STUDY

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European Port Strategy



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European Port Strategy

Abstract

This study assesses the challenges facing European ports across five key areas: **competitiveness**, **safety** and **security**, **energy transition** and **decarbonisation**, **digital systems**, and **hinterland connectivity**. Drawing on two non-EU port case studies, it develops a strategic framework for **strengthening EU port competitiveness**, **assesses the EU Ports Strategy** adopted by the European Commission and offers targeted **policy recommendations** to advance the strategy's goals. This document was provided at the request of the TRAN Committee.

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LIST OF ABBREVIATIONS

AFIR	Alternative Fuels Infrastructure Regulation
AI	Artificial Intelligence
API	Application Programming Interface
CEF	Connecting Europe Facility
CER Directive	Critical Entities Resilience Directive
C-ITS	Cooperative Intelligent Transport Systems
CO_2	Carbon dioxide
EC	European Commission
ECA	European Court of Auditors
EEA	European Economic Area
eFTI	Electronic Freight Transport Information
EIB	European Investment Bank
EMCDDA	European Monitoring Centre for Drugs and Drug Addiction
eMSW	European Maritime Single Window
EOPSA	European Onshore Power Supply Association
EP	European Parliament
ERA	European Union Agency for Railways
ERDF	European Regional Development Fund
ERTMS	European Rail Traffic Management System
ESPO	European Sea Ports Organisation
ETS	Emissions Trading System
EU	European Union
EUDA	System European Union Drugs Agency

EU ETS	European Union Emissions Trading
EUR	Euro (currency)
FuelEU Maritime	EU regulation on the greenhouse gas intensity of energy used on board ships
GHG	Greenhouse gas
IMO	International Maritime Organization
InvestEU	EU investment programme supporting public and private investment
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information technologies
JASPERS	Joint Assistance to Support Projects in European Regions
LPI	Logistics Performance Index
LSCI	Liner Shipping Connectivity Index
MFF	Multiannual Financial Framework
MPA	Maritime and Port Authority of Singapore
NIS2	Network and Information Security; Directive on measures for a high common level of cybersecurity across the Union
OPS	Onshore Power Supply
OT	Operational technologies
PCS	Port Community System
Ro-Ro	Roll-on/Roll-off
TEN-T	Trans-European Transport Network
TEU	Twenty-foot Equivalent Unit
TMSA	Tanger Med Special Agency
TOS	Terminal Operating Systems

TRAN	Committee on Transport and Tourism of the European Parliament
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development

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EXECUTIVE SUMMARY

KEY FINDINGS

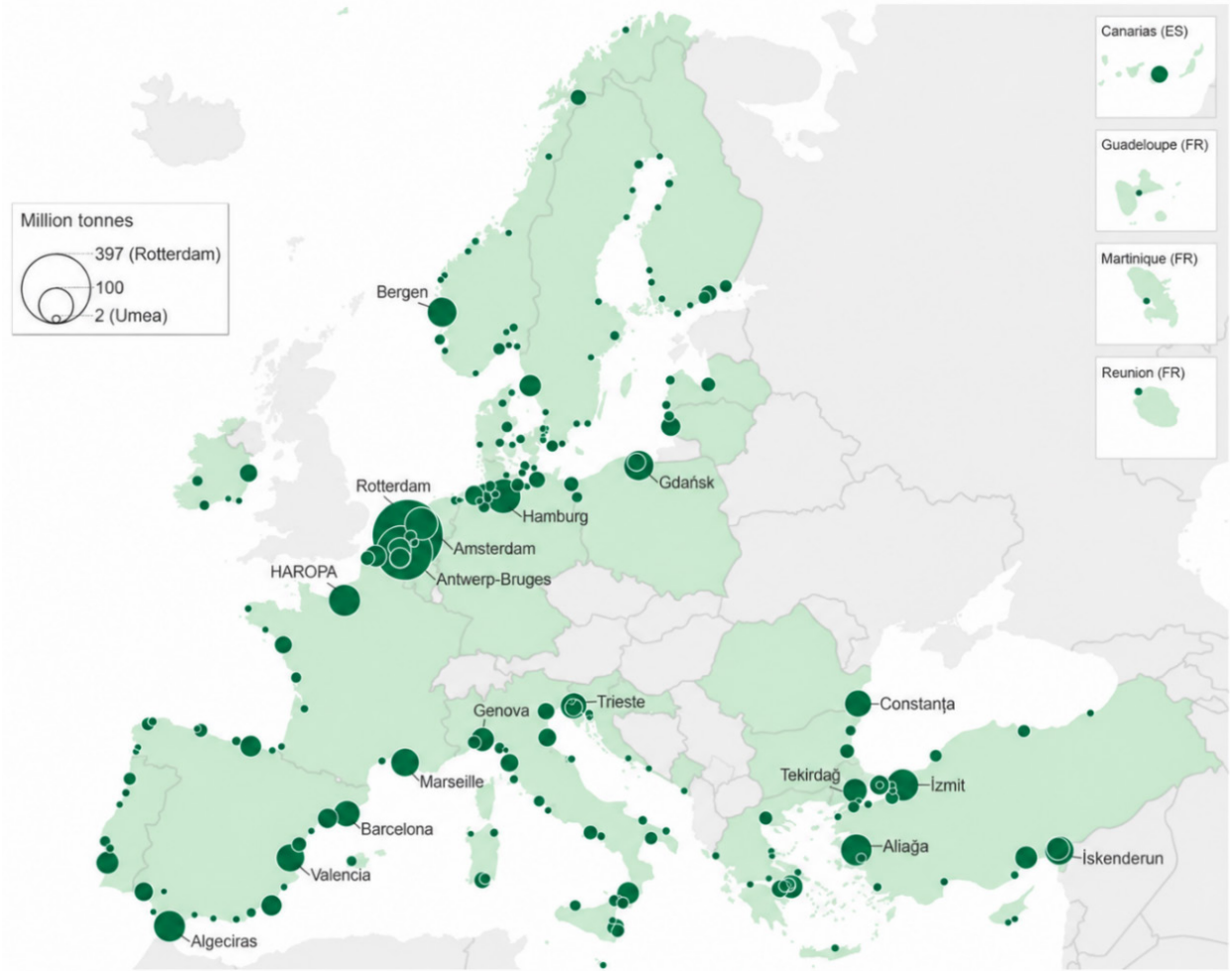
- **The EU Ports Strategy**, adopted in March 2026, **provides a relevant strategic direction, but implementation is now the central challenge**. Its effectiveness will depend on translating broad objectives into coordinated action, investment and operational capabilities across a highly diverse European port system.
- **European port competitiveness is multidimensional**. Beyond cargo volumes and transhipment, it depends on connectivity, logistics and industrial activities, technological capabilities, investment conditions and resilience, requiring a broader evidence base for EU policy.
- **The transformation of ports creates closely interconnected opportunities and risks**. Digitalisation, the energy transition and stronger hinterland integration can improve competitiveness and sustainability, but also require substantial investment, interoperability, cybersecurity and predictable long-term conditions.
- **The strategic role of ports increasingly extends beyond commercial transport**. Resilience, energy security, crisis preparedness and military mobility need to be considered alongside commercial functions, through proportionate approaches reflecting different port roles and risks.
- **Coordination and proportionality are recurring requirements across all policy areas**. Implementation needs to reflect differences between ports and strengthen coordination across policies, governance levels and public and private actors; these needs become more urgent under geopolitical fragmentation and stronger international competition.

The European port system and policy context

EU ports form an extensive and diverse system that is central to European trade and connectivity. Beyond transport, they support major logistics, industrial and energy activities and connect maritime flows with European supply chains and inland networks. The system ranges from major gateways and transhipment hubs to numerous small and medium-sized ports and specialised industrial, energy and passenger ports. Consequently, challenges and investment needs vary considerably according to port size, function, geographical position and strategic role.

The EU Ports Strategy, published by the European Commission in March 2026, reflects the expanding role of ports within European policy, increasingly recognising them as strategic infrastructure for competitiveness, security and resilience, the energy transition, digitalisation and connectivity. This study assesses these challenges, examines how the Strategy addresses them and identifies areas where further action could support its implementation.

Figure 1: Main cargo ports in Europe by gross weight of goods handled, 2024



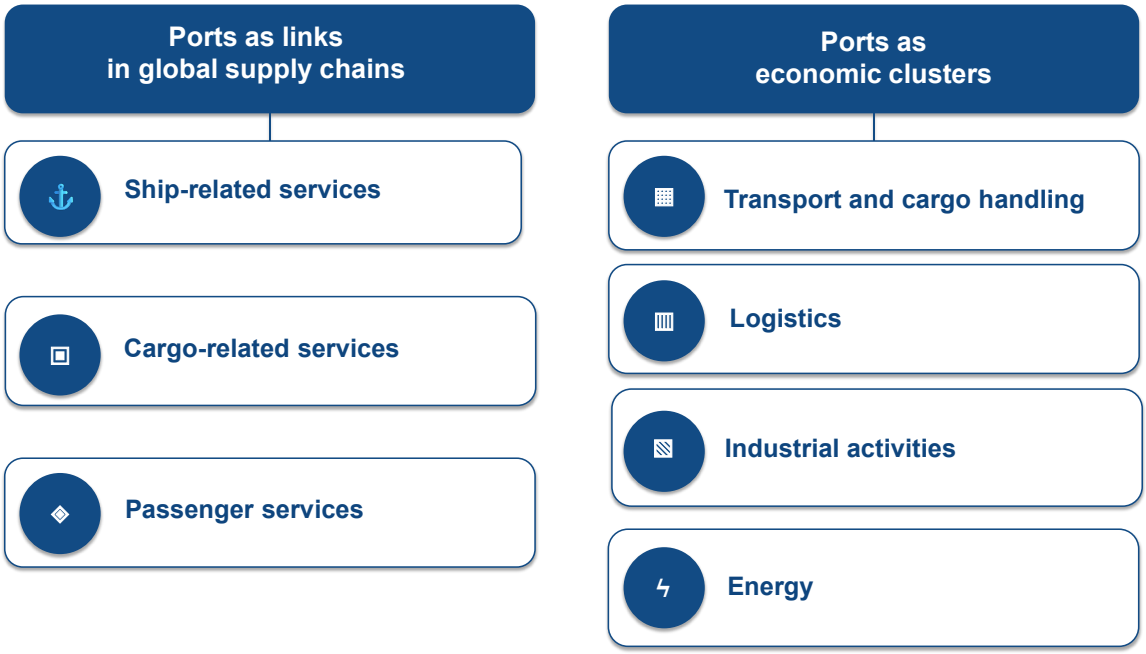
Source: (Eurostat, 2026b).

Main findings

Overall, the study finds the EU Ports Strategy timely, relevant and broadly aligned with the evidence reviewed. Its main added value lies in providing an integrated strategic direction across competitiveness, safety and security, sustainability and energy transition, digitalisation and hinterland connectivity. The principal challenge is therefore not the strategic direction itself, but its effective and proportionate implementation across a highly diverse port system.

Competitiveness is broader than cargo volumes and transhipment. It concerns the ability of EU ports to attract shipping services, logistics and industrial activities, investment and technological capabilities. Regulatory asymmetries, permitting, energy and grid conditions, state aid and access to funding are important factors requiring greater consideration in EU policy. Transhipment leakage remains a credible concern, particularly for Mediterranean ports exposed to nearby non-EU competition. The international cases also show that there is no single competitiveness model: rather than replicating non-EU ports, the opportunity lies in strengthening coordination, interoperability and innovation deployment.

Figure 2: Core functions of the ports



Source: Authors, based on Notteboom et al., 2026.

Security and resilience increasingly concern interconnected physical, digital and operational systems. Cybersecurity threats, organised crime, critical infrastructure vulnerabilities and geopolitical risks can affect ports and wider logistics chains, while dual-use infrastructure creates additional requirements for resilience and crisis preparedness. Existing EU instruments provide a substantial policy basis; the main challenge is achieving consistent operational capabilities across ports with different resources, governance and strategic roles.

Ports are important enablers of the energy transition, but are not the main drivers of alternative-fuel uptake. They provide infrastructure, land, planning, coordination and safety arrangements, while demand, supply and investment are largely shaped by shipping, fuel and market actors and the wider regulatory environment. Uncertainty over future fuel pathways can delay investment, highlighting the importance of predictable long-term policy signals while retaining technological flexibility.

Digitalisation increasingly connects ports with wider transport and supply chains, but also creates new dependencies and security risks. Digital technologies can improve planning, automation, coordination and end-to-end visibility, while greater connectivity increases exposure to cyber incidents and cascading disruption. Adoption in EU ports remains uneven, making interoperability, secure data governance, investment capacity and scaling up proven solutions' important challenges.

Port-hinterland connectivity is central to competitiveness, decarbonisation and resilience, but remains uneven. Formal TEN-T connection does not necessarily ensure sufficient capacity, interoperability, multimodal integration or alternative routing. The analysis points to corridor-level planning and monitoring, integrated investment and, where strategically relevant, proportionate consideration of resilience and dual-use requirements.

Key policy recommendations

Drawing on the study findings and interviews with a broad range of port-sector stakeholders, the study develops targeted policy recommendations to support implementation of the EU Ports Strategy.

- **On competitiveness, the EU should strengthen the evidence base and monitoring of European port competitiveness**, including through a robust and stakeholder-supported methodology to assess potential business leakage and competitiveness impacts associated with the EU ETS and FuelEU Maritime Regulation (EU) 2023/1805. This should be complemented by stronger consideration of port competitiveness in EU policy processes and a concrete agenda for deploying port innovation and strengthening technological leadership.
- **On security and resilience, the EU should strengthen implementation capacity in relation to cybersecurity, critical-infrastructure resilience and organised crime**, supporting consistent application of existing requirements, common risk assessment and preparedness, and stronger cooperation across ports and wider logistics chains.
- **On the energy transition, EU policy should translate long-term decarbonisation objectives into predictable investment conditions for ports**, while supporting international alignment through the IMO and recognising the uncertainties surrounding future fuel demand, supply and infrastructure requirements.
- **On digitalisation, greater emphasis should be placed on scaling and replicating proven solutions and strengthening interoperable data exchange**. This could include dedicated scale-up programmes, peer learning and knowledge sharing, alongside a stronger EU governance framework for interoperable port, hinterland and supply-chain data.
- **On hinterland connectivity, the EU should develop a common monitoring framework to assess whether ports are effectively integrated into multimodal and resilient hinterland corridors**. EU funding could strategically support integrated port-access investments, while resilience and dual-use considerations could be mainstreamed into the appraisal of strategically relevant port-hinterland corridors.

The study tests the recommendations against **four scenarios to 2040**, differentiated by the pace of decarbonisation and the level of geopolitical cooperation. All recommendations remain relevant across the scenarios, but their urgency is greatest under geopolitical fragmentation, while more cooperative scenarios shift the focus towards investment, technology deployment and market opportunities.

1. INTRODUCTION

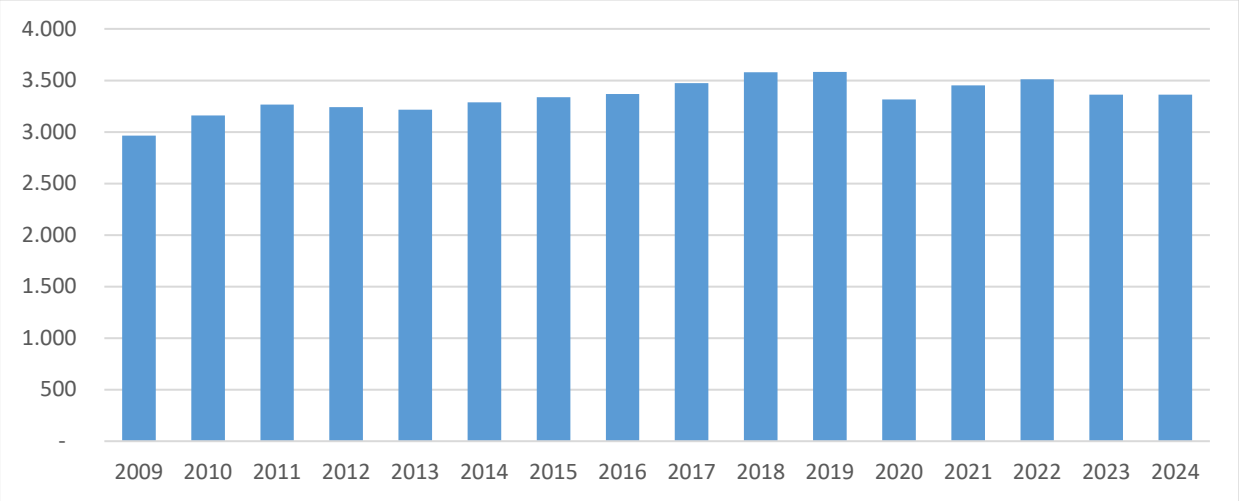
1.1. Background and context

1.1.1. The European port system

EU ports are strategic gateways for Europe's economy, security and connectivity. They underpin the **functioning** of the **internal market**, enable **global trade**, and form a **critical part** of the wider **European transport** and **logistics ecosystem**. Each year around 3.4 billion tonnes of goods pass through EU ports, which is 74% of the EU's external trade, as well as nearly 395 million passengers (Eurostat, 2026a).

As shown in Figure 3, **seaborne freight volumes** have remained **broadly stable over the longer term**, albeit with several distinct fluctuations. Following a gradual recovery after the 2009 economic crisis, freight activity increased from around 2014 and reached its highest levels in 2018–2019. This upward trend was interrupted by a marked decline in 2020, largely associated with the COVID-19 pandemic and related restrictions on economic activity and transport. Volumes subsequently recovered, reaching around 3.5 billion tonnes in 2022, before declining again in 2023 and remaining broadly stable in 2024. The more recent reduction is in part influenced by changes in trade flows following Russia's war of aggression against Ukraine and the resulting restrictions on trade with Russia.

