Authority.

Source: Author's elaboration

The social, economic, and environmental value represented in the last row of the DBMfS refers to the outcomes, namely the long-term results generated by the AdSP's sustainability strategies (Cosenz et al., 2020). To complement the KPIs developed for performance drivers and outputs, a second set of outcome measures has been designed. These indicators capture the systemic impacts across the three dimensions of sustainability, thus offering a comprehensive perspective on the long-term sustainable public value creation.
The proposed outcome indicators are presented in Table 4.

Outcome dimension	Description	Measurement
Community welfare and development	Assesses the social impacts of port strategies by evaluating changes in residents' quality of life and in local employment opportunities within the waterfront area.	i) Δ residents' perceived quality of life (survey-based) (ii) Δ employment in the waterfront area
Economic development of the port area	Measures the contribution of port activities to local and regional economic growth, including industrial spillovers, tourism, and waterfront regeneration.	Δ total turnover of waterfront businesses

Investment attractiveness	Captures the port's ability to mobilize capital and attract private investors, reflecting institutional credibility, competitiveness, and the capacity to foster partnerships.	Δ value of private investments attracted
Pollution-free pier area	Assesses the impact of pier regeneration on air quality, relating CO_2 emissions to regenerated surface area.	Tons of CO_2 emissions/m^2 of regenerated pier area
Carbon neutrality	Measures the Authority's progress toward achieving net-zero emissions by comparing current CO_2 levels with a defined baseline year. If the value decreases, the indicator improves, showing greater progress in decarbonization and a smaller gap to full neutrality.	Tons of CO_2 emitted in year t/Tons of CO_2 emitted in baseline year (before interventions)

Table 4. Key performance indicators (KPIs) measuring the outcomes of the sustainable value generation processes in the Western Sicily Seaport Authority.

Source: Author's elaboration

Overall, Tables 3 and 4 translate the DBMfS sustainable value proposition into practice. They provide two integrated sets of indicators: the first addresses performance drivers and outputs, capturing the short-term results directly linked to the Authority's strategies; the second focuses on outcomes, reflecting the long-term results that embody the sustainable value generated over time. Taken together, these indicators not only enable the measurement, assessment, monitoring, and reporting of sustainability performance but also serve as levers for continuous improvement, as further discussed in the following section.

3.6.3 Discussion

The findings from the Western Sicily AdSP case study demonstrate how the application of the DBMfS facilitates the identification of key sustainability drivers and their interdependencies within the complex setting of port management.

By integrating a System Dynamics perspective with business model design, the DBMfS provides a structured framework that explicitly highlights how core sustainability processes - such as waterfront regeneration, dock electrification, and renewable energy implementation - interact over time to generate long-term economic, social, and environmental value. For instance, the regeneration of the waterfront enhances the port's image while acting as both an economic and social catalyst. This process stimulates business density and tourism, contributing simultaneously to the local development and community well-being.

By creating green and pedestrian areas, the waterfront regeneration also generates long-term environmental value.

Similarly, the deployment of renewable energy infrastructure reinforces both environmental and economic performance by increasing the share of green energy in operations, reducing dependence on traditional sources, and lowering electricity costs over time. The transition toward renewable energy also contributes to emission reduction and improved air quality, supporting the AdSP's long-term commitment to carbon neutrality.

Dock electrification, implemented through cold ironing systems, represents another crucial process for minimizing the environmental impact of port activities. By enabling ships to connect to the port's electrical grid while docked, instead of burning fuel, cold ironing reduces fuel consumption per vessel and lowers greenhouse gas emissions. Improvements in air quality directly benefit the surrounding community and align with broader sustainability objectives, thereby combining environmental responsibility with protection of social well-being. Overall, the application of the DBMfS to the AdSP offers valuable insights into integrating sustainability into seaport strategic planning and management.

The framework operationalizes the Triple Bottom Line by explicitly connecting the economic, social, and environmental dimensions of sustainability within a single systemic representation. By systematically mapping causal relationships, the model makes explicit the feedback loops that connect resources, processes, drivers, outputs, and outcomes, thereby offering a clear view of the pathways through which sustainable value is created (Cosenz et al.,

2020).
One of the main advantages of the DBMfS lies in its value proposition, which incorporates a set of tailored KPIs designed specifically for performance management in seaport contexts. These indicators, combined with the systemic and dynamic perspective of the model, provide the basis for continuous monitoring and management of sustainability performance, enabling timely and well-informed strategic decisions.

In particular, the framework supports port management through backward analysis, guiding corrective actions when actual results deviate from established targets.

This logic reflects the Dynamic Performance Management (DPM) approach developed by Bianchi (2010, 2016) according to which planning and control systems and decision-making can be strengthened by adopting a dynamic perspective that, starting from the objectives, proceeds backwards to identify results and performance drivers (measured through indicators), and then the processes and resources on which to act to improve decision-making and performance.
For example, in the case of the Western Sicily AdSP, if the goal of achieving carbon neutrality is not reached despite the implementation of sustainability strategies, the DBMfS enables a backward analysis starting from its outcome indicators. A high value of the carbon neutrality indicator signals that decarbonization results are insufficient, meaning that the reduction in CO_2 emissions remains below expectations. This gap may be due to the limited number of electrified docks, which reduces the impact of cold ironing systems, or to insufficient renewable energy production. More specifically, a discrepancy in the Yearly carbon footprint indicator may be linked to high average fuel consumption per vessel or to the modest contribution of renewable energy. In such situations, the framework supports corrective measures, including allocating additional resources to expand cold ironing infrastructure or accelerating the installation of renewable energy sources.

Similarly, if the economic development of the seaport area falls short of expectations despite targeted investments - such as those directed toward waterfront regeneration - the DBMfS provides a means to conduct backward analysis to uncover the root causes of the gap. By analyzing indicators such as Tourism and foot traffic rates, Business density, Pier regeneration coverage, and Relative waterfront image, and by tracing their links to resources, activities, and enabling factors, the model helps to reveal potential strategic misalignments or operational bottlenecks.
For example, the limited impact may be due to a regenerated area that is too small to deliver

substantial results. Alternatively, the regenerated space may be sufficiently large. However, economic results still fall short of expectations due to issues such as low business density, inadequate accessibility, or limited improvements in the perceived attractiveness of the waterfront. In such circumstances, the DBMfS allows these shortcomings to be identified by examining how strategic actions have influenced actual performance. It then guides the formulation of corrective measures, such as broadening the scope of regeneration, enhancing the area's commercial appeal, or upgrading the waterfront service facilities, to improve the alignment between sustainability strategies and desired results.

Through this structured diagnostic capability, the DBMfS enhances evidence-based decision-making and strengthens the ability of port authorities to adapt and refine their sustainability pathways in a timely and effective manner. The framework thus operates as a practical strategic tool for actively managing performance deviations, consolidating its role as a decision-support system in port governance.

Furthermore, the DBMfS enables the assessment of how strategic initiatives contribute to achieving the SDGs and allows for the exploration of the impact of emerging technologies - such as digitalization, AI, cold ironing systems, and renewable energy solutions - on sustainable performance, thereby supporting innovation-oriented strategies.

Moreover, if integrated into sustainability reports or other official documents adopted by the AdSP, the model offers not only a record of results but also a dynamic and systemic reading of the mechanisms through which strategies generate sustainable public value. In this way, reporting can provide stakeholders with a deeper understanding of the processes underlying value creation, while also strengthening transparency, accountability, and institutional legitimacy.

Despite these advantages, the framework is not free from limitations. Its reliance on qualitative reasoning to establish causal links introduces a degree of subjectivity, which may affect accuracy (Cosenz et al., 2020; Sterman, 2000). Moreover, the collection of data - especially for social and environmental indicators - remains demanding and is often undermined by inconsistent reporting practices.

In the specific case of the Western Sicily AdSP, an additional limitation is the absence of robust time-series data, as several sustainability initiatives are still under implementation or not yet fully consolidated. This condition restricts the possibility of quantitatively validating the framework and of assessing its full potential in practice.

This gap could be addressed through future research, particularly in the form of longitudinal applications of the DBMfS, once the initiatives are completed and their impacts become measurable.

Future studies could also enrich the framework by introducing a quantitative dimension. A data-driven application of the DBMfS would allow a more rigorous assessment of the measurable results of interventions such as waterfront redevelopment, dock electrification, and renewable energy projects. This would strengthen decision-making by enabling a more robust evaluation of expected impacts and interdependencies.

A further issue relates to generalizability. While the DBMfS has proven effective in capturing the dynamics of the Western Sicily AdSP, its findings cannot be automatically transferred to other ports. Variations in governance models, regulatory systems, and operational contexts may influence the relationships observed. Although the framework itself is adaptable, applying it in different contexts requires a careful recalibration of key performance drivers and their causal connections.

Overall, while some limitations remain - mainly related to data availability and the specificity of the case study - the DBMfS stands out as an innovative approach for embedding the three dimensions of sustainability into strategic planning, performance management, and reporting. By doing so, it provides port authorities with a structured pathway to manage sustainability challenges systemically and dynamically, generate long-term public value, and enhance sustainable port governance and performance.