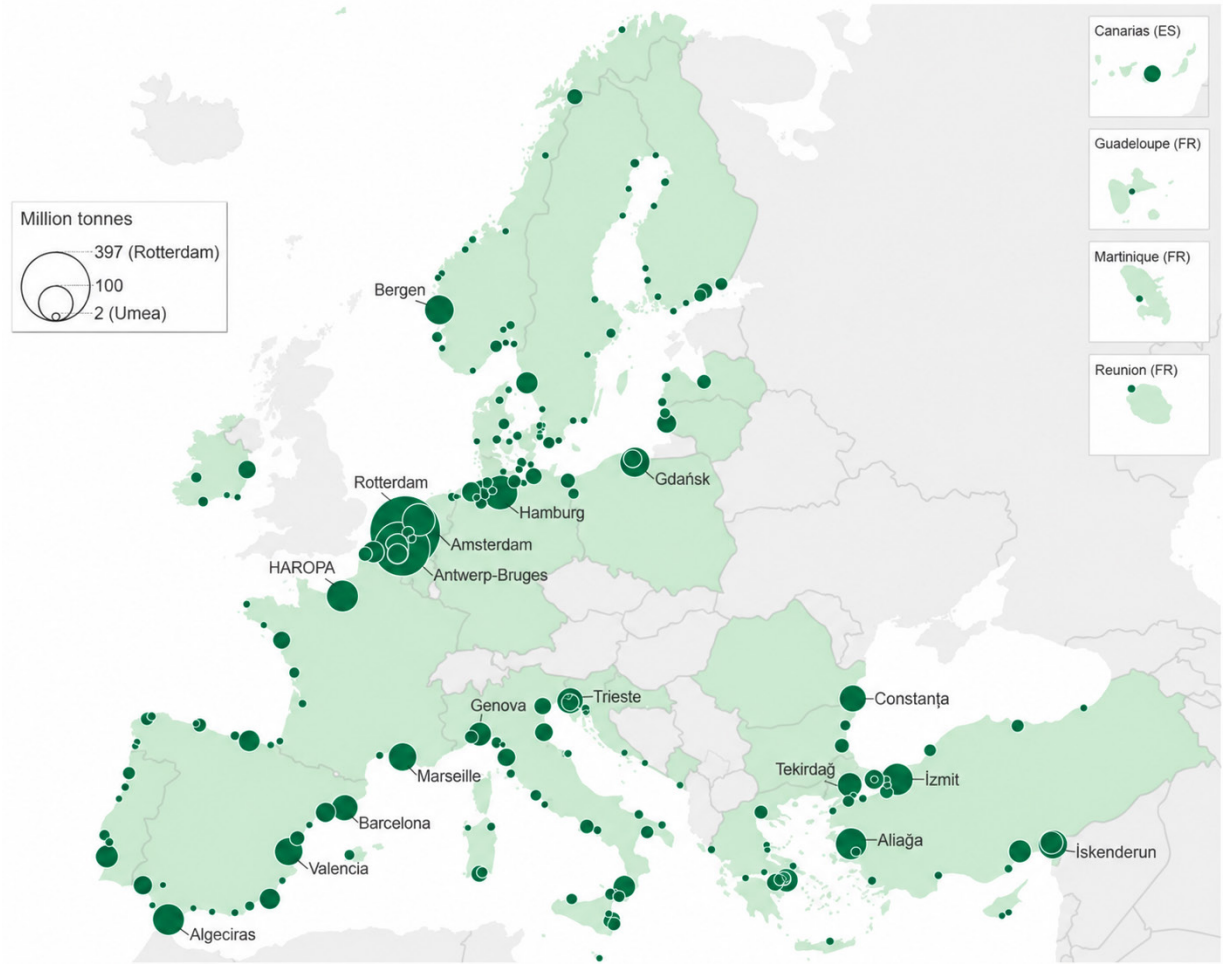
Figure 3: Gross weight of seaborne goods handled in all ports by direction (million tonnes), EU 27, 2009-2024



Source: (Eurostat, 2026b).

The European port system is geographically extensive and highly diverse. As illustrated in Figure 4, a relatively limited number of large ports handle very substantial volumes, while numerous small and medium-sized ports are spread across European coastlines. In 2024, the highest freight volumes are concentrated in several major port regions, including the North Sea range and parts of the Mediterranean, while significant port activity is also present across other European maritime regions.

Figure 4: Main cargo ports in Europe by gross weight of goods handled, 2024



Source: (Eurostat, 2026b).

The diversity of the port system extends beyond differences in scale. Ports vary considerably in their traffic composition, geographical position and economic function. Some ports handle a broad mix of cargoes, while others are more specialised in particular traffic segments, such as containers, dry bulk, liquid bulk, Roll-on/Roll-off (Ro-Ro) or general cargo. Their economic and transport functions also differ:

- **Gateway ports** connect maritime services with European production and consumption centres through road, rail and inland waterways.
- **Transhipment ports** facilitate the transfer of cargo between maritime services, often linking deep-sea routes with regional or feeder connections.
- Other ports have a strong **industrial or energy function**, with production facilities, refineries, terminals and increasingly infrastructure associated with renewable energy and alternative fuels.
- **Passenger and ferry ports** handle regular passenger and vehicle services, providing links between mainland, island and cross-border destinations.

Many ports combine several of these functions rather than fitting into a single category.

The role of ports extends beyond the handling of ships and cargo. Major ports often function as **logistics and industrial clusters**, bringing together terminal operators, shipping companies, freight

forwarders, energy companies, manufacturers and public authorities. Beyond their transport function, ports also make an important direct contribution to the European economy. In 2022, the sector generated an estimated turnover of around EUR 90 billion and supported approximately 423,000 direct jobs (EC, 2025d). Particularly in larger ports, these activities form extensive port-related industrial and logistics clusters, where maritime transport is linked with manufacturing, energy production, distribution and other economic activities.

This diversity is relevant to the analysis undertaken in this study. **The challenges facing European ports do not affect all ports in the same way or to the same extent**. Exposure to international competition is particularly pronounced for ports competing for transhipment or gateway traffic, while decarbonisation and energy-transition requirements may have especially significant implications for industrial and energy ports. Hinterland capacity constraints are more acute for ports dependent on high-volume connections with inland markets (i.e., gateway ports), while smaller ports may face different constraints related to investment capacity or compliance with regulatory requirements. The assessment of EU ports therefore needs to take account of the diversity of the European port system rather than treating EU ports as a homogeneous group.

1.1.2. Evolving role and EU policy context

European ports are undergoing transformation. **Decarbonisation requirements, technological innovation, geopolitical instability and growing demand for resilient infrastructure are reshaping their role and investment needs**.

The policy context has therefore shifted significantly since the previous EU ports framework, *Ports: an Engine for Growth*, was adopted in 2013 (EC, 2013). Subsequent EU strategies have placed ports **more firmly within the Union's sustainability, digitalisation, competitiveness and resilience agendas**. This includes the Sustainable and Smart Mobility Strategy (EC, 2020), the New Approach for a Sustainable Blue Economy (EC, 2021), the European Council's Strategic Agenda 2024–2029 (European Council, 2024), and the revised TEN-T Regulation (EC, 2022a), which frames ports as cross-border multimodal nodes and transport hubs.

This expanded role is also reflected in recent work on competitiveness and security. The Draghi report on the future of European competitiveness highlights ports' importance as **transport hubs and their exposure to wider dependencies, including energy, electrification and digital infrastructure** (Draghi, 2024). The defence agenda similarly underlines the importance of ports for **military mobility and dual-use infrastructure** (EC, 2026f). In this context, ports are no longer only logistics gateways; they are platforms for clean energy, new industry, innovation, defence readiness and the blue economy.

Following this changing framing of ports, the Commission started working on updating the EU's port strategy. In the Political Guidelines 2024–2029, President von der Leyen announced an **EU Ports Strategy focusing on security, competitiveness and Europe's economic security and independence** (EC, 2024b). The Guidelines align with the European Parliament's call in its Resolution of 17 January 2024 (2023/2059(INI)) for a comprehensive European port strategy addressing issues such as foreign influence, security, ports' role in the energy transition, and the competitiveness of EU ports and companies (European Parliament, 2024).

In March 2026, the Commission adopted the **EU Ports Strategy** (EC, 2026a), together with the **EU Industrial Maritime Strategy** (EC, 2026b), to strengthen competitiveness, sustainability, security and resilience across the wider waterborne sector, including ports, shipping and shipbuilding. The Ports Strategy brings together ongoing and new initiatives, simplification measures and guidance on implementing current legislation, while the Industrial Maritime Strategy addresses the competitiveness,

innovation and technological leadership of Europe's maritime manufacturing and shipping industries. Together, they provide the immediate policy framework for EU action on ports.

Shortly after the publication of the EU Ports Strategy, the European Commission and the European Investment Bank launched a new capacity-building programme under the JASPERS[1] (Joint Assistance to Support Projects in European Regions) mandate, aimed specifically at small and medium-sized ports on the Trans-European Transport (TEN-T) network (DG MOVE, 2026). The Strategy also received political reinforcement from the Council, when Member States approved conclusions on the EU Ports Strategy in June 2026 (Council of the EU, 2026). Recognising that ports are increasingly evolving into multi-functional industrial hubs and gateways for trade, energy and mobility, member states emphasise the importance of ensuring the efficient and proportionate implementation of the strategy.

1.2. Study objectives

These EU policy developments raise important questions about the **direction, implementation and oversight of EU ports policy**. This study supports that work by assessing the challenges facing European ports, the policy choices available, and the instruments needed to strengthen competitiveness, security, sustainability and resilience.

The study is structured around five analytical topics:

1. **Global Competitiveness**: What are the main constraints that limit the global competitiveness of EU ports compared to non-EU ports?
2. **Safety and security**: What are current safety and security challenges, including threats from illegal activities (i.e. drug smuggling), cyber risks, and dual use of infrastructure?
3. **Energy efficiency and decarbonisation**: How can low-carbon technologies, alternative fuels, energy efficiency measures, and associated investment support the EU energy transition?
4. **Digital systems**: How can the adoption of digital systems, data interoperability, and innovative solutions streamline operations, reduce administrative burdens, and improve competitiveness?
5. **Hinterland connectivity:** How can port infrastructure and its integration with road, rail, and inland waterways, with the help of EU financial instruments and future EU investment needs, enhance multimodal efficiency and TEN-T network connectivity?

In addition to these five analytical topics, the study includes two complementary issues:

6. **Case studies:** What are the effective policies of major ports outside the EU that can inform actionable EU policy proposals?
7. **Scenarios:** Which different medium-term scenarios up to 2040 are there, and what policy direction, investment needs, and measures are required to ensure coherence with sustainable and environmental objectives?

Together, these questions provide the basis for the study's policy recommendations. Each topic concludes with an analysis of the EU Ports Strategy, assessing how the Strategy addresses the identified challenges in that area. The methodological approach used to develop this analysis and formulate the recommendations is reported into Annex 1.

[1] JASPERS is an EIB-managed advisory programme that supports public authorities and project promoters in preparing and implementing EU-supported investments.

1.3. Study outline

This report is structured as follows:

- **Chapters 2** to **6** assess the five analytical topics in turn: global competitiveness, safety and security, energy efficiency and decarbonisation, digital systems and hinterland connectivity.
- **Chapter 7** presents two international case studies—Singapore and Tanger Med—to identify governance approaches and operational practices that may provide relevant lessons for European ports.
- **Chapter 8** introduces the four alternative medium-term scenarios to 2040.
- **Chapter 9** brings together the policy recommendations identified throughout the study into a single integrated framework. It then assesses their relevance under four medium-term scenarios, illustrating how different geopolitical, economic and environmental futures may affect the urgency and prioritisation of EU policy action.

A synthesis of the findings emerging from the stakeholders' consultation, highlighting cross-cutting themes that extend across multiple policy areas, is reported in Annex 2.

2. GLOBAL COMPETITIVENESS

KEY FINDINGS

- **Global port competitiveness is shaped by a broad range of factors**. The literature distinguishes, among others, nautical conditions, terminal characteristics and services, management strategies, and the wider external environment.
- As not all of these factors are directly influenced by EU policy, this chapter focuses on three dimensions that are particularly relevant from an EU policy perspective: **transhipment, the wider investment attractiveness of EU ports, and technological leadership**.
- **The vulnerability of EU transhipment hubs remains a credible competitiveness concern, particularly in the Mediterranean**. However, current evidence is inconclusive in showing systematic relocation of transhipment activity to neighbouring non-EU ports.
- **Port competitiveness goes beyond transhipment**. It also depends on the broader ability of EU ports to attract transport, logistics and industrial activity, compared to non-EU ports. Based on stakeholder interviews, key barriers include regulatory asymmetry, permitting, energy prices, grid capacity, state aid rules and access to funding.
- **Technological leadership also offers an opportunity to improve competitive advantage**, but implementation and scaling remain important challenges.
- **The EU Ports Strategy** identifies these three dimensions as risks and priorities, but **remains too high-level on how they are monitored, quantified and translated** into concrete implementation measures.

2.1. Context

The EU Ports Strategy presents **enhancing competitiveness as one of the central objectives of the strategy**. The Strategy aims to strengthen the competitiveness, resilience, security and sustainability of European ports, and frames ports as strategic infrastructures for trade, logistics, energy, industrial activity and wider EU policy objectives. In this sense, competitiveness is not treated only as a question of port charges or terminal efficiency, but as a broader issue concerning the ability of EU ports to remain attractive nodes in global maritime networks and important locations for economic activity, compared to non-EU ports.

This chapter uses the term **global competitiveness** to refer to the position of the EU port system relative to non-EU ports. For the purposes of this chapter, global competitiveness is therefore understood as *the capacity of EU ports,* as a collective European port system, to attract and retain cargo flows, shipping services, logistics activity, industrial investment and strategic maritime functions compared with non-EU ports.

This chapter examines global competitiveness through three dimensions most relevant for global competitiveness for the EU ports system:

- vulnerability of EU transhipment hubs;
- port cost and efficiency; and
- technological leadership as a driver of global competitiveness.

Before examining these components, the chapter first defines what is meant by global competitiveness in the context of EU ports.

2.1.1. Conceptualising port competitiveness

While global competitiveness is a key concept in the Commission's EU Ports Strategy, it does not formalise the concept of competitiveness or provide an operational definition for assessing it. To analyse the issue more systematically, this section therefore draws on port economics and maritime logistics literature to conceptualise port competitiveness and identify the main drivers through which competitive pressure may arise.

In port economics and maritime logistics literature, port competitiveness is generally defined based on the role of a port in maritime logistics and supply chain management. Yu et al. (2025) define port competitiveness as a port's capacity to attract cargo flows and investment through a combination of favourable operational, infrastructural and institutional conditions, including container-handling capacity, geographical and natural advantages, policy frameworks and technological capabilities. These drivers of port competitiveness are not determined by a single driver. Many **drivers** exist, which can be roughly classified across four topics: nautical conditions, terminal offerings, management and strategies and external environment (Yu et al., 2025).

Table 1: Main dimensions and drivers of port competitiveness identified in the literature

Aspect of port competitiveness	Description	Drivers of competitiveness
Nautical conditions	The physical and spatial characteristics that shape a port's ability to receive vessels and attract maritime traffic.	Location; cargo volume; coastline characteristics / coastal accessibility
Terminal offerings	The quality, capacity and efficiency of port and terminal services.	Cost; infrastructure and superstructure; operational efficiency; service quality; customer-related factors; shipment size; terminal responsiveness
Management strategies	The internal managerial, organisational and strategic capabilities that influence port performance.	Human resources; supply-chain management; reputation; information technology; ocean services; safety and security; cargo damage/loss performance; port cooperation between ports; information sources; innovation; port risk management; institutional structure; firm strategy; flexibility
External environment	The wider economic, regulatory and transport environment in which a port operates.	Hinterland connectivity; hinterland network; economic environment; government support; legal framework; maritime connectivity; feeder services; green environmental policy

Source: own elaboration based on Yu et al. (2025).

Recent literature confirms that the relative **importance of these drivers varies across stakeholders and market segments**. Shipping lines may prioritise operational efficiency, reliability, nautical accessibility and network connectivity (Kaliszewski et al., 2020), whereas port authorities and terminal operators may place greater emphasis on location, infrastructure capacity, service offer and commercial development potential (Baştuğ et al., 2022; Yu et al., 2025). Cargo owners and logistics providers often evaluate ports through a broader supply-chain lens, where the port itself is only one element of a door-to-door logistics chain. From this perspective, hinterland connections, predictability and total logistics cost may matter more than the level of port dues (Rosa Pires da Cruz et al., 2013).

2.1.2. Port competitiveness from an EU policy perspective

This chapter focuses on **which factors affect the ability of the EU port system as a whole to compete with non-EU ports and to retain cargo flows**, while also supporting wider public objectives. This distinction changes the relevance of individual competitiveness drivers. A factor that is highly important for competition between, for example, Rotterdam, Antwerp-Bruges, Hamburg, Valencia or Piraeus, is not automatically the most relevant factor for EU-level competitiveness. From an EU perspective, the key question is whether a given driver affects Europe's position in global maritime networks and whether it can be influenced through EU policy.

Two filtering criteria are therefore needed. The first is **external contestability**. A competitiveness driver is particularly relevant for this study when it affects activities that can realistically cause cargo business to shift from EU ports to non-EU ports. This is especially the case for containerised transhipment cargo, which, unlike gateway cargo, is not tied to a specific hinterland and is therefore more footloose (Notteboom & Rodrigue, 2005). Empirical research supports this distinction, showing that ports with a higher dependence on transhipment traffic tend to experience greater throughput volatility than gateway-oriented ports (Bordeaux & Couto, 2026; Notteboom et al., 2019). This makes transhipment particularly relevant for assessing the global competitiveness of the EU ports system, especially where nearby non-EU hubs offer credible alternatives.

The second filtering criterion is **EU policy intervention**. Some drivers are important in explaining port competitiveness but are less suited for the EU level. Natural location, existing cargo volumes and inherited port geography, for example, are difficult to change through EU policy. Similarly, port governance can influence the performance of ports (Langen & Saragiotis, 2018), but the EU has traditionally avoided imposing a single governance or port management model. This is reflected in recital 10 in Regulation (EU) 2017/352, which explicitly states that the EU does not impose a specific model for the management of maritime ports, while establishing common rules on the provision of port services and financial transparency (EC, 2017). For this reason, port governance models are relevant but are not treated here as a primary EU-level competitiveness lever.