3.7 Concluding remarks

This chapter provides an in-depth analysis of the Western Sicily Port System Authority, reconstructing its institutional profile, governance model, and performance across the three dimensions of sustainability - economic, social, and environmental - alongside the most recent sustainability strategies and tools that have been planned or adopted. The analysis highlights how the AdSP has progressively evolved from a mere infrastructure manager into a multi-port system authority, assuming an increasingly complex and systemic role, tasked with balancing competitiveness, urban integration, and sustainability within a constantly evolving regulatory and operational context, characterized by pressing sustainability challenges and new opportunities offered by emerging technologies and AI.

At the core of the chapter lies the empirical application of the DBMfS to the case study. This model demonstrates its ability to map, analyze, and visually represent the interdependencies among resources, processes, performance drivers, and end results, providing an integrated view of the three sustainability dimensions. Moreover, the DBMfS enables the translation of complex institutional strategies into clearly identifiable mechanisms of public value creation, and, most importantly, into concrete and monitorable indicators.

The introduction of KPIs, presented in Tables 3 and 4, demonstrates how the DBMfS evolves from a conceptual framework to an operational tool that supports strategic decision-making. Through these indicators, the model enables the measurement, monitoring, and evaluation of the AdSP's sustainability strategies, promoting greater transparency and strengthening its capacity for timely intervention.

In this sense, through its systemic and dynamic lens, the DBMfS allows the identification of discrepancies between expected and actual results, the analysis of their causes, and the activation of targeted corrective actions, thereby reinforcing the link between strategic planning and management control.

However, the application has also highlighted certain structural limitations. In particular, the absence of a quantitative model reflects the ongoing implementation phase of many sustainability strategies: several initiatives launched by the Authority are either still under implementation or have not yet generated reliable historical data series. This condition currently limits the possibility of validating the model through robust quantitative analyses.

In conclusion, the DBMfS emerges as an innovative and valuable methodological approach for sustainable port governance. Its application to the case of the Western Sicily Seaport Authority demonstrates the model's ability to integrate the three dimensions of sustainability into the planning and performance management of seaport authorities, supporting evidence-based decision-making and guiding the creation of sustainable public value in the long term.

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4 Research conclusions

Seaport Authorities represent highly complex systems, as they manage multiple ports and terminals along with a wide range of resources, activities, and processes, while pursuing objectives that must be balanced within multifactorial ecosystems where infrastructures, operations, regulatory frameworks, and socio-economic dynamics are deeply interconnected (Bergantino et al., 2013; Ensslin et al., 2018; Lim et al., 2019; Notteboom et al., 2022). This complexity directly affects performance management systems, which must reconcile operational efficiency and financial sustainability with the mitigation of the environmental and social impacts of port activities, adopting a long-term vision in which sustainability is not an ancillary element but a fundamental pillar of strategic decision-making (UNCTAD, 2022). The dynamic complexity that characterizes port systems, together with the externalities generated by AdSPs - highlighting the urgency of addressing sustainability challenges to safeguard community well-being and the environment - and the opportunities offered by advanced technologies to foster more sustainable practices (Bjerkan & Seter, 2019; Garrido Salsas et al., 2022; Mudronja et al., 2022), requires a profound rethinking of current performance management systems. Traditional approaches to port governance are predominantly static and focused on short-term economic performance (Di Vaio & Varriale, 2018; Martins et al., 2024) and are therefore unable to capture the interdependent nature of the economic, social, and environmental dimensions, as well as the delays, feedback loops, and non-linear interactions that define complex systems.

There is therefore a need for integrated methodological frameworks that can provide concrete support for planning and managing sustainability in ports. Such tools should enable not only the implementation but also the monitoring of sustainability strategies, while ensuring a balance between economic competitiveness, environmental protection, and social inclusion (Ashrafi et al., 2019; Bucak et al., 2020; Caliskan, 2022; Di Vaio & Varriale, 2018; Martins et al., 2024).