2.1.3. Three relevant port competitiveness factors for EU policy

Together, these two filtering criteria narrow the analysis to competitiveness drivers that are both relevant to competition with non-EU ports and susceptible to EU policy intervention. This leads to three priority areas:

- First, **vulnerability of transhipment hubs** is selected because transhipment cargo is relatively footloose. Unlike gateway cargo, it is not tied to a specific hinterland and can be redirected when shipping lines adjust their networks in response to cost, reliability or regulatory differences.
- Second, **port costs and efficiency** are selected because they remain central drivers of port choice. From an EU perspective, the relevant issue is whether EU regulatory, administrative or

infrastructure-related costs affect the ability of the EU ports system to compete with non-EU alternatives.

- Third, **technological leadership as a driver of global competitiveness** is selected because it represents an area where EU policy can actively shape competitiveness.

2.2. Vulnerability of transhipment hubs

2.2.1. Regulatory exposure and cargo diversion risks for EU transhipment hubs

The competitiveness of EU transhipment hubs has become an important policy debate in the context of recent EU maritime climate legislation, such as the extension of the EU Emissions Trading System (EU ETS) to maritime transport and the implementation of FuelEU Maritime. Box 1 (Rodrigue & Notteboom, 2010) illustrates the higher exposure of transhipment cargo to regulatory competition. Shipping lines can, at least in principle, shift transhipment activity to nearby non-EU hubs if this reduces costs or avoids regulatory exposure. This vulnerability is well established in the port literature.

Box 1: Transhipment versus gateway cargo: different exposure to regulatory competition

EU ETS and FuelEU Maritime may affect transhipment hubs **differently from gateway ports because transhipment cargo is more mobile**. The maritime EU ETS applies to ships calling at or departing from European Economic Area (EEA) ports, covering 100% of emissions from voyages between EEA ports and emissions within EEA ports, and 50% of emissions from voyages between an EEA port and a non-EEA port. FuelEU Maritime follows a broadly similar route-based logic, with requirements applying fully to energy used on intra-EU/EEA voyages and for 50% to voyages between EU/EEA and non-EU/EEA ports.

A practical example illustrates how transhipment ports and gateway ports are affected differently. A container shipped from Asia to Central Europe could be transferred from a deep-sea vessel to a feeder service at an EU Mediterranean transhipment hub, such as Algeciras or Valencia, or at a nearby non-EU hub, such as Tanger Med. If using the EU hub creates higher regulatory or compliance costs, the shipping line may be able to shift the transhipment operation to the non-EU hub while keeping the final destination broadly the same.

Gateway cargo is **less exposed to this type of rerouting**. A container destined for a customer in Germany, the Netherlands or Belgium cannot easily avoid a major gateway port such as Rotterdam, Antwerp-Bruges or Hamburg without changing the inland logistics chain, hinterland transport route, delivery time and cost structure.

This does not mean that gateway ports are unaffected by EU ETS or FuelEU Maritime, but that the competitive risk operates differently: for transhipment hubs, the main concern is the rerouting of mobile cargo flows, while for gateway ports the concern is more about the cumulative effect of regulatory costs on the wider logistics chain.

Source: Authors' own elaboration.

The debate has intensified because **EU maritime climate rules create additional compliance costs for ships calling at EU or EEA ports**. From the perspective of EU ports, the concern is that EU regulations may create incentives for carriers to reroute through nearby non-EU ports that are outside, or only partly inside, the regulatory perimeter of EU climate legislation (Lagouvardou & Psaraftis, 2022; Wu et al., 2024).

The exposure of EU ports is geographically uneven:

- The **Mediterranean** is generally considered the most vulnerable region because several non-EU ports, including Tanger Med, East Port Said and other North African or Eastern Mediterranean hubs, are close to EU transhipment ports and located on major East-West shipping lanes. These ports can, in some cases, serve as substitutes for EU transhipment functions.
- **North Sea ports face a different and generally more limited exposure**. The main nearby non-EU alternative is the United Kingdom. Because it is outside the EU and EEA, UK ports could in principle be used in call-order strategies on North Atlantic and North-West European services, although they are less likely to replace major continental gateway ports.
- **Baltic Sea ports also appear comparatively less exposed to transhipment leakage**. From a geographical perspective, Norwegian ports could potentially provide an alternative to some EU port calls in the wider Nordic region. However, Norway is part of the EEA and therefore falls within the EU ETS scope for maritime transport.
- **For Atlantic ports, potential leakage risks have received comparatively little attention in the literature**. This may reflect the more limited availability of nearby non-EU transhipment hubs that could readily substitute for EU Atlantic ports. Potential exposure could nevertheless arise through changes in port-call patterns involving the United Kingdom or North African ports, but the extent and relevance of such effects remain less well established than for the Mediterranean.
- **Black Sea ports may face some potential exposure to nearby non-EU ports, particularly in Türkiye, but this risk has also received limited attention in the literature**. In principle, non-EU Black Sea ports could provide alternative calls or routing options for services involving EU ports such as Constanța, Varna or Burgas. However, the Black Sea has a different traffic structure from the Mediterranean and fewer large-scale container transhipment hubs that could readily substitute for EU port functions.

The European Commission has recognised this risk by including specific design features in the EU ETS and FuelEU Maritime Regulation that are aimed at, or could have an effect on, mitigating maritime carbon or business leakage. For the EU ETS, this risk is explicitly reflected in Recital 28 of Directive (EU) 2023/959, which refers to the **risk of evasion linked to increased shipping costs and to the possible relocation of container transhipment activities**. The Directive also excludes stops by container ships at certain neighbouring container transhipment ports from the definition of "port of call", with the list established under Article 3ga(2). **Tanger Med** in Morocco **and East Port Said** in Egypt have been identified as such ports under Commission Implementing Regulation (EU) 2023/2297 (EC, 2023c).

In addition, Article 3gg(3) of Directive 2003/87/EC requires the Commission to **monitor and report every two years on the implementation of the ETS extension to maritime transport** (EC, 2023a). This monitoring is intended, among other things, to **detect evasive behaviour at an early stage** and, where appropriate, to **propose measures to ensure the effective implementation of the Directive**. FuelEU Maritime contains a comparable mechanism in Article 2(2) of Regulation (EU) 2023/1805 (EU, 2023c), with East Port Said and Tanger Med identified as neighbouring container transhipment ports under Commission Implementing Regulation (EU) 2025/1127 (EC, 2025a).

The **EU Ports Strategy** highlights in section 2.1 that the Commission is preparing to update the EU Emissions Trading System in Q3 2026, followed by a planned review of the FuelEU Maritime Regulation. The update will examine potential implementation challenges affecting the competitiveness of European ports, particularly the risk of traffic being diverted to non-EU transhipment ports (EC, 2026a).

2.2.2. Current evidence on cargo diversion and business leakage

Current evidence on actual competitiveness loss is mixed. Ex-ante academic modelling identifies a **credible risk of transhipment relocation and carbon leakage**, especially in the Mediterranean (Lagouvardou & Psaraftis, 2022; Wu et al., 2024). A systematic review of maritime EU ETS literature concludes that the EU ETS can support emissions reductions and stimulate decarbonisation, but that **uncertainties remain regarding carbon leakage and uneven economic effects** (Kotzampasakis, 2025). Another study notes that the literature remains relatively limited and case-specific, with some studies finding limited leakage risk and others finding that containerships may be incentivised to call at neighbouring non-EEA ports (Kotzampasakis & Wooley, 2025). Flodén et al. (2024) suggest also possible modal shift from maritime to road transport may occur. Vierth et al. (2024) estimate that the effect of EU's climate policy on maritime shipping in Sweden is minimal. Table 2: summarises modelled cost comparisons between existing EU port-call structures and alternative non-EU routing options available in the literature.

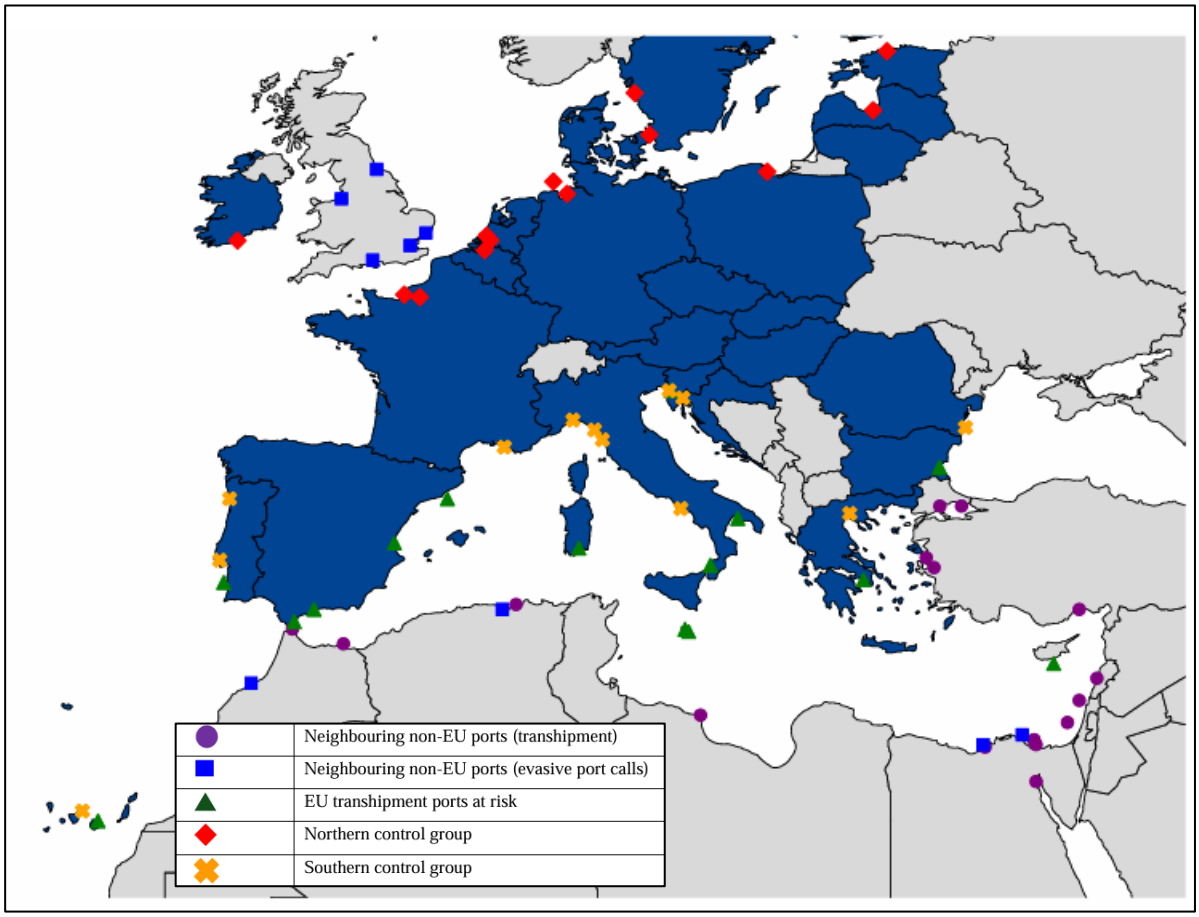
Figure 5 provides a broader geographical overview of potential leakage and evasive-routing risks, drawing on the ports considered in the European Commission's monitoring of the implementation of the maritime EU ETS. The monitoring framework distinguishes EU transhipment ports considered potentially at risk, neighbouring non-EU ports that could attract transhipment activity or additional port calls, and northern and southern EU control ports used to assess whether observed traffic developments are attributable to the EU ETS.

Table 2: Cost comparisons between existing EU port-call structures and alternative non-EU routing options

Current route / port-call structure	Alternative route / port-call structure	Cost difference between routes	Source
EU-Asia services using Piraeus as an EU/EEA transhipment hub	Relocation of transhipment activity to Izmir	Switch becomes cost-effective at EU ETS allowance prices above approximately EUR 25/mtCO_2.	Lagouvardou and Psaraftis (2022)
EU-Asia services using Algeciras as an EU transhipment hub	Relocation of transhipment activity to Tanger Med	Switch may become cost-effective at EU ETS allowance prices above approximately EUR 6/mtCO_2.	Lagouvardou and Psaraftis (2022)
East Asia–Rotterdam service with intermediate stop at Algeciras	Replace the Algeciras call with Tanger Med,	Net cost difference ranges from approximately EUR 300,000 to EUR 799,000 per round trip, depending on assumptions. The evasion risk is assessed as substantial.	CE Delft (2022)
East Asia–Rotterdam service with intermediate stop at Algeciras	Add London Gateway between Algeciras and Rotterdam	The additional call lowers EU ETS costs, but CE Delft finds that the additional costs are higher than the benefits in all scenarios assessed.	CE Delft (2022)
West USA – North-west EU service	Calling at UK before any EU ports	Evasion route is slightly cost-effective.	CE Delft (2022)
East Asia – North-west Eu service	Calling at UK before any EU ports	Evasion route is slightly cost-effective.	CE Delft (2022)

Source: Authors.

Figure 5: Ports considered in the monitoring of potential EU ETS leakage and evasive behaviour



Source : (EC, 2025h).

a. Commission's first implementation monitoring report in 2025

The Commission's first implementation monitoring report provides important context for this debate (EC, 2025h). It did **not identify a generalised relocation of container transhipment activity from EU ports to neighbouring non-EU ports** during the first monitored period. Key findings from the report are:

- For route announcements, the Commission found that there were a few examples that could suggest a risk of evasion through **additional UK calls**, but its analysis of 2025 transatlantic routes did not reveal a discernible evasive trend through UK ports.
- For **Mediterranean routes**, the Commission considered that route developments remain strongly affected by the Red Sea crisis, making it difficult to isolate the effect of the EU ETS from wider network disruption.
- In relation to **investment**, the Commission also found no clear evidence of a general shift away from EU port investment towards non-EU neighbouring ports, although it identified the recent capacity expansion at Damietta in Egypt and the expected substantial expansion of container-handling capacity at Nador in Morocco in 2027 as developments that should be monitored closely.
- Finally, the Commission did not identify **legislative or regulatory developments** in neighbouring non-EU countries that would increase future evasion risks; on the contrary, it noted that **Türkiye**'s announced carbon-pricing system for maritime transport and the inclusion

of domestic maritime emissions in the UK ETS could partly mitigate such risks. Box 3 provides more information on the UK as possible evasion opportunity for maritime shipping.

Box 2: UK as possible evasion opportunity for maritime shipping

The UK is considered a less significant leakage risk than Mediterranean non-EU transhipment hubs. In principle, leakage could occur if shipping lines add or reorder UK port calls to reduce exposure under the EU ETS or FuelEU Maritime (CE Delft, 2022). However, this risk appears limited so far.

A relevant factor is the scope of the UK ETS. **The UK ETS is being extended to maritime transport**, but its confirmed initial scope is limited to domestic UK maritime activity, covering domestic voyages and emissions in UK ports from July 2026 (UK Government, 2026). International voyages between UK and non-UK ports are not yet covered. This leaves an important part of UK-related maritime traffic outside the UK ETS scope, including those international services that could be relevant for leakage from the EU perspective.

The Commission's first monitoring report found no significant increase in containership calls at relevant UK ports before or after EU port calls, including for North-West Europe specifically. This is consistent with stakeholder evidence. A representative of North Sea Port noted that **UK ports were initially envisaged as a possible leakage risk, but that this has not materialised**, partly because of the uncertain UK political climate and the expectation that UK policy would broadly follow the EU direction (Port administration 2 and 3).

Recent UK policy developments support this interpretation. In May 2025, the UK and EU **agreed to work towards linking their respective emissions trading schemes** (UK Government, 2026). In addition, the UK is considering extending the UK ETS to international maritime voyages, including voyages between UK and EEA ports (UK Government, 2026). If implemented, this would reduce the regulatory gap with the EU ETS and weaken the incentive to use UK port calls as a way to reduce EU ETS exposure.

Source: Authors' own elaboration.

The Commission's first implementation monitoring report should be interpreted as **early evidence rather than a definitive assessment**. It was published around fourteen months after the EU ETS extension to maritime transport entered into application, but its underlying market analysis covered only the first nine months of 2024, when the ETS was still in its initial phase-in period. Moreover, it largely predates the full application of FuelEU Maritime from January 2025. The report therefore does not remove the risk of evasion or cargo diversion, but it suggests that **the strongest evidence so far remains potential and modelled, while early observed market evidence is still inconclusive**.

b. Stakeholders remain concerned about potential leakage

Nevertheless, stakeholders remain concerned, in particular with regard to the **Mediterranean**. In January 2025, Maersk announced that its Middle East–India–US service would stop calling at Algeciras and would instead call at Tanger Med (Maersk, 2025). Some political stakeholders treated this as an example of the type of diversion feared under the EU ETS (Parliamentary question, 2025). Maersk stated that the decision was commercial and related to transit-time improvements, not to the avoidance of the EU ETS (EFE, 2025).

In May 2026, the European Sea Ports Organisation (ESPO) called for the EU ETS review to address what it described as **risks to the level playing field and business leakage from European ports**. It argued that these risks are most visible for large Mediterranean transhipment ports, but also referred to

changes in call orders elsewhere in Europe and possible effects on direct connectivity with markets such as Asia (ESPO, 2026). The ESPO statement does not, in itself, provide route-level or investment data sufficient to establish causality between the EU ETS and observed changes in port calls or terminal investment.

c. Stakeholder consultation findings

Stakeholder consultation for this study confirmed that **possible business leakage towards non-EU ports remains a major concern for the sector**, particularly in relation to transhipment activity (EU sector organisation stakeholder 1, 2 & 4; Expert 1). A concern is whether the current monitoring framework is sufficient to detect competitiveness losses at an early stage (EU Sector organisation 2; Expert 2). One stakeholder argued that monitoring should also cover ports with a transhipment share below the 65% threshold or should make greater use of predictive tools rather than relying primarily on historical data (EU Sector organisation 2). It was also suggested that monitoring should not only assess investment developments in non-EEA ports, but also track reductions or delays in investment in EEA ports, since these may indicate that EU ports are negatively affected by the maritime ETS and are postponing or cancelling projects (EU Sector organisation 2).