To address this need, this research proposes the adoption of the DBMfS (Cosenz et al., 2020) as both a robust theoretical framework and an operational tool, capable of integrating the three dimensions of sustainability into port performance management. Rooted in the TBL paradigm (Elkington, 1998), the DBMfS combines the perspective of SD with the architecture of the BMC (Osterwalder & Pigneur, 2010), offering a systemic representation of sustainability drivers and a dynamic understanding of their interdependencies over time (Abdelkafi & Täuscher, 2016; Forrester, 1961; Sterman, 2000, 2002).
The methodological support offered by SD to business model design is widely recognized in

the literature, including in relation to sustainability. Since the pioneering studies of Forrester (1961) and Sterman (2000), SD has established itself as an effective approach for representing systems characterized by dynamic complexity, thanks to its ability to model feedback loops, resource accumulations, time delays, and non-linear relationships. In the managerial field, SD has proven to provide valuable support for strategic analysis and performance management (Bianchi, 2016; Morecroft, 2007, 2015). More recent contributions have highlighted its specific applicability to business model design and business model innovation (Cosenz & Noto, 2016, 2018).

Adopting a dynamic and systemic perspective is particularly relevant, as the business model itself can be interpreted as a complex system composed of interconnected resources, processes, and relationships that interact through feedback mechanisms and generate nonlinear effects (Casadesus-Masanell & Ricart, 2010; Demil & Lecocq, 2010). Furthermore, several studies have emphasized the potential of SD in the field of business models for sustainability, showing how it makes it possible to capture and analyze causal interdependencies among variables, simulate alternative scenarios, and evaluate trade-offs between economic, social, and environmental objectives (Abdelkafi & Täuscher, 2016; Cosenz et al., 2020, 2024; Täuscher & Abdelkafi, 2018).

To highlight these potentialities as a tool capable of systematically integrating the three dimensions of sustainability into port performance management, this research has developed a practical application of the DBMfS to the case of the AdSP MSO. The case was selected for its strategic role within the Italian and European port system, as evidenced by port traffic analyses, and for its strong commitment to implementing sustainability-oriented strategies in recent years, as detailed in Chapter 3.

The application of the DBMfS to this case study demonstrates, first and foremost, how the model provides a structured and systemic lens for mapping and analyzing sustainable value creation processes. After identifying the key sustainability drivers, linked to three strategic initiatives of the AdSP- namely, waterfront regeneration, energy efficiency through renewable energy plants, and quay electrification via cold ironing - the process of sustainable value creation was analyzed from the perspective of SD. To operationalize these mechanisms, the sustainable value proposition block of the DBMfS was translated into two complementary sets of KPIs. The first set, related to drivers and performance outputs, provides an operational view of short- and medium-term results, showing how resources and activities generate immediate and intermediate effects. The second set, instead, focuses on outcomes and assesses the long-term impacts across the economic, social, and environmental dimensions, thereby reflecting the broader process of sustainable value creation in line with the SDGs.

The measurement, evaluation, and continuous monitoring of these indicators ensure consistent alignment between short-term actions and long-term objectives. This approach not only allows sustainable seaport performance to be assessed against predefined targets but also - thanks to the dynamic perspective of the model - enables backward-looking analyses to trace the causes of potential deviations and design targeted corrective measures.

The findings of this research carry significant implications for both theory and practice. The study contributes to the academic debate on seaport sustainability by addressing several limitations highlighted in existing literature. Much of the existing research has predominantly focused on the environmental dimension of sustainability, examining impacts such as emissions, air quality, waste management, and energy consumption (Di Vaio & Varriale, 2018; Puig et al., 2014; Styliadis et al., 2022). Economic analyses have often been limited to employment and regional development (Artal-Tura et al., 2016; Braun et al., 2002), while the social dimension has remained largely underexplored, despite the contribution of ports to income creation, professional training, and local community development (Styliadis et al., 2022). By combining a systemic and dynamic approach with sustainability-oriented business model design, this study demonstrates the feasibility of operationalizing the TBL approach in an integrated manner, even within a complex context such as seaports. At the same time, it contributes to advancing the academic debate on dynamic business modeling for sustainability (Bordoli et al., 2023; Cosenz et al., 2020; Cosenz et al., 2024).

From a practical perspective, this study introduces an operational decision-support tool for seaport governance. The DBMfS enhances strategic decision-making, guides resource allocation, and supports transparent reporting processes, while also promoting effective communication with stakeholders by aligning operational activities with the SDGs (Cosenz et al., 2020). Moreover, the adoption of a systemic and dynamic perspective, together with the use of carefully calibrated KPIs, enables retrospective analyses, facilitates the identification of performance gaps, and allows for the attribution of their causes to specific drivers, actions, or resource misalignments. This, in turn, promotes a proactive and evidence-based approach to governance and supports the design and implementation of strategies aimed at the long-term creation of sustainable outcomes and public value, in line with the approaches of Dynamic Performance Management and Governance (Bianchi, 2010, 2016, 2021, 2022; Bianchi et al., 2019; Bianchi & Grippi, 2025).