A full assessment of whether the Commission's monitoring framework captures all relevant dimensions of EU port competitiveness is not the primary focus of this study. However, the stakeholder confirms that there is **no full consensus on whether existing monitoring is sufficient**. This suggests that **additional scrutiny may be needed on monitoring business leakage**, particularly regarding investment trends.

Stakeholders in the North Sea port range also mention possible competition from UK ports. However, as shown in Box 2, they generally noted that **this risk has not yet materialised to a significant extent**. This was partly explained by the uncertain political and regulatory situation in the United Kingdom. These observations support the conclusion that, while risks exist in several regions, the Mediterranean remains the main area of concern for transhipment-related leakage.

2.3. Port costs and efficiency

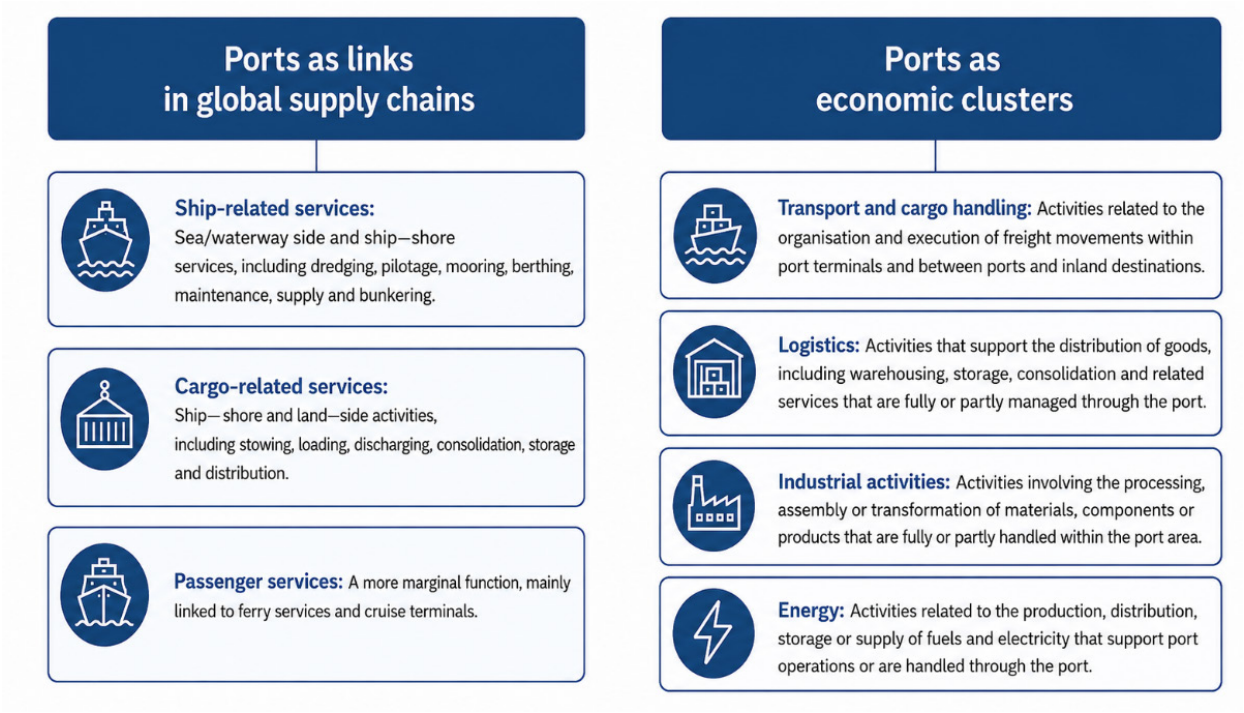
2.3.1. Port efficiency as a driver of competitiveness

As set out in Section 2.1.1, port competitiveness is determined by a combination of nautical conditions, terminal offerings, management strategies and the external environment. Cost and operational efficiency are particularly important elements of a port's terminal offering, but their relevance extends beyond the terminal itself. For cargo owners and logistics providers, ports are one component of a wider door-to-door supply chain, meaning that total logistics costs, reliability, connectivity and the time required to move cargo through the port and onwards to its destination can be more important than individual port charges (Rosa Pires da Cruz et al., 2013; Yu et al., 2025).

This distinction is important when considering what constitutes an efficient port. **From the perspective of shippers, efficiency concerns the cost, speed and reliability with which cargo can move through the port as part of the wider logistics chain.** This depends not only on terminal productivity, but also on factors such as vessel and cargo turnaround times, available capacity, maritime connectivity, hinterland connections and the efficiency of administrative processes. A port may therefore perform efficiently at terminal level but still offer a comparatively costly or unreliable logistics solution if cargo faces congestion, lengthy administrative procedures or weak hinterland connections.

This broad understanding of efficiency also reflects the two core functions through which ports create economic value. Ports operate both as **links in global supply chains** and in their wider role as **economic clusters for logistics**, industrial and energy-related activity (see Figure 6).

Figure 6: Core functions of ports



Source: Authors, based on Notteboom et al., 2026.

The two dimensions are closely connected (Langen & Haezendonck, 2012). A strong position as an industrial cluster can make a port more attractive to shipping lines, because it generates stable volumes and demand for services. Conversely, frequent port calls, efficient terminals and strong hinterland links can make a port area more attractive for industrial and logistics activity.

For EU ports, this broader understanding of competitiveness is increasingly relevant. The EU Ports Strategy aims to support EU ports in "maintaining and strengthening their competitiveness" (EC, 2026a). **But if EU ports collectively become less attractive as logistics nodes or as locations for economic activity, they risk losing competitiveness relative to nearby non-EU ports**.

A full assessment of all drivers identified in Section 2.1.1 would require a detailed and resource-intensive analysis that goes beyond the scope of this study. Moreover, several determinants are examined separately elsewhere in the study, notably digitalisation and hinterland connectivity. Therefore, the following section focuses on **stakeholder experiences related to the general competitiveness of the EU ports** system and on practical suggestions for strengthening the EU Ports Strategy.

2.3.2. Policy-relevant barriers to EU port competitiveness

Many stakeholders recognised that the EU ports system face increasing competitive pressure from nearby non-EU ports. The concerns most frequently raised relate to **regulatory asymmetry, permitting procedures, energy prices, grid capacity, state aid rules and access to funding**. These issues do not capture all possible determinants of port competitiveness, but they are particularly relevant for this study because they concern constraints that can, at least partly, be influenced by EU

policy or EU-level coordination. Table 3 summarises the main themes identified in the stakeholder consultations, which are discussed in more detail below.

Table 3: Summary of main stakeholder concerns that may affect the global competitiveness of the EU ports system

Competitiveness concern	Main stakeholders point
Regulatory asymmetry	EU ports face competitive pressure from nearby non-EU ports operating under different regulatory conditions. This affects not only transhipment, but also logistics, industrial and energy-related investment.
Permitting procedures	Lengthy and complex permitting procedures delay investment and reduce the attractiveness of EU ports. Some stakeholders reported EU permitting timelines of three to five years, or up to ten years for brownfield modernisation projects.
Scope of EU simplification efforts	Current EU simplification efforts may support environmental assessments and port decarbonisation projects, but may not address the full range of administrative procedures affecting port investments.
Energy prices	Structurally high energy prices put pressure on port-based industries and may contribute to investment leakage, especially in energy-intensive sectors such as chemicals and refining.
Grid capacity and reinforcement	Insufficient grid capacity and slow grid reinforcement are seen as critical bottlenecks for competitiveness and decarbonisation. Without sufficient grid access, ports may struggle to support industrial and technological transitions.
State aid	State aid rules may limit public funding for port-related investments, including projects considered strategically important for competitiveness, sustainability or resilience. Stakeholders want the review of state aid rules to preserve fair competition while allowing sufficient flexibility for strategic port investments.
Funding needs	Ports are increasingly expected to deliver strategic public objectives, such as resilience, security and sustainability, which cannot always be financed through commercial revenues alone.
Unclear and complex EU funding	The EU Ports Strategy identifies funding priorities but gives limited detail on budgets or implementation. Stakeholders also noted that EU funding instruments are administratively complex.

Source: Authors.

a. Regulatory and administrative procedures

First, **regulatory asymmetry** was mentioned by most stakeholders as an important cause of competitive pressure on the EU ports system (Expert 6, EU sector organisation 1, 2, 5, 6, Port Administration 3, 6). This issue is already well known in relation to the competitiveness of transhipment hubs, as discussed in the previous section. However, stakeholders also stressed that **regulatory asymmetry affects the broader competitiveness of the EU ports system**, including their attractiveness as locations for logistics, industrial and energy-related investment.

Permitting procedures were repeatedly identified as a barrier to competitiveness. Stakeholders described EU permitting processes as lengthy, complex and bureaucratic, which can delay investment and reduce the attractiveness of the EU ports system compared with competing regions outside the

EU. One stakeholder indicated that permitting procedures in the EU may take three to five years, while comparable procedures in competing regions outside the EU can be completed within eight to ten months (EU Sector Organisation 2). Another stakeholder noted that a brownfield modernisation project in a port context may take up to ten years (Port Administration 3). **Such delays can negatively affect the willingness of companies to invest in EU port areas, particularly when faster alternatives are available outside the EU**. This may endanger high-CAPEX infrastructure like grid reinforcement and alternative fuels, which also helps to achieve broader EU policy objectives (Expert 7). One expert also notes that the competitiveness of non-EU ports such as Tanger Med and Port Said also stems from the presence of large Special Economic Zones offering favourable tax regimes, simplified administrative procedures and investment incentives (Expert 4).

The EU Ports Strategy recognises that slow permitting processes can put the EU's competitive advantages at risk. However, stakeholders considered that **the strategy does not yet provide sufficiently concrete EU-level actions to address this issue**. Some simplification efforts are taking place through broader EU initiatives, including Omnibus packages, which include a proposal for a **Regulation on speeding up environmental assessments**, COM(2025) 984 (EC, 2025g). This document explicitly mentions the decarbonisation of ports as a strategic sector under the proposed regulation.

However, the emphasis on decarbonisation raises questions about whether the proposed simplification measures sufficiently address the broader competitiveness concerns identified by stakeholders. Faster environmental assessments are relevant for port infrastructure and energy-transition projects, but they do not necessarily resolve other procedural barriers affecting investment decisions in EU ports.

One stakeholder noted that the practical impact of these reforms **may come too late** for many ongoing investment projects (EU sector organisation 1). Another stakeholder suggested that while many procedures indeed depend on Member States, the EU could also take further steps to make permitting procedures faster and more predictable (Member State Ministry 1). At the same time, one sector organisation stressed that faster procedures should not come at the expense of environmental protection (EU sector organisation 3).

b. Funding

Funding was also raised as an important concern by stakeholders. Several stakeholders argued that **ports are increasingly expected to deliver public or strategic objectives**, including resilience, security, sustainability and infrastructure modernisation, **which cannot always be financed solely through ordinary commercial revenues** (Port Administration 2, 9, 11, EU Sector Organisation 1, 7, 9, Expert 6, 7). In their view, these responsibilities go beyond the traditional commercial role of ports and therefore require stronger public support at EU level.

Stakeholders therefore called on the Commission to provide more targeted financial support for strategic port investments, particularly where these investments **contribute to EU-wide objectives** such as resilience, security, decarbonisation, digitalisation and supply chain reliability. While the EU Ports Strategy identifies several funding priorities, stakeholders noted that **it currently provides limited concrete information on available budgets, funding volumes or implementation mechanisms** (Port Administration 1, 3). As a result, it remains unclear to what extent the strategy will be supported by sufficient financial resources.

In addition to the availability of funding, stakeholders also highlighted the administrative complexity of accessing EU funding instruments (Member State Ministry 1; EU Sector Organisation 2). They noted that there are many different funding frameworks, eligibility conditions and supporting documents to consider, which makes it difficult for ports and companies even to assess whether a funding

opportunity may be relevant for a specific project. This complexity can discourage potential applicants and reduce the practical effectiveness of EU financial support. While the EU Ports Strategy mentions it will provide support to small and medium-sized ports, the two stakeholders mention this is also needed for larger ports.

c. Energy and electricity grid

Energy prices were identified as an important competitiveness concern. Several stakeholders noted that EU ports and port-based industries face structurally high energy prices, particularly in recent years, which puts pressure on the profitability of industrial activities located in port areas (Port Administration 1, 3 Expert 1, 2). This is especially relevant for energy-intensive sectors. One stakeholder specifically warned that high energy prices may contribute to the leakage of investment from chemical and refining industries to locations outside the EU (Port Administration 1).

Related to this, the **energy grid** is identified as a critical bottleneck that **poses a direct risk to the competitiveness and decarbonisation goals of EU ports**. Stakeholders emphasise that without sufficient grid capacity and faster reinforcement, ports cannot support the industrial and technological transitions required to compete globally (Port Administration 1, 2, 6, 9, 11, 13, EU Sector Organisation 1, 6, Expert 1, 2, 7). The topic of grid capacity is further discussed in the chapter on topic 3, Sustainability and the Energy transition.

d. State aid

Finally, state aid rules were mentioned as a relevant factor for port competitiveness (EU Sector Organisation 1, 2, Member State Ministry 1, Expert 4). Stakeholders noted that **state aid rules can limit the public funding of certain port-related investments, even where these investments may be strategically important** for competitiveness, sustainability or resilience. The EU Ports Strategy already recognises state aid as an area that may require further review. For stakeholders, this review should clarify how state aid rules can continue to safeguard fair competition within the internal market while allowing sufficient flexibility to support strategic port investments.

2.4. Technological leadership as driver of global competitiveness

2.4.1. Technology as a driver of future port competitiveness

Leadership in port technologies may become a source of future competitive advantage of the EU ports system compared to non-EU ports. In this context, technological leadership refers to the ability of EU ports to develop, adopt and scale technologies that improve operations performance, , enable the transition towards low-carbon maritime and industrial activity, and support integration into increasingly digital and automated logistics systems.

Two technological domains are particularly relevant: **energy technologies** and **digital technologies**. Their detailed development and deployment are examined elsewhere in this study, in Chapter 4 regarding sustainability and in Chapter 5 regarding digital technologies.

Leadership in energy technologies refers to the ability of ports to develop the infrastructure needed for the decarbonisation of maritime transport, port-industrial activity, or inland energy systems. Energy technologies are particularly important because ports are increasingly becoming energy hubs (Notteboom et al., 2026).This makes ports relevant not only for maritime decarbonisation, but also for the transformation of industrial clusters and inland energy systems. From a competitiveness perspective, the relevance lies in whether access to alternative fuels, renewable electricity and

associated infrastructure makes EU ports more attractive to shipping services and to industrial activities seeking to decarbonise.

Leadership in digital technologies refers to the integration of information technologies into business processes in ports (Notteboom et al., 2026). This includes technologies such as port community systems, digital twins, artificial intelligence, sensor networks, automated terminal processes, port-call optimisation, cargo-tracking systems, customs and administrative platforms, and systems that improve coordination with hinterland transport. Leadership in digital technologies is strategically important for ports, as it strengthens their role as **efficient, connected and adaptive logistics nodes** within wider supply chains (Heilig & Voß, 2017).

Some technological developments cut across the energy and digital domains. **Green shipping corridors**, for example, require the coordinated deployment of alternative-fuel infrastructure between ports and shipping operators, but may also depend on digital information exchange, operational coordination and common standards (Ismail et al., 2024). More generally, the transition towards low-carbon and increasingly automated maritime transport is likely to require closer interaction between energy infrastructure, digital systems, vessels, ports and hinterland networks (Belmoukari et al., 2023).

2.4.2. Future port technologies and EU competitive positioning

Energy and digital leadership can strengthen EU port competitiveness in several ways. This is further explained in the text below.

First, **it can improve the overall attractiveness and competitiveness of ports** in the sense discussed in the previous section on port costs and efficiency. Digitalisation can improve the competitiveness of ports through efficiency gains, reduced delays, improved coordination between actors and increased predictability for shipping lines, shippers and logistics operators (Belmoukari et al., 2023; Heilig & Voß, 2017). Similarly, energy technologies can make ports more attractive as investment locations, particularly for companies seeking industrial environments with access to renewable energy, alternative fuels, grid infrastructure or low-carbon value chains (Song, 2024).

Second, and perhaps more importantly, leadership in port technologies may **create first-mover advantages vis-à-vis non-EU ports**. The general innovation literature shows that early movers can benefit through learning effects, reputation, user lock-in, access to scarce assets and the ability to shape emerging markets, although such advantages are not automatic and may also involve risks (Lieberman & Montgomery, 1988). Applied to ports, this may allow leading EU ports to build operational experience, attract early users and develop specialised capabilities before competing ports. However, these advantages depend on whether the relevant technologies become mature and commercially viable. It also depends on whether early investments align with future market needs and technical standards.

Such advantages may arise through early participation in **green and digital corridors** (Akhavan, 2025). Such initiatives can provide environments in which ports, shipping companies, energy suppliers and other actors test new technologies, operating models and standards together.

Third, technological competition may increasingly concern **integrated port and maritime ecosystems rather than individual technologies**. The value of an automated container terminal, for example, depends partly on its interaction with shipping services, port-call systems and hinterland transport. Predictive systems become more useful when they can draw on information from multiple actors across the supply chain rather than from a single terminal or port authority.

Fourth, technical leadership is closely linked to **leadership in standard setting**. Participation in standard-setting processes may allow firms to monitor and shape emerging standards and access relevant knowledge (Wakke et al., 2016). Energy and digital port technologies often depend on interoperability. Port-related stakeholders such as management authorities and shipping lines need compatible systems, safety rules, data formats and technical standards. If EU ports and EU policy frameworks contribute to setting these standards at an early stage, this may strengthen Europe's position in future maritime and port technologies.

At the same time**, leadership in port technologies is not automatic**. Energy and digital transitions require, among others, high upfront investment, coordination between public and private actors, regulatory certainty, grid capacity, skills, cybersecurity and governance arrangements. Heilig and Voß (2017) emphasise that digitalisation in ports depends on collaboration across multiple actors, while Notteboom and Haralambides (2023) show that the development of ports as hydrogen hubs depends on wider market, infrastructure and governance conditions.

There is also a risk that technological development proceeds **unevenly across EU ports**. Large ports may have greater financial resources, technical expertise and opportunities to test new technologies, whereas smaller ports may face greater difficulties in financing and implementing advanced energy or digital systems (Brunila et al., 2021).

For the EU ports system, this is particularly important in comparison with nearby non-EU competitors. EU climate and digital policy may create additional obligations and investment needs, but it may also help **EU ports build infrastructure and standards earlier than competing ports**. EU ports need to convert higher costs into long-term advantages in efficiency, investment attraction, technological capability and standard setting.

In the stakeholder reports, leadership in future port technologies is framed not as a guaranteed status, but as a **position currently under threat** or a **strategic objective** that requires urgent intervention. Stakeholders specifically highlight that while Europe aims to be a frontrunner, it is currently at risk of being surpassed by global competitors:

- One stakeholder highlights reinvesting ETS revenues into port infrastructure to maintain EU leadership in alternative fuel suppliers. They argue that if non-EU ports develop this infrastructure faster, the EU's competitive position will erode (EU sector organisation 2).
- Another stakeholder calls for specific actions to strengthen European leadership in innovation and deployment by moving beyond pilot projects to large-scale implementation of clean and digital technologies (EU sector organisation 8). Similarly, Expert 7 calls for the EU to de-risk first-of-a-kind projects, to ensure projects become scalable reality rather than just a series of isolated experiments.
- It is noted by another stakeholder that the EU is losing its lead because countries like China, Japan, and South Korea are already implementing concepts like the "physical internet" at scale with strong government backing, while Europe remains stuck in the research phase (EU sector organisation 9).

Stakeholders are concerned that the EU could lose its technological leadership and are calling for action to maintain it.

2.5. Conclusion

2.5.1. Thematic assessment of the EU Ports Strategy

a. Vulnerability of transhipment hubs

The EU Ports Strategy recognises that European ports face competitiveness risks in a global market and that traffic diversion to non-EU transhipment ports is a specific concern. It also notes that the review of the EU ETS extension to maritime transport and the later review of FuelEU Maritime will examine implementation challenges affecting the competitiveness of European ports.

However, the Strategy remains relatively general on **how such risks should be assessed**. This is important because the stakeholder consultation shows that the robustness of the monitoring framework is itself a key concern. For example, detecting leakage and competitiveness also requires attention **to possible delays or reductions in investment at EU ports**.

The main issue is therefore not whether the EU Ports Strategy recognises the risk, but whether the follow-up process will provide a sufficiently transparent, regionally sensitive and stakeholder-supported methodology for identifying competitiveness effects at an early stage. This is **particularly relevant for Mediterranean transhipment hubs**, and to a lesser extent for other regions.

b. Port cost and efficiency

As discussed in section 2.1.1, Port competitiveness is shaped by a broad set of interrelated factors. To keep the analysis targeted and closely aligned with the EU Ports Strategy, stakeholder interviews focused specifically on port competitiveness-related issues addressed in the Strategy. The following issues emerged particularly strongly from these discussions: **permitting procedures, state aid, funding, energy prices and electricity grid capacity**.

At the same time, the **available evidence does not allow for firm conclusions on the scale to which these Strategy-related issues affect the competitiveness of EU ports.** In particular, the study did not identify sufficient data to determine whether these factors have already led to lower investment in EU ports compared with nearby non-EU ports. The findings should therefore be understood as identifying **credible areas of competitiveness concern, rather than as quantifying actual investment diversion or competitiveness loss**.

Nevertheless, the stakeholders highlighted several competitiveness-related areas addressed in the EU Ports Strategy where related EU policy initiatives may warrant particular attention from the European Parliament:

- Regarding the EU Ports Strategy's objective to accelerate permitting and assessment procedures for strategic energy and environmental port projects, pay particular attention to the Environmental Omnibus package, especially the proposal for a Regulation on speeding up environmental assessments, COM(2025) 984.
- Regarding the Strategy's emphasis on port electrification and improved access to electricity grids, pay particular attention to the European Grids Package, COM(2025) 1005, including the proposal to revise the TEN-E Regulation and the proposal to accelerate permit-granting procedures for grids, storage, renewables and recharging infrastructure.
- Regarding the Strategy's priority on access to finance and investment, ensure that port priorities are reflected in the design of upcoming EU funding schemes under the next Multiannual Financial Framework, and the proposal for the European Competitiveness Fund, COM(2025) 555.

Regarding **access to financing**, the EU Ports Strategy gives attention to small and medium-sized ports, but simplified access to EU financing and clearer funding guidance are also relevant for larger strategic ports.

As the State aid framework for ports is already expected to undergo review, no separate recommendation is proposed on this issue. Nevertheless, it may be appropriate for the European policy makers to monitor whether the review sufficiently reflects the specific nature of port investments that contribute to public-interest objectives, such as decarbonisation, resilience, security, dual-use infrastructure and hinterland connectivity.

c. Technological leadership as source of global competitiveness

The EU Ports Strategy recognises the importance of this issue by placing emphasis on innovation and technological leadership. It states that:

- The Commission will, as described in section 2.3, **strengthen the technological leadership of the Union** in the use of alternative fuels, electrification, design, retrofitting of equipment, energy efficiency and digitalisation, including energy conversion systems, circularity and digital solutions.
- It also refers in section 2.3 to the reinforcement of public-private cooperation under the **2028–2034 Horizon Europe Framework Programme** in priority areas, where it will focus on deployment beyond the pilot phase.
- In addition, the strategy asks in section 2.1 and Annex 3 **Member States to play a leading role in setting global technical standards** in relevant international fora, including the International Organization for Standardization (ISO), while the Commission will support these efforts through a new workstream on Innovative Ports and Terminals under the High-Level Forum on European Standardisation.

Overall, the EU Ports Strategy addresses technological leadership as a relevant source of future competitiveness.

However, the Strategy remains relatively high-level. It does not yet set out a detailed pathway for turning technological leadership into competitive advantage for the EU ports system. In particular, it provides limited detail on **funding, implementation responsibilities, interoperability, support for ports of different sizes, or how successful technologies will be scaled across the port system**. The Strategy therefore addresses the issue adequately as an agenda-setting document, but not yet comprehensively as **an implementation framework**.

2.5.2. Key takeaways

- **Port competitiveness is shaped by a broad range of factors.** The literature distinguishes, among others, nautical conditions, terminal characteristics and services, management strategies, and the wider external environment. **In this chapter, global competitiveness is understood as the competitive position of EU ports relative to non-EU ports.** The analysis focuses on three dimensions that are particularly relevant from an EU policy perspective: regulatory competition and transhipment, the wider investment attractiveness of EU ports, and technological leadership.
- **EU transhipment hubs remain exposed to regulatory competition, especially in the Mediterranean.** The EU Ports Strategy recognises this risk. However, the current evidence does not yet show generalised business leakage or systematic relocation of transhipment activity to

neighbouring non-EU ports. The key issue for follow-up is therefore whether monitoring will be robust enough to detect changes in traffic and investment at an early stage**.**

- **Several policy-relevant barriers may weaken the competitiveness of EU ports.** This study identifies regulatory asymmetry, permitting procedures, energy prices, electricity grid capacity, state aid rules and access to funding as recurring competitiveness concerns. The EU Ports Strategy recognises several of these issues, but remains relatively high-level on how their cumulative effect on port costs, efficiency and investment attractiveness should be assessed or addressed.
- **Technological leadership offers an opportunity to turn policy pressure into competitive advantage.** The EU Ports Strategy remains more convincing as an agenda-setting document than as an implementation framework, since it provides limited detail on funding, interoperability, scaling successful technologies and supporting ports of different sizes.

3. SAFETY AND SECURITY

KEY FINDINGS

- **Cybersecurity has become an integral component of port resilience**. The increasing digitalisation of port operations and the convergence of information and operational technologies have amplified the potential impact of cyber incidents. The EU has established a substantial regulatory basis through the NIS2 Directive, the CER Directive and the EU Maritime Security Strategy. However, implementation remains uneven across ports, reflecting differences in governance arrangements, digital maturity and access to specialised skills and resources, particularly among smaller, peripheral and island ports.
- **The resilience of critical port infrastructure requires a more integrated, cross-sector approach**. Ports increasingly combine transport, energy, digital and logistics functions and are therefore exposed to interconnected disruptions. Existing EU frameworks provide an important basis for resilience and preparedness, but differences in national approaches, risk assessment practices, governance and crisis management capacity can result in varying levels of preparedness across the European port system.
- **Organised crime and other illicit activities increasingly affect the security of the wider logistics chain, not only the port perimeter**. Drug trafficking, customs fraud, insider threats and the exploitation of digital and logistical vulnerabilities require closer cooperation among port authorities, customs, law-enforcement agencies, cybersecurity actors and other supply chain stakeholders. The effectiveness of existing initiatives therefore depends significantly on information sharing, coordinated enforcement and the capacity to address vulnerabilities across the whole logistics chain.
- **The strategic role of ports is expanding beyond commercial transport functions**. Ports are increasingly important for energy security, crisis preparedness and military mobility. The dual-use dimension therefore needs to be considered in infrastructure and corridor planning, while recognising the diversity of European ports and avoiding disproportionate requirements that could restrict normal commercial operations.
- The **EU Ports Strategy** provides a comprehensive framework for strengthening port security and resilience. The main policy challenge is to ensure its coordinated, proportionate and effective implementation across the diverse EU port system, particularly in smaller, peripheral and island ports.

3.1. Context

Strengthening the resilience of European ports requires an integrated approach that brings together three closely interconnected dimensions:

- **Operational safety** aims to prevent accidents and protect people, assets and the environment during port activities.

- **Security** focuses on protecting ports against deliberate threats, including organised crime, terrorism, sabotage, smuggling and interference with critical infrastructure.
- **Cybersecurity** addresses the resilience of the digital and operational technologies that increasingly support cargo handling, vessel traffic management, logistics and energy systems.

As physical and digital infrastructure becomes progressively interconnected, weaknesses in one domain can rapidly propagate across the wider transport and logistics network, reinforcing the need for integrated resilience planning (Progoulakis et al, 2022; Progoulakis et al, 2021; Romero and Fernadez, 2023).

This chapter examines the main safety and security challenges facing European ports, drawing on both available evidence and stakeholder consultations undertaken for this study. The analysis is organised around three interrelated themes: (i) cybersecurity and digital resilience, (ii) the protection of critical port infrastructure and preparedness for security-related disruptions, and (iii) illegal activities, organised crime and border security. Across these themes, particular attention is given to governance arrangements, implementation challenges, investment needs and the policy implications for the future European Port Strategy.

Stakeholder consultations indicate broad agreement that **the EU has established a strong legislative foundation** through initiatives such as the NIS2 Directive, the Critical Entities Resilience Directive (European Commission, 2023e) and the revised EU Maritime Security Strategy (European Parliament and Council of the European Union. (2022); European Parliament & Council of the European Union. (2022b); European Commission & High Representative, 2023). However, stakeholders consistently point to **significant implementation challenges**, including uneven resilience across ports, fragmented governance, limited interoperability, skills shortages and increasing pressures arising from geopolitical developments and the deployment of new energy technologies. The analysis therefore focuses not only on identifying emerging risks but also on assessing where additional EU action could strengthen the resilience, preparedness and long-term competitiveness of the European port system.

Table 4: Overview of safety and security challenges in EU ports

Dimension	Main risks	Key evidence from the analysis	Main implementation challenges	Strategic policy focus
Cybersecurity and digital security	Ransomware and other cyberattacks; supply-chain intrusions, manipulation of cargo information, unauthorised access to logistics platforms, attacks affecting operational technologies and critical infrastructure.	Increasing digitalisation and IT/OT convergence are intensifying interdependencies between digital systems and physical port operations. Reported incidents show that cyber disruptions can affect terminals and broader logistics chains. Stakeholders emphasise cyber preparedness, secure information sharing, interoperability, and specialised skills.	Uneven cyber maturity across ports, shortages of specialised expertise, limited resources, particularly in smaller, peripheral and island ports, fragmented information-sharing and governance.	Consistent implementation of NIS2, cyber resilience by design, secure and interoperable digital ecosystems, information-sharing, exercises and testing, workforce development.

Dimension	Main risks	Key evidence from the analysis	Main implementation challenges	Strategic policy focus
Critical infrastructure and resilience	Physical disruption, sabotage, terrorism, geopolitical threats, disruption of energy and digital infrastructure, cascading failures across interconnected systems.	Ports increasingly operate as transport, energy, industrial and logistics hubs. Disruption to critical assets can affect wider European transport and supply chains. Stakeholders are calling for integrated resilience planning that covers physical, digital, energy and hinterland infrastructure.	Different national approaches to critical infrastructure identification and risk assessment, fragmented responsibilities, uneven levels of preparedness and crisis-management capacity, and limited common approaches to resilience benchmarking.	Harmonised risk assessment and resilience approaches, integrated crisis preparedness, stronger coordination between authorities and operators, resilience by design, and support for ports with limited capacity.
Illegal activities, organised crime and border security	Drug trafficking, customs fraud, corruption and insider threats, exploitation of logistics and digital systems, criminal activity extending into hinterland corridors.	European ports are major entry points for illicit goods. Criminal networks increasingly exploit information, logistics processes and trusted insiders in addition to physical access. Stakeholders stress intelligence sharing and security across the wider logistics chain.	Fragmented responsibilities between customs, police, border authorities, cybersecurity actors and port operators, information-sharing gaps, and the need to balance security with efficient cargo flows.	Integrated intelligence and information-sharing, stronger customs–law enforcement–port cooperation, supply-chain risk monitoring, digital traceability, insider risk management, and proportionate security measures.

Source: Authors.

3.2. Cybersecurity and digital security of EU ports

Cybersecurity has become a strategic prerequisite for the competitiveness, operational continuity and resilience of European ports. The rapid digitalisation of port operations has transformed the management of cargo handling, vessel traffic, customs procedures, logistics coordination and hinterland transport. Technologies such as Port Community Systems (PCS), Terminal Operating Systems (TOS), Internet of Things (IoT) applications and Artificial Intelligence (AI)-supported logistics solutions have improved operational efficiency and enabled greater integration across the maritime supply chain. At the same time, this increasing connectivity has created new vulnerabilities by expanding the attack surface and deepening the interdependencies between digital and physical infrastructure. As a result, **cyber incidents** can no longer be viewed as isolated technical events but increasingly **represent systemic risks capable of disrupting port operations, logistics chains and wider transport networks** (Progoulakis et al., 2023; Afenyo and Caesar, 2023).

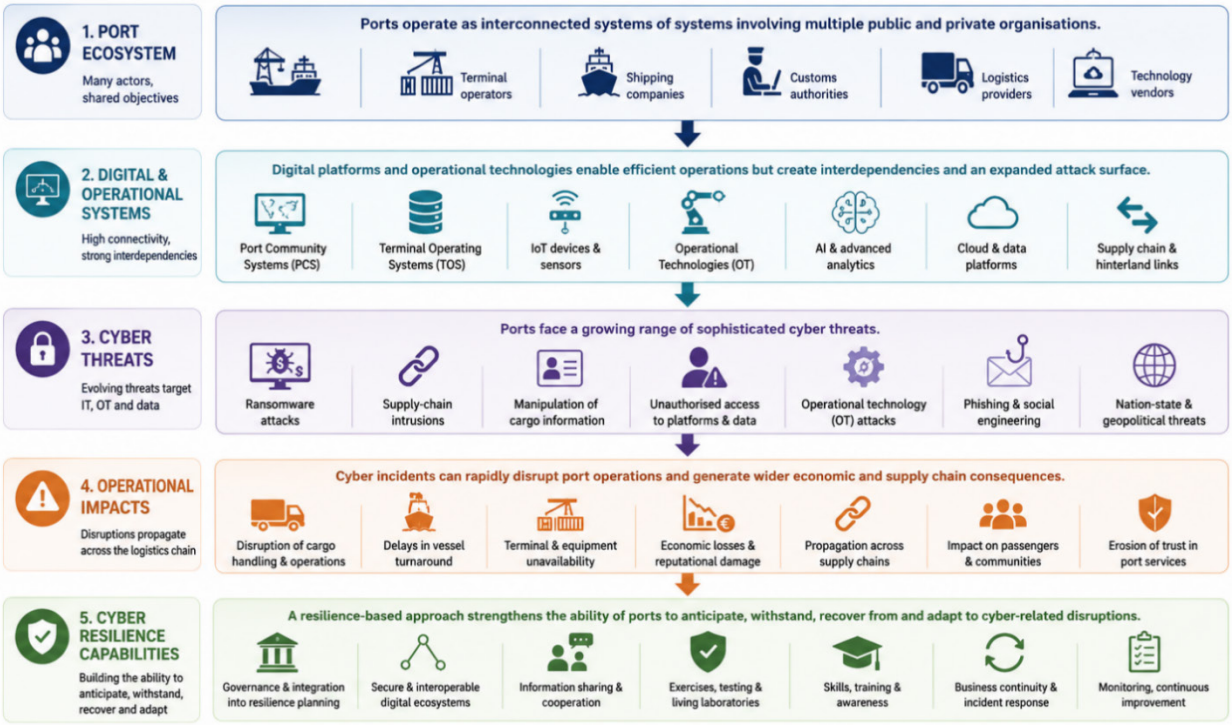
Rather than operating as isolated entities, ports function as interconnected systems of systems in **which multiple public and private organisations** (including port authorities, terminal operators, shipping companies, customs authorities, logistics providers and technology vendors) rely on shared digital and operational infrastructures. Consequently, cyber risks frequently arise across organisational boundaries, and their operational consequences can rapidly propagate throughout the wider logistics

chain (Progoulakis et al., 2023; Afenyo and Caesar, 2023). This reinforces the need for coordinated governance, secure information-sharing and resilience-based approaches that extend beyond individual organisations.