For example, to verify the achievement of the Port Authority's goal of reducing CO_2 emissions using renewable energy, energy efficiency measures, and low-impact technologies, it is necessary to monitor the outcome indicator carbon neutrality, which compares the emissions produced in a given year with those of a baseline year before the implementation of interventions. If this indicator does not show progress, it becomes necessary to analyze the yearly carbon footprint, which measures the total emissions generated annually by port activities. A high value indicates that the implemented interventions are not producing the desired effects. In such cases, port decision-makers can trace back to the performance drivers, namely the green energy production rate, fuel consumption per vessel, and the share of the budget allocated to energy efficiency measures and berth electrification. Monitoring these drivers enables the identification of the causes of poor performance and, retrospectively, the strategic resources on which to intervene to realign performance with established objectives. In particular, a stagnant or reduced green energy production rate – which measures the share of self-produced green energy compared to total consumption – indicates an insufficient level of investment in renewable energy facilities, with repercussions also on energy costs. Similarly, a high fuel consumption per vessel reflects low energy efficiency in port operations, suggesting the need to expand the capacity of electrified berths to promote the adoption of cold ironing. By leveraging these strategic resources, the drivers can improve, the annual carbon footprint can be reduced, and, consequently, the outcome indicator of carbon neutrality can demonstrate tangible progress towards the decarbonization goal.

Port System Authorities can thus employ the DBMfS both as a strategic compass for long-term planning and as a dashboard for short-term performance monitoring, while simultaneously enhancing stakeholder engagement and ensuring reporting processes in line with international standards.

Overall, the DBMfS represents not only a conceptual advancement but also an operational innovation, capable of balancing economic growth, environmental protection, and social well-being. In doing so, the model equips Port Authorities with the necessary tools to address complexity, accelerate the transition toward greener, smarter, and more resilient operations, and generate sustainable public value over the long term.

Despite the advantages highlighted, this study presents some limitations. First, reliance on a qualitative mapping of causal relationships inevitably introduces margins of subjectivity. The complexity of port systems also entails the risk of overlooking relevant variables or dynamics, which can lead to simplifications that may omit significant interactions. Another critical issue concerns the lack of standardized and comparable data across ports, which limits the possibility of conducting quantitative validations, particularly with respect to social and environmental indicators. This challenge is further compounded by the fact that many of the sustainability strategies considered are still in the implementation phase, making a quantitative assessment premature. Consequently, the study employs a qualitative approach, which, although it does not provide numerical quantification of results, enables the identification of causal relationships and systemic dynamics of high conceptual value, transferable to other port contexts.

The framework is adaptable to other port contexts. However, the set of indicators developed in this study was designed *ad hoc* to reflect the specific priorities and strategies of the Western Sicily Seaport Authority. Nonetheless, several indicators suggest a high degree of transferability, as measures such as waterfront regeneration, cold ironing, and energy efficiency are becoming increasingly widespread across both national and international ports.

Future comparative studies conducted across multiple ports, supported by harmonized and high-quality datasets, could strengthen the external validity of the model and enable a more robust quantitative operationalization. These aspects, however, should not be interpreted as intrinsic weaknesses of the model, but rather as structural challenges linked to data availability and quality, institutional diversity, and the inherent complexity of port ecosystems.

Future research should build on the CLDs developed in this study to advance the quantitative operationalization of the DBMfS. Translating the identified variables into measurable components requires access to harmonized, high-quality datasets, which remain a significant challenge in the port sector, particularly in terms of social and environmental dimensions. Another promising avenue involves integrating the DBMfS with advanced technologies, such as AI, digital twins, and blockchain. These tools could expand the model's capabilities in terms of monitoring, forecasting, and transparent reporting, while also supporting decision-making processes in complex and uncertain contexts.

Comparative applications conducted across multiple port systems would further allow testing the adaptability and scalability of the model in different governance, regulatory, and institutional settings, providing stronger evidence of its potential as a generalizable framework for sustainable port governance.

In conclusion, the application of the DBMfS to the AdSP MSO confirms both the theoretical robustness and the practical utility of the model, while also highlighting the challenges that remain open. Based on these results, the framework can serve as a reference for Port System Authorities seeking to integrate sustainability management into strategic planning and performance management. Achieving this objective, however, will depend on the ability to ensure continuous innovation, secure reliable data, and foster active collaboration among policymakers, managers, and local stakeholders. Only through such systemic and collective efforts will it be possible to reconcile competitiveness with sustainability, enabling ports to maintain their strategic role in the global economy while simultaneously protecting the environment and enhancing community well-being.

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