The increasing integration of operational technologies, digital platforms and physical infrastructure also means that ports can be understood as cyber-physical systems, in which disruptions to digital systems may affect physical operations and the continuity of essential services (Progoulakis et al., 2023).

On this basis, this study considers cybersecurity not only as the protection of information systems but also as a strategic resilience capability supporting the ability of ports to anticipate, withstand, recover from and adapt to cyber-related disruptions while maintaining essential logistics and transport services. The relationship between port digitalisation, cyber-physical interdependencies, cyber threats, operational impacts and resilience capabilities is illustrated in Figure 7.

Figure 7: Cyber-physical interdependencies and resilience of EU ports



Source: Authors' own elaboration based on the literature review and stakeholder consultations.

Recent evidence indicates that **the nature of cyber threats affecting ports is becoming more complex**. In addition to ransomware attacks, ports are increasingly exposed to supply-chain intrusions, manipulation of cargo information, unauthorised access to logistics platforms and attacks targeting operational technologies that support critical infrastructure (Senarak, 2024).

Cyberattacks affecting ports and maritime logistics have shown that disruptions can extend beyond individual terminals and generate significant operational and economic consequences across wider supply chains. Reported incidents include the compromise of the Port of Antwerp's container management systems, disruptions to customs-related systems at the Port of Rotterdam, the 2017 Peyta attack on A.P. Moller–Maersk, which affected 17 terminals worldwide, and subsequent attacks on the Ports of Barcelona and San Diego, as well as on a COSCO-affiliated terminal at the Port of Long Beach (De la Peña Zarzuelo, 2021).

3.2.1. Stakeholder views on cybersecurity and digital resilience

Stakeholder consultations consistently confirmed this strategic shift. Representatives from EU sector organisations and experts (EU Sector Organisation 4, EU Sector Organisation 6, EU Sector Organisation 8, Expert 6, Expert 7 and Expert 8) emphasised that **cybersecurity should be embedded within broader resilience and business continuity strategies** rather than managed exclusively through technical protection measures. Interviewees highlighted five priorities for strengthening cyber resilience across the European port system:

- integrating cybersecurity into overall port governance and resilience planning;
- strengthening secure and interoperable digital ecosystems across the maritime supply chain;
- improving information sharing and cooperation between public authorities and private operators;
- expanding cyber preparedness through regular exercises, testing environments and living laboratories; and
- investing in specialised workforce skills and organisational capabilities.

Several stakeholders highlighted the growing importance of **addressing cybersecurity across the full chain of port-related digital and operational systems**. In particular, the increasing interconnection between port authorities, terminal operators, logistics providers, customs authorities and technology suppliers means that weaknesses in one organisation may create vulnerabilities for others. Secure information sharing, effective management of third-party risks and clearer responsibilities across organisational interfaces were therefore identified as important elements of robust cyber resilience. Several stakeholders also identified emerging risks associated with unmanned aerial systems and other technologies that interact with port digital and operational infrastructure. They also stressed that cybersecurity strategies need to evolve in response to geopolitical developments and the increasing convergence of cyber, physical and multi-domain threats.

A recurring issue was the uneven capacity of European ports to develop and maintain cyber resilience. Smaller, peripheral and island ports may face particular constraints in accessing specialised expertise, financing advanced security systems, and maintaining continuous monitoring and testing capabilities. Stakeholders therefore considered capacity building, workforce development and access to technical expertise important complements to regulatory requirements.

3.2.2. Assessment of the current EU framework

The EU has significantly strengthened its cybersecurity and resilience framework through a combination of horizonal and sector-specific instruments, providing a more **robust regulatory foundation** for improving cyber resilience across critical transport infrastructure (European Parliament and Council of the European Union, 2022a; European Parliament and Council of the European Union, 2022b; European Commission, 2023e):

- **The NIS2 Directive** establishes requirements for cybersecurity risk management, governance, incident reporting and supply-chain security for entities within its scope (European Parliament and Council of the European Union, 2022a).
- The **CER Directive** complements the cybersecurity framework by strengthening requirements for preparedness, continuity and resilience against a broader range of risks (European Parliament and Council of the European Union, 2022b).
- The **revised EU Maritime Security Strategy** further provides a sectoral framework for addressing maritime security, including cyber and hybrid threats (European Commission and High Representative, 2023).

Taken together, these instruments substantially strengthen the EU framework by addressing cybersecurity, resilience, continuity and maritime security in a more integrated way.

However, the largely horizontal nature of the existing instruments means that their practical application to the specific **operational, governance and IT/OT characteristics of ports** can remain uneven. Ports differ considerably in size, ownership and governance models, operational complexity, digital maturity and access to specialised expertise. These differences can result in significant variations in cybersecurity capability and preparedness across the European port system.

Box 3: Degree of operational maturity across the European port system

Both the literature and stakeholder consultations indicate that **operational maturity remains uneven across the European port system**. Differences in cybersecurity maturity, shortages of specialised expertise and limited information sharing continue to constrain effective implementation (Pala and Zhuang, 2019; Afenyo and Caesar, 2023; Ćelić et al., 2025).

Small and medium-sized ports face particular challenges because of limited financial resources, organisational capacity and access to specialised technical expertise (Boullauazan et al., 2023; Oruc et al., 2024; Bharot et al., 2025).

Stakeholders also highlighted that ports located in **peripheral and island regions** often require additional technical and financial support to achieve levels of cyber resilience comparable to those of larger ports.

Source: Authors' own elaboration.

Across the consultations, workforce development emerged as a recurring enabling factor. Interviewees argued that strengthening cyber resilience requires not only investment in technology but also **continuous training, multidisciplinary expertise and stronger cooperation across the maritime logistics chain**. Stakeholders also emphasised that interoperable and trusted digital ecosystems should be recognised as a strategic resilience capability, supported by common standards, secure data-sharing arrangements and coordinated governance at European level.

The current EU framework therefore provides a strong basis for strengthening cybersecurity in European ports, but its effectiveness depends on consistent implementation, interoperability, organisational capacity and cooperation across ports and the wider logistics ecosystem. The diversity of port governance models and levels of digital maturity remains an important consideration for the practical implementation of EU cybersecurity requirements.

Based on the evidence presented above, including the assessment of the EU cybersecurity and resilience framework, the available literature, and the findings from stakeholder consultations, the principal challenge for European port policy increasingly concerns the **consistent implementation of existing cybersecurity requirements across a highly diverse port system**, rather than the absence of an EU-level regulatory basis. Future policy should therefore focus on reducing disparities in cyber maturity, strengthening cross-border cooperation and information sharing, supporting smaller ports, and promoting resilience by design in the deployment of digital infrastructure. Achieving these objectives will be essential to ensuring that increasing digitalisation enhances both the competitiveness and the resilience of European ports.

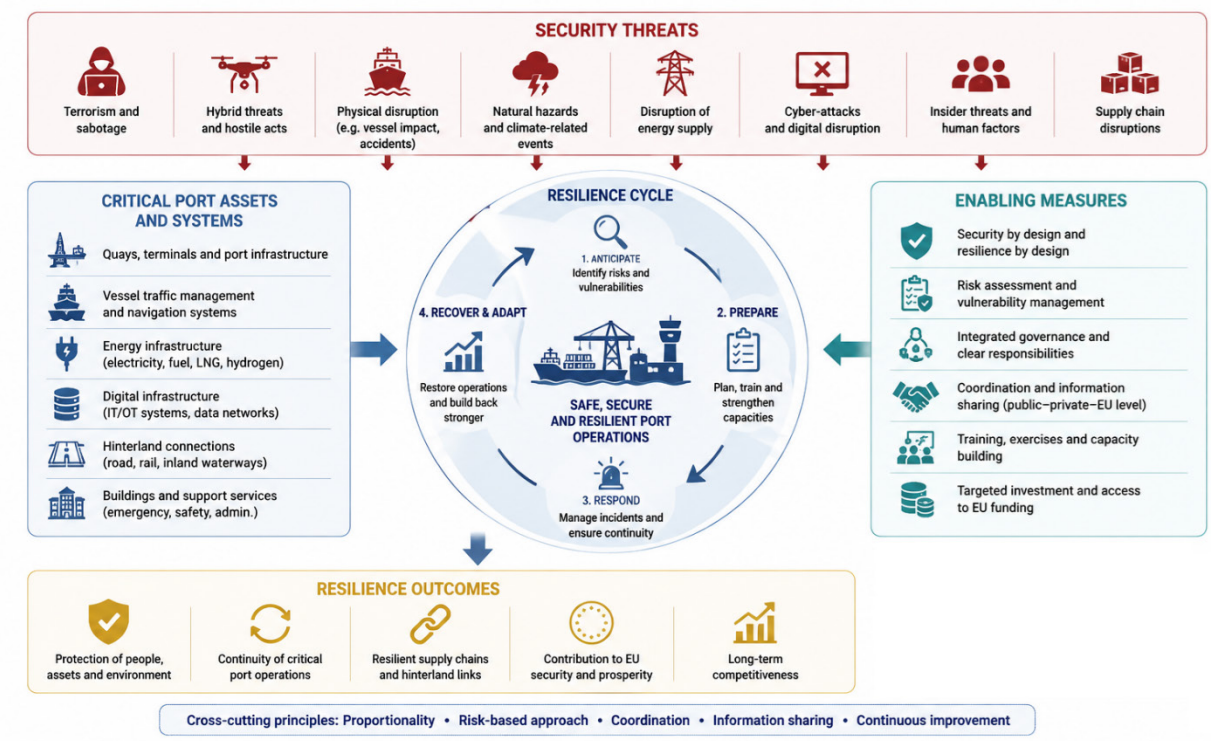
3.3. Protection of critical port infrastructure and resilience against security threats

The protection of critical port infrastructure has become a strategic priority for the European Union as ports assume an increasingly important role in transport, energy security and industrial value chains. Beyond their traditional logistics function, ports are evolving into integrated transport, industrial and energy hubs that support the functioning of the Single Market and the resilience of European supply chains (EC, 2026a). Consequently, disruptions affecting critical port infrastructure (whether resulting from sabotage, terrorism, geopolitical tensions, multiple threats or intentional interference with strategic logistics flows) can have consequences that extend well beyond individual ports and rapidly affect wider European transport networks (European Parliament & Council of the European Union, 2022b).

The growing interdependence between transport, energy, digital and logistics systems further reinforce the systemic nature of these risks. Depending on national circumstances, critical infrastructure may include energy terminals, digital control systems, navigation infrastructure, hinterland connections, logistics hubs and other assets essential to maintaining the continuity of transport and energy services (Miętkiewicz, 2021; O'Kelly, 2025). Protecting such assets therefore requires an integrated approach that addresses physical infrastructure, digital systems, operational dependencies and the wider logistics network.

Despite this growing strategic importance, **the identification and protection of critical port infrastructure remain uneven across the European Union**. Member States apply different methodologies and criteria to determine which assets should be considered critical, resulting in differing priorities for risk assessment, investment and protective measures (Romero-Faz and Camarero-Orive, 2017). This diversity reflects varied national governance arrangements and security responsibilities, but it can also make it more difficult to establish comparable approaches to resilience and preparedness across the European port system. Figure 8 summarises the main elements underpinning the protection of critical port infrastructure and a resilience-based approach to security threats.

Figure 8: Protection of critical port infrastructure and resilience against security threats



Source: Authors' own elaboration based on the literature review, EU policy and regulatory framework, and stakeholder consultations.

Ports play an important role as points of entry for international trade and as environments for customs control and law enforcement (Pourakbar and Zuidwijk, 2018). This makes them particularly exposed to organised crime and illicit activities. **Large-scale drug trafficking remains a significant threat, while criminal networks increasingly exploit cargo flows, logistics processes, digital information, and vulnerabilities involving personnel and third-party operators**. The security challenge therefore extends beyond the physical port perimeter to inland logistics centres, freight operators, and hinterland transport corridors (EMCDDA and Europol, 2024; Sardet et al., 2021).

The evolution of these threats reinforces the need to treat physical security, critical infrastructure resilience, organised crime and border security as interconnected dimensions of port security. Effective resilience depends not only on protecting individual assets but also on the capacity of authorities and private operators to anticipate disruptions, maintain essential services, coordinate responses and recover from incidents across the wider multimodal logistics system.

3.3.1. Stakeholder views on infrastructure resilience and security threats

Stakeholder consultations confirmed that **resilience** is increasingly understood as a **broader governance challenge** rather than simply a matter of protecting physical infrastructure. Representatives from port authorities, EU sector organisations and independent experts (Port Administration 2, Port Administration 11, EU Sector Organisation 2, EU Sector Organisation 8, Expert 1, Expert 6 and Expert 8) consistently argued that resilient ports require integrated planning across physical infrastructure, digital systems, energy networks and logistics operations. Interviewees identified several priorities for strengthening resilience:

- improving **continuity planning** and **crisis preparedness** through regular multi-agency exercises;
- establishing **clearer governance arrangements** between public authorities, port authorities and private operators;
- strengthening **risk assessment methodologies** and **preparedness** for complex, cross-sector disruptions;
- **reducing strategic dependencies** associated with the ownership or control of critical infrastructure and digital assets; and
- extending **resilience planning beyond the port perimeter** to include hinterland transport corridors and border procedures.

Stakeholders also emphasised that the changing role of ports requires a **broader understanding of resilience**. As ports become major energy hubs supporting the deployment of hydrogen, ammonia, methanol, battery technologies and shore-side electricity infrastructure, new operational and safety challenges are emerging alongside new opportunities for decarbonisation. Interviewees therefore stressed the importance of harmonised operational safety standards, common emergency procedures and specialised workforce training to support the safe deployment of alternative fuels across European ports.

Stakeholder consultations further confirmed that **organised crime is becoming increasingly adaptive and technologically sophisticated**. Representatives from EU sector organisations, port authorities and independent experts highlighted that criminal organisations increasingly exploit operational information, digital systems and vulnerabilities across the wider logistics chain, rather than relying solely on the physical infiltration of port facilities. Interviewees identified several priorities for strengthening security governance:

- enhancing intelligence sharing between customs authorities, law-enforcement agencies, port authorities and private operators;
- improving cooperation between cybersecurity specialists and traditional security authorities;
- strengthening monitoring and risk analysis across the entire logistics chain, including inland terminals and freight corridors;
- expanding the use of digital technologies to improve traceability and identify suspicious activities; and
- ensuring that security measures remain proportionate and do not unnecessarily reduce the efficiency and competitiveness of European logistics chains.

Stakeholders also stressed that organised crime increasingly extends beyond the physical boundaries of ports. Inland logistics centres, freight operators and hinterland transport corridors can form part of the same vulnerabilities exploited by criminal networks. This underlines the need for coordinated security strategies covering the wider multimodal transport system, rather than focusing exclusively on port facilities.

A recurring concern was the fragmentation of responsibilities among port authorities, customs, police, border management authorities, cybersecurity actors, terminal operators and infrastructure managers. Stakeholders considered stronger cooperation and information exchange essential for overcoming these institutional boundaries. They also emphasised the importance of maintaining an appropriate balance between security and operational efficiency, so that enhanced controls and security procedures do not create disproportionate administrative burdens or delays for legitimate trade.

3.3.2. EU policy and regulatory framework for infrastructure resilience and security

The EU policy has progressively shifted from protecting individual infrastructure assets towards **strengthening the resilience of entire port systems**. Increasingly, resilience is understood as the capacity to anticipate disruptions, maintain essential services, recover rapidly and adapt to future risks rather than simply prevent incidents (Vanlaer et al., 2022; Tsoulfas, 2025). This broader perspective reflects the growing complexity of the risks facing European ports, including multiple threats, geopolitical instability, strategic supply-chain disruption and military contingencies (Bathke et al., 2022; Li et al., 2026).

The **Critical Entities Resilience Directive** (European Commission, 2023e) provides an important basis for strengthening the preparedness, continuity and resilience of entities providing essential services. This framework is complemented by other EU instruments and initiatives addressing different dimensions of port infrastructure and resilience:

- The **EU Maritime Security Strategy** (2023) strengthens the framework for addressing maritime security risks and improving preparedness for threats affecting the maritime domain.
- The **Union Civil Protection Mechanism** (2013) and related preparedness arrangements support coordinated prevention, preparedness and response to major disruptions and emergencies.
- The **EU Ports Strategy** (2026) reinforces this strategic direction by recognising ports as critical nodes within European transport, energy and logistics systems. It calls for strengthening vulnerable infrastructure, superstructure and equipment, improving redundancy and increasing the capacity of logistics chains to absorb disruptions. It also recognises the importance of port preparedness in relation to security of supply and military mobility.

Nevertheless, implementation challenges remain substantial. Stakeholders consistently identified **fragmented governance** and **uneven implementation across Member States** as **major obstacles** to effective resilience planning. Responsibilities for safety, security and crisis management are frequently distributed among multiple public authorities, port authorities, terminal operators and infrastructure managers, particularly within landlord port models. This institutional fragmentation can weaken preparedness measures and complicate coordinated responses during crises.

The consultations also highlighted the **lack of common European approaches to risk assessment**, **crisis scenarios** and **resilience benchmarking**. Existing studies similarly identify fragmented institutional responsibilities, inconsistent methodologies and limited cross-border coordination as persistent barriers to strengthening resilience across the European port system (Kapalidis et al., 2022; Salmon et al., 2011; Hochrainer-Stigler and Lorant, 2018). Interviewees therefore stressed that greater consistency in governance arrangements, preparedness planning and communication protocols would improve both national resilience and cross-border crisis management.

The EU has also strengthened its response to organised crime through enhanced customs cooperation, intelligence-sharing mechanisms and initiatives targeting drug trafficking, corruption and other forms of illicit activity. The **European Ports Alliance** (EC, 2024c), **EU customs reform** (EC, 2023d) and Europol activities contribute to a broader approach based on closer cooperation between customs authorities, law enforcement agencies and the port community. However, the effectiveness of these measures still depends substantially on implementation and operational coordination. Responsibilities for customs control, policing, cybersecurity, border management and port operations remain divided among authorities with different mandates and procedures. This fragmentation can slow information exchange, complicate operational coordination and create vulnerabilities that criminal organisations can exploit (Dinchel and Easton, 2020; Gruszczak, 2016).

The nature of organised crime is also evolving. Criminal networks increasingly exploit access to operational information, logistics processes and trusted insiders. Corruption prevention, personnel vetting and insider risk management are therefore becoming increasingly important components of modern port security. At the same time, digital traceability tools, behavioural analytics and secure information-sharing platforms can support the identification of high-risk cargo movements and intelligence-led enforcement (Adams et al., 2021; Kayisoglu et al., 2025).

Overall, the EU has established a substantial policy and regulatory basis for protecting critical port infrastructure, strengthening resilience and addressing organised crime. The main challenge identified by the evidence is therefore not the absence of an EU framework, but its consistent and coordinated implementation across a highly diverse European port system.

3.4. Illegal activities, organised crime, and border security

European ports play a dual strategic role within the European Union. They are essential gateways for international trade and supply chains, while simultaneously serving as critical border control and law enforcement environments (European Commission, 2023e; EC. 2026l). This dual function makes ports particularly vulnerable to organised crime, which increasingly exploits both the high volume of legitimate trade and the growing digitalisation of logistics operations. As ports become more interconnected, criminal organisations are adopting increasingly sophisticated methods that combine physical infiltration of logistics chains with the manipulation of digital systems and operational processes (European Commission & High Representative, 2023; EC, 2026l).

From a safety and security perspective, dual-use capability depends on more than the physical characteristics of individual port assets. It also requires operational flexibility, secure access, appropriate procedures and effective coordination between civilian and military actors. In this context, two interconnected security threats are particularly relevant:

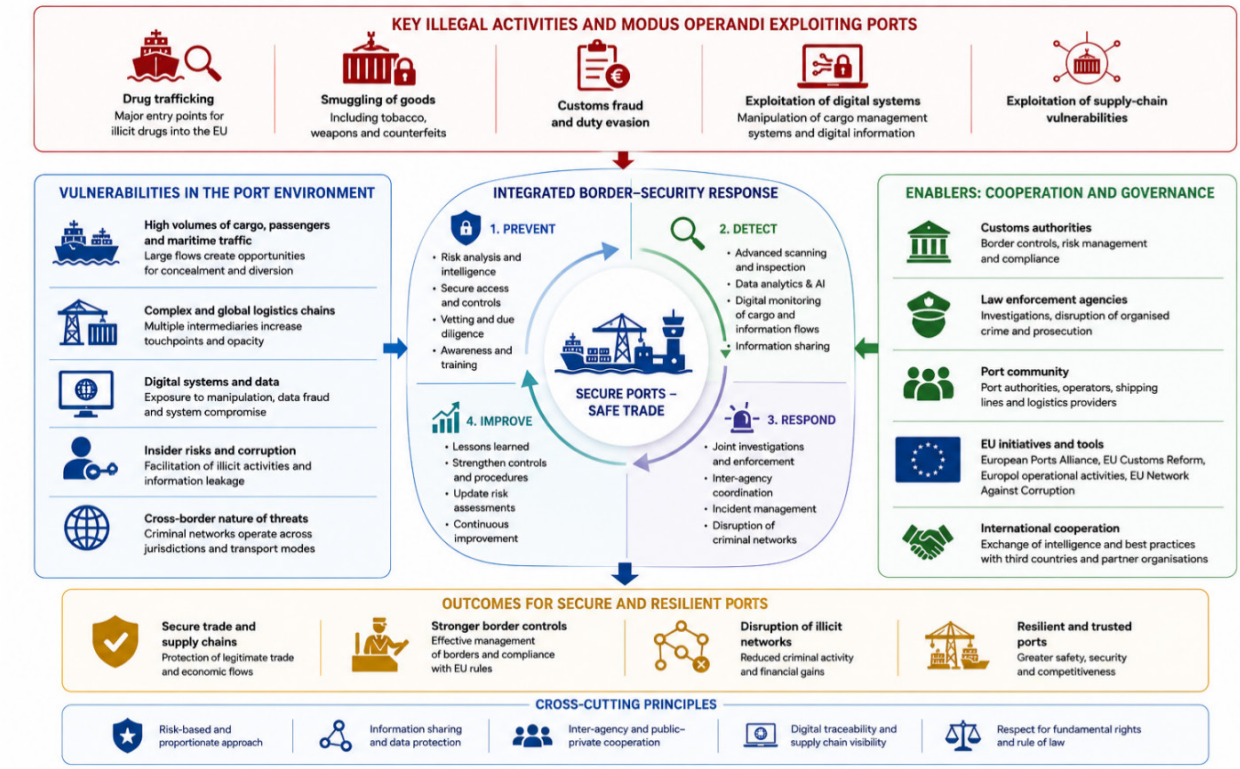
- **Large-scale drug trafficking** remains the most visible threat, with Europol and the European Union Drugs Agency (EUDA, formerly EMCDDA) identifying ports such as Antwerp, Rotterdam, Hamburg and Algeciras as key entry points for illicit goods into the European market (EMCDDA and Europol, 2024).
- **Criminal networks** are **increasingly exploiting digital information, cargo management systems and supply chain vulnerabilities** to facilitate smuggling, customs fraud and other illicit activities (Sardet et al., 2021).

These developments demonstrate that effective port security can no longer focus solely on physical access control but must also address the protection of information flows, logistics processes and interconnected digital infrastructure.

The European Union has responded to these challenges through a number of initiatives, including the European Ports Alliance, the ongoing EU Customs Reform, Europol operational activities and the EU Network Against Corruption. Together, these initiatives reflect a broader shift towards integrated security governance based on closer cooperation between customs authorities, law enforcement agencies and the port community. They also create synergies between military mobility, resilient commercial logistics and the wider objectives of the TEN-T network.

Taken together, these developments point to the need for an integrated approach that combines prevention, detection, coordinated enforcement and continuous improvement across the port and wider logistics environment, as illustrated in Figure 9.

Figure 9: Illegal activities, organised crime, and border security in EU ports



Source: Authors' own elaboration based on the literature review, EU policy and regulatory framework, and stakeholder consultations.

3.4.1. Dual-use requirements of port-hinterland corridors

The ability of ports and their connecting hinterland corridors to support both commercial and strategic movements depends on the compatibility of infrastructure, operational capacity and administrative procedures (EC, 2025i). Relevant infrastructure requirements may include adequate load-bearing capacity, suitable loading gauge and rail compatibility, appropriate handling facilities, secure staging areas and sufficient capacity to accommodate abnormal or oversized movements where strategically necessary (EC. 2026l). These requirements may differ from those associated with normal commercial freight, even where the same infrastructure is used.

Dual-use readiness also depends on the continuity of the full port-to-destination route. Weak last-mile connections, insufficient rail or road capacity, technical incompatibilities, constrained terminals and bottlenecks at border crossings can limit the effective use of an otherwise strategically suitable port (Karam et al., 2023; Abu-Aisha et al., 2024). Consequently, **dual-use requirements should be assessed together with wider port–hinterland connectivity and TEN-T planning**, rather than treated as an isolated port infrastructure issue (EC. 2026l). A more detailed assessment of infrastructure requirements, corridor performance and funding instruments is provided in section 6.

Administrative and procedural readiness is equally relevant. Cross-border permissions, customs procedures, dangerous-goods requirements, abnormal-load authorisations and arrangements for prioritising strategic movements can influence the speed and predictability of military mobility (Karam et al., 2023; EC. 2026f). These procedures therefore need to be considered alongside physical infrastructure when assessing the resilience of strategically relevant corridors.

3.4.2. Governance, corridor coordination and proportionality

The effective use of dual-use infrastructure depends on **coordination among actors with different responsibilities**, including port authorities, infrastructure managers, transport authorities, defence authorities, customs and border authorities and logistics operators (Dinchel and Easton, 2020; Gruszczak, 2016). Because strategic movements may cross several jurisdictions and transport modes, coordination needs to extend beyond the individual port to the wider corridor. A corridor-based governance approach can help ensure that infrastructure investments, operational procedures and contingency arrangements are considered together. Coordination should cover, where relevant, infrastructure planning, capacity allocation, emergency access, traffic management, cross-border procedures and arrangements for prioritising strategic movements during crises. These arrangements should be established in advance and tested through appropriate preparedness and contingency exercises.

Proportionality is also essential. Applying identical military mobility requirements to all European ports could lead to inefficient investment and impose unnecessary constraints on commercial operations (Sollfrank and Boeke, 2024). EU-level action should therefore support common principles for identifying strategically relevant infrastructure and assessing dual-use requirements, while allowing implementation to reflect national and regional circumstances and the specific role of individual ports (EC, 2025i). The objective should not be to create a separate dual-use regulatory regime for all ports, but to integrate military mobility considerations into existing TEN-T, resilience and investment planning frameworks. This would allow infrastructure investments to support several objectives simultaneously (including commercial connectivity, supply chain resilience, crisis preparedness and strategic mobility) while preserving the primary commercial functions of European ports.

3.5. Conclusions

3.5.1. Thematic assessment of the EU Ports Strategy

The EU Ports Strategy represents a significant reinforcement of the European policy framework for the safety, security and resilience of European ports. It recognises that ports are strategic infrastructure whose role extends beyond the provision of transport services to encompass the **resilience of supply chains, energy security, digital connectivity, crisis preparedness and, increasingly, military mobility**. In this respect, the Strategy is broadly aligned with the main challenges identified in this chapter, including cyber and hybrid threats, vulnerabilities affecting critical infrastructure, organised crime and illicit activities, and the need to strengthen the resilience of strategically important port and hinterland infrastructure.

The Strategy also complements and reinforces a broader body of existing EU legislation and initiatives. In particular, the **NIS2 Directive** and the **Critical Entities Resilience Directive** provide important **foundations** for **cybersecurity** and **critical infrastructure resilience**, while the **EU Maritime Security Strategy**, customs and law-enforcement cooperation, and initiatives addressing organised crime contribute to a wider security framework. The EU Ports Strategy adds value by bringing these dimensions together within a more explicitly port-focused strategic framework and by recognising the interconnected nature of physical, digital, logistical and geopolitical risks affecting European ports.

The analysis nevertheless indicates that **the principal challenge is implementation** rather than the absence of an EU policy framework. The effectiveness of existing and newly proposed measures will depend on their consistent and proportionate application across a highly diverse European port system. Differences in national governance arrangements, port size and ownership, digital maturity, access to

specialised expertise and institutional capacity can result in significant variations in preparedness and resilience. This is particularly relevant for smaller, peripheral and island ports, which may face greater difficulties in maintaining specialised cybersecurity, security and resilience capabilities.

The EU Ports Strategy can therefore be strengthened through a clearer focus on operational implementation and coordination. Priority should be given to **improving the interoperability of risk assessment and preparedness approaches**, strengthening **information-sharing** between relevant public and private actors, promoting regular multi-agency exercises and supporting systematic learning from incidents. Such measures would help translate the strategic objectives of the EU Ports Strategy into practical capabilities while allowing implementation to remain proportionate to the characteristics and strategic role of individual ports.

The dual-use dimension further illustrates the importance of an **integrated and proportionate approach**. The Strategy's recognition of the strategic role of ports and transport corridors provides an appropriate basis for considering military mobility alongside commercial operations, resilience and TEN-T development. However, dual-use requirements should be assessed at corridor level and incorporated into existing infrastructure and investment-planning frameworks rather than applied uniformly to all ports. This would allow strategically relevant infrastructure to support military mobility and crisis preparedness while preserving the efficiency and competitiveness of commercial port operations.

3.5.2. Key takeaways

- The **EU Ports Strategy** significantly strengthens the strategic framework for port safety, security and resilience. It addresses increasingly interconnected risks arising from cybersecurity threats, organised crime, critical infrastructure vulnerabilities, geopolitical developments and the expanding strategic role of ports.
- Existing EU legislation and initiatives provide a substantial foundation, but differences in national implementation, governance arrangements, port characteristics, digital maturity and access to specialised expertise can result in **uneven resilience across European ports**.
- **Cybersecurity and critical infrastructure resilience require a stronger operationalisation of existing frameworks**. Common or interoperable risk-assessment approaches, effective information-sharing, regular preparedness exercises, measurable resilience objectives and appropriate support for smaller and peripheral ports can strengthen the practical implementation of existing requirements.
- **Security** against **organised crime** increasingly requires a **whole-logistics-chain perspective**. Cooperation among port authorities, customs, law-enforcement authorities, cybersecurity actors and inland logistics operators is essential to address vulnerabilities extending beyond the physical port perimeter while maintaining the efficiency of legitimate trade
- **Dual-use infrastructure should be addressed proportionately and at corridor level**. Military mobility requirements should be integrated into existing TEN-T, resilience and investment-planning frameworks, taking account of the strategic role and characteristics of individual ports and avoiding unnecessary constraints on commercial operations.
- **Effective implementation requires stronger coordination and learning across the European port system**. Improved cooperation between public and private actors, regular multi-agency preparedness exercises, structured information exchange and systematic learning from incidents can help translate the strategic objectives of the EU Ports Strategy into operational resilience.

4. ENERGY TRANSITION AND DECARBONISATION

KEY FINDINGS

- **Ports are important to the energy transition** because they bring together maritime transport, port operations, energy infrastructure and industrial activity. This concentration creates opportunities to reduce emissions within port areas and support decarbonisation across wider maritime, logistics and industrial value chains.
- The **energy transition has different implications for different ports and shipping segments**, so infrastructure needs associated with the energy transition cannot be addressed through a uniform approach. Relevant pathways depend on factors such as vessel characteristics, port functions, energy availability and local infrastructure conditions.
- **Ports primarily hold an enabling role in alternative fuel deployment through infrastructure, land use, coordination and safety arrangements**. Fuel demand, supply and investment remain largely market driven.
- **Uncertainty over the future fuel mix and location of demand** can delay investment in fuel-specific port infrastructure.
- Port electrification technology is mature, but growing electricity demand from OPS, terminal equipment, charging infrastructure and industrial activity can place increasing pressure on local grids.
- **OPS pricing transparency warrants attention**.
- Energy efficiency can reduce the pressure on energy systems related port operations and industrial clusters, but investment and organisational barriers can limit uptake.
- The **EU Ports Strategy** addresses the main issues identified in this chapter. The principal challenge is translating its objectives into implementation across different port contexts.

This chapter assesses the role of the EU ports system in supporting the EU energy transition and decarbonisation. For the purposes of this report, these issues are understood as reducing the greenhouse gas (GHG) intensity of energy used in ports and maritime transport, and the energy intensity of port operations and port-based industrial activity.

This chapter focuses on three components that are particularly relevant for EU policy: i) **alternative fuels and port readiness**; ii) **port electrification**; and iii) **energy efficiency in port operations and industrial clusters**. These components are largely based on a meta-study of port decarbonisation (Fadiga et al., 2024). For each component, the chapter first explains its relevance for EU ports and then assesses the main developments and challenges based on the literature, stakeholder consultation and relevant EU policy frameworks.

4.1. Context

4.1.1. Conceptualising sustainability and energy transition in the context of ports

Ports are relevant to the energy transition because they bring together energy-intensive port operations, maritime transport, energy infrastructure, and industrial activities. Many EU ports already function as energy hubs, although their current role is largely linked to fossil fuel supply chains. Additionally, ports are closely connected to energy intensive industries. These factors create opportunities to reduce emissions at source within EU port areas. In addition, activities at EU ports can support decarbonisation across wider maritime, logistics and industrial value chains, such as through supporting the import and export of fuels and feedstocks for fuel production.

Moreover, Table 5 elaborates on the various dimensions of sustainability and the energy transition in ports. These dimensions provide the analytical framework for considering how the energy transition affects ports.

Table 5: Dimensions of sustainability and the energy transition in ports

Dimension	Description	Examples
Port operations	Reducing energy use and greenhouse gas emissions from activities and infrastructure within the port area.	Energy-efficient terminal equipment; electrification of cargo-handling equipment; improved building performance; energy management; operational improvements; reduced energy losses.
Maritime transport	Enabling the decarbonisation of vessels calling at ports by providing the necessary energy infrastructure and operational conditions.	Alternative-fuel bunkering; fuel storage and handling; charging infrastructure; onshore power supply (OPS); support for safe fuel and electricity operations.
Port-based industry	Supporting the decarbonisation of industrial activities located in or connected to port areas.	Industrial electrification; use of renewable and low-carbon fuels and feedstocks; energy efficiency; shared energy infrastructure; integration between industrial and port energy demand.
Energy hub functions	Supporting the transition of ports from predominantly fossil-energy gateways towards more diversified nodes in renewable and low-carbon energy systems.	Import, export, production, storage and distribution of alternative fuels and energy carriers; renewable-energy integration; connections with electricity grids and wider energy networks.

Source: Authors' own elaboration, based on Fadiga et al. (2024), Notteboom and Haralambides (2023) and Song (2024).

4.1.2. Port and shipping diversity in the energy transition

The implications of the energy transition differ across EU ports because ports serve different maritime segments and combine different transport, industrial and energy functions. As such, the dimensions identified in Table 6 are not equally relevant for every port.

For **port operations**, relevant measures can include electrification of cargo-handling equipment and improved energy management. These measures may be particularly relevant for ports with limited

industrial activity, where decarbonisation efforts are more likely to focus on port operations and services to vessels. For **maritime transport**, vessel size, route length, operating patterns and cargo type influence the suitability of electrification, alternative fuels and energy-efficiency measures. For example, shorter and more predictable services may be suited to battery-electric solutions, while deep-sea shipping is more likely to rely on fuel-based pathways.

For ports with substantial **port-based industry**, industrial electrification and energy sharing are particularly relevant. **Energy-hub functions** can include the import, storage and distribution of renewable and low-carbon fuels. Ports already handling substantial energy flows may be better positioned to develop such functions, depending also on local energy availability and infrastructure conditions.

These **differences affect the suitability of different decarbonisation pathways** and can result in different infrastructure requirements across ports (Kirkels et al., 2026; Prussi et al., 2021). Stakeholders likewise stressed that energy transition needs differ by port size, function and geography, making a uniform approach inadvisable (EU Sector organisation 7; Expert 2; Port administration 1, 3 & 6).

4.1.3. Focus areas for EU port policy

This study focuses on three areas that are particularly relevant for EU port policy: i) **alternative fuels and port readiness**; ii) **port electrification**; and iii) and **energy efficiency in port operations and industrial clusters**. These areas have been identified as prominent in the literature and stakeholder consultations. They also hold relevance to EU policy action and are reflected in the EU Ports Strategy (Section 4.5.1).

These focus areas are not separate dimensions of the analytical framework, but cross-cutting areas that affect several of the dimensions identified in Table 6. Alternative fuels and port readiness are relevant to maritime transport and energy-hub functions, while also linked to port-based industry. Port electrification concerns maritime transport, port operations and industrial activities. Energy efficiency is particularly relevant to port operations and port-based industry. Together, these capture key elements of the clean energy, energy system and operational measures identified in the literature.

Climate resilience is also relevant to the sustainability of EU ports and is briefly addressed in Box 4. However, a detailed assessment of climate-related resilience risks falls outside the specifications of this study and did not emerge from the stakeholder consultation as a priority for further analysis. Climate resilience is therefore acknowledged as a relevant consideration, but is not examined in depth in the remainder of this study. Key topics to be investigated could include, among others: i) Are some of Europe's ports at risk of becoming less functional, or even unstable over the course of this century? ii) Can mitigation measures be developed in sufficient time, within available funding? iii) Will Europe face tough choices about which to save and which to leave to the sea? And what impact would that have on the effectiveness and coverage of Europe's port systems?

Box 4: Climate resilience of EU ports

Ports are exposed to climate-related hazards because much of their infrastructure is located in coastal and estuarine areas. Sea-level rise, flooding, storms, extreme waves and winds, heatwaves and drought pose a risk to port operations and affect connected energy and hinterland transport systems. These hazards can create different types of risks for ports:

- **Physical risks** include damage to or flooding of quays, terminals, storage areas and other infrastructure.
- **Operational risks** include disruptions to navigation, cargo handling and other port activities.
- **Wider network risks** can arise when climate impacts affect electricity supply, road and rail connections or inland water ways.

The level and type of exposure differ between ports according to their location, infrastructure and functions. For example, coastal ports can be particularly exposed to sea-level rise, storm surges and waves, while ports connected to inland waterways may be affected by low water levels and drought.

The EU Ports Strategy recognises these risks and calls for port climate-resilience plans and the application of climate-resilience-by-design principles when port infrastructure is constructed or refurbished.

Source: Authors, based on (Asariotis et al., 2024; EC, 2026a; Tsoulfas, 2025).

4.2. Alternative fuels and port readiness

4.2.1. Port role and readiness for alternative fuel deployment

Alternative fuels are critical to the EU energy transition. They **help reduce emissions from maritime transport, port-based operations and industrial activities**. The EU Ports Strategy states the intention to strengthen the Union's technological leadership in the use of alternative fuels (EC, 2026a).

Ports can play a role in the import, export, production, and storage of such fuels across various sectors and wider supply chains. For some European ports, this transition may broaden their role from logistics nodes to multi-fuel energy hubs (EU Sector organisation 1 & 8; Port administration 9). However, the direct influence of ports on alternative fuel deployment may be limited. Fuel production, storage and bunkering generally remain market activities, and stakeholder input confirms that port authorities primarily act as asset managers and facilitators (EU Sector organisation 1; Port administration 3, 9 & 11). If ports attempt to enforce fuel or decarbonisation measures, they risk driving away business or finding themselves in financial distress, which could ultimately undermine the EU Ports Strategy.

For maritime transport, ports can support decarbonisation by facilitating the infrastructure and operational arrangements required to store, handle, bunker and use alternative fuels safely. This makes **port readiness** an important implementation issue for the maritime energy transition. In this context, port readiness refers not only to the **availability of physical infrastructure**, but also to **safety procedures, permitting, spatial planning, land allocation and coordination between port authorities, terminal operators, fuel suppliers, shipping companies and public authorities**.

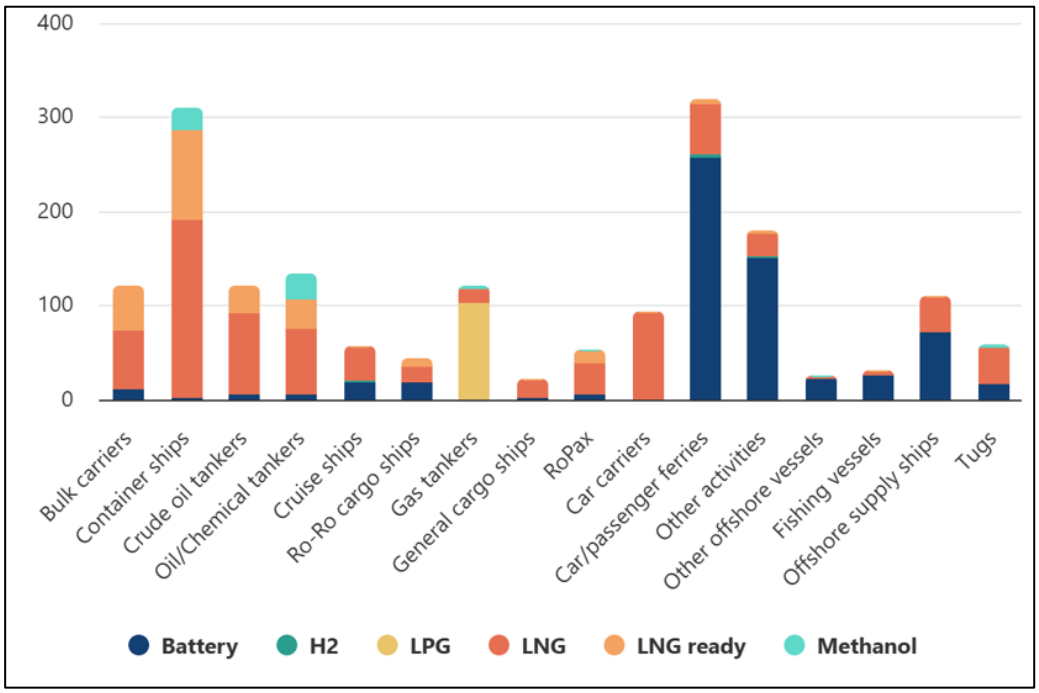
Port authorities do not necessarily carry out bunkering activities themselves. However, through their roles as landlords, authorities, and **facilitators,** they can have some influence on where and how alternative-fuel infrastructure is developed, including through spatial planning, concession conditions and the allocation of land for storage, bunkering and related energy infrastructure (Damman & Steen, 2021).

4.2.2. Multi-fuel transition, EU policy and coordination challenges

a. Multi-fuel approach

As shown in Figure 10, different alternative energy carriers and fuels, including **hydrogen, ammonia, methanol, methane and electricity**, may play a role in different shipping segments (Foretich et al., 2021).

Figure 10: Global overview of current uptake of alternative fuels by marine vessels (total number of ships)



Source: (EC, 2026e).

As discussed in Section 4.1, battery-electric solutions are particularly relevant for shorter-range and more predictable services, while deep-sea shipping is more likely to depend on fuel-based pathways. As such, **the future market shares of various alternative fuels remain uncertain** and their climate benefits depend strongly on the production pathway used (Robalo-Cabrera et al., 2025). The implications for ports also differ between energy carriers because storage, handling, bunkering, safety and infrastructure requirements vary by fuel (Foretich et al., 2021; Klopott et al., 2023).

FuelEU Maritime provides a clear demand-side signal for the uptake of lower-GHG energy in maritime transport by setting progressively stricter limits on the GHG intensity of energy used on board ships. However, its approach is **largely technology-neutral** and does not prescribe which fuel should be used to comply (EP, 2023). Stakeholders stressed that uncertainty over which fuels will dominate and where demand will emerge continues to delay investment in fuel-specific infrastructure (EU Sector organisation 1 & 7; Expert 7; Port administration 2, 9 & 11).

Shipowners may wait for reliable fuel availability before investing in compatible vessels, while ports and fuel suppliers may wait for reliable demand signals. Stakeholder input describes this as a **'chicken-and-egg' dilemma**, particularly where there is a lack of credible demand commitments from shipping lines before deciding whether to invest in new infrastructure and procedures (Port administration 9; EU Sector organisation 7).

Ports and fuel suppliers therefore face an investment-coordination problem rather than an absence of policy demand. Decisions on land allocation, bunkering infrastructure, safety procedures and related investment may need to be taken before the future fuel mix, location and scale of demand are sufficiently clear. This can delay investment and create a **risk of underutilised infrastructure** where deployment does not match subsequent vessel uptake (dos Santos et al., 2022; Kolakowski et al., 2024).

Given the uncertainty surrounding future fuel pathways, **a multi-fuel approach** can preserve flexibility as technologies and markets develop (EC, 2026c, 2026i; Prussi et al., 2021). However, it can also increase the range of infrastructure, spatial and safety requirements that ports need to consider.

Simultaneously, such an approach **raises practical implementation questions for ports**, including how to allocate limited port space and mobilise investment. Stakeholders noted that alternative fuels may require more physical space for storage and handling than conventional fossil fuels (EU Sector organisation 3 & 7; Expert 2). This can further increase pressure on port land, and, where expansion is required, may encounter environmental restrictions or public opposition. It also requires ports to address fuel-specific **safety, permitting, training and emergency-response requirements**, since hydrogen, ammonia, methanol, methane and electricity each involve different operational requirements.

b. Synergies between industry and alternative fuels

In port-based industrial clusters, the presence of alternative fuel feedstocks and concentrated demand for alternative fuels can create important synergies. The proposed **Industrial Accelerator Act (IAA)** (EU, 2026b) could further reinforce these synergies by supporting the decarbonisation of energy-intensive industries and strengthening demand for low-carbon products and clean technologies.

The EU Ports Strategy identifies **fragmented planning, limited coordination between ports and industrial clusters and uncertainty over future energy infrastructure** as notable examples of barriers to investment and system efficiency (EC, 2026c). The strategy calls on Member States to support structured cooperation between ports and local industrial clusters (EC, 2026c).

In this context, ports can play a role in **facilitating information exchange and joint planning** between industrial and energy actors. This can help identify synergies related to land use, grid connections, fuel storage and safety requirements. For example, this could be highly relevant for molecular flows that require dedicated handling conditions, such as ammonia.

Fuel production, supply and vessel-technology choices largely remain **commercial decisions by market actors** (EU Sector organisation 1; Port administration 3, 9 & 11). Public authorities and port authorities will mainly have **enabling and coordinating roles**, such as spatial planning, permitting, safety frameworks and infrastructure coordination (Damman & Steen, 2021). These roles complement rather than replace investment, fuel-supply and vessel-technology decisions by market actors (Kolakowski et al., 2024).

c. EU policy and international coordination for alternative fuels

EU policy sets the baseline for alternative-fuel deployment in ports. Instruments such as the **Alternative Fuels Infrastructure Regulation (AFIR), the FuelEU Maritime Regulation**, and the **EU ETS Directive** create a regulatory framework to stimulate the supply and demand for lower-carbon fuels (EU, 2023b). Under AFIR, Member States must ensure an appropriate number of liquefied methane refuelling points in maritime TEN-T ports, while FuelEU Maritime creates a demand-side incentive for the use of renewable and low-carbon fuels by ships calling at EU ports (EC, 2024a, 2025c).

The inclusion of maritime transport in the EU ETS further strengthens the economic incentive to reduce shipping emissions and supports the uptake of alternative low-carbon fuels (EC, 2026h).

At international level, the **International Maritime Organisation** (IMO) provides the global framework for reducing GHG emissions from shipping, including targets for the uptake of zero and near-zero emission fuels under its 2023 GHG Strategy (IMO, 2023). This framework supports the EU's preference for global alignment on climate policy, which holds particular relevance for international shipping. The IMO can help to **reduce regulatory fragmentation and differences in competitive conditions** between EU and non-EU ports. The IMO is currently developing its Net-Zero Framework, which combines a global marine fuel standard with a GHG emissions pricing mechanism (IMO, 2026). Stakeholders also stressed the importance of internationally coordinated approaches to maritime decarbonisation (Port administration 4, 5, 11 & 14; Expert 4; EU Sector organisation 6).

TEN-T provides the framework for port refuelling points for alternative fuels, while **TEN-E** is relevant to cross-border energy infrastructure, including hydrogen, electrolysers and CO_2-networks (EC, 2026k, 2026l). In addition to the EU regulatory framework, wider EU financing initiatives and international industry-led guidance support the deployment of alternative fuels in ports. **The European Hydrogen Bank**, launched in 2022, provides an example of an EU-level competitive auction mechanism that can support renewable hydrogen production (EC, 2026e).

Box 5: Long-term policy, regulatory stability, and long-term investment commitments

Long-term policy and regulatory stability should accompany long-term investment commitments. The transformation of a large and capital-intensive sector such as European ports requires substantial investments with long implementation cycles and payback periods. While policy and regulatory frameworks necessarily need to evolve in response to technological, environmental and strategic developments, **sufficient predictability and continuity are important to provide industry actors with confidence to undertake long-term investments**.

Significant or frequent changes in requirements can create regulatory uncertainty, potentially affecting investment decisions or reducing the value of investments undertaken in response to previous policy objectives. This highlights the importance of **clear long-term policy signals, transparent transition pathways and appropriate implementation periods**, so that the long-term commitments expected from industry are supported by a sufficiently stable and predictable policy environment.

d. Coordination barriers for alternative fuels at EU ports

Studies on seaports and port readiness underline that alternative fuel deployment depends on **adequate bunkering infrastructure, storage capacity, safety procedures and coordination with shipping and fuel supply actors** (Klopott et al., 2023).

The existing EU instruments do not fully resolve the investment and coordination challenges facing ports. Barriers include **uncertain demand, low demand, high capital costs, limited operational experience, fuel availability, technological readiness and evolving safety requirements** (Foretich et al., 2021; Klopott et al., 2023; Kolakowski et al., 2024). Financing is also a relevant consideration, as the costs and risks of early infrastructure deployment may not be borne by the same actors that benefit from future fuel availability. Stakeholders further emphasised that **high capital expenditure and long payback periods** can make private investment dependent on stable and predictable policy frameworks (Port administration 2 & 13).

Investment in alternative-fuel infrastructure, **training and safety procedures** does not ensure sufficient utilisation. Kołakowski et al. (2024), based on a case study of Polish seaports, identify access to supply and demand, the **reliability of upstream fuel supply chains and delivery safety** as important criteria for locating alternative-fuel bunkering infrastructure (Kolakowski et al., 2024). Evidence from conventional bunkering in Mediterranean tramp shipping also shows that **fuel prices and port waiting times** can affect bunkering-port decisions (Fuentes et al., 2024). These findings should not be generalised to all alternative fuels, vessel segments or EU regions. They nevertheless illustrate that **utilisation risk is location- and market-specific**: infrastructure contributes to decarbonisation only where it is matched by sufficient vessel demand and reliable fuel supply.

4.3. Port electrification

4.3.1. Role of port electrification in the energy transition

Port electrification can support the EU energy transition by **reducing emissions from vessels at berth through onshore power supply** (OPS). It can also reduce emissions associated with **energy use in port-side operations and industrial activities** (Alzahrani et al., 2021). At the same time, fully electric vessel propulsion remains most relevant for specific market segments, such as ferries, inland vessels and harbour crafts , rather than for deep-sea shipping (Kirkels et al., 2026).

Electrification is one of the most direct ways for ports to cut GHG emissions, especially where electricity supply is increasingly renewable. Electrification is one of the more mature decarbonisation pathways, which makes it an important near-term decarbonisation option for EU ports.

4.3.2. OPS deployment, grid capacity and pricing

a. AFIR and FuelEU Maritime: OPS deployment and use

AFIR and FuelEU Maritime **establish complementary requirements for the deployment and use of OPS** in ports. Under Article 9 of AFIR, by 31 December 2029 Member States must ensure that TEN-T core and comprehensive maritime ports exceeding specified traffic thresholds are equipped to provide shore-side electricity to at least 90% of the relevant quayside calls by seagoing container and passenger ships above 5.000 gross tonnes (EU, 2026a). The applicable thresholds, based on the average annual number of calls over the preceding three years, are more than 100 calls for container ships, more than 40 for ro-ro passenger ships and high-speed passenger craft, and more than 25 for other passenger ships (EU, 2026a).

FuelEU Maritime complements this port-side infrastructure requirement with a **ship-side use obligation**. From 1 January 2030, ships within scope that are moored at the quayside in ports covered by Article 9 of AFIR must use OPS for their electrical power demand at berth, subject to specified exceptions (EP, 2023). From 1 January 2035, the obligation also applies at other EU ports where OPS is available (EP, 2023). The OPS obligation applies to the relevant container and passenger ship categories covered by FuelEU Maritime.

AFIR therefore establishes minimum coverage of relevant vessel calls rather than a fixed electricity-capacity requirement for each port. However, an implementation question is **whether the minimum AFIR requirements will be sufficient to meet expected demand under FuelEU Maritime towards 2030**. Estimates by EOPSA and Sustainable Ships place average annual shore-power electricity demand across EU ports from 2030 at approximately 6–13 TWh, illustrating the potential scale and uncertainty of future infrastructure requirements (EOPSA, 2025). This **expansion will require**

coordinated investment in fixed infrastructure. It would also require careful consideration and management of utilisation risks, electricity costs, and grid charges (EP, 2026b).

The EU Ports Strategy **recognises these implementation challenges**. It states that OPS deployment will continue to be monitored through the **European Maritime Safety Agency** and the **European Alternative Fuels Observatory**, and announced further measures through the recently published Electrification Action Plan (EC, 2026d, 2026m). The Strategy also calls for better demand forecasting, greater transparency in OPS pricing and timely and non-discriminatory access to the grid (EC, 2026c).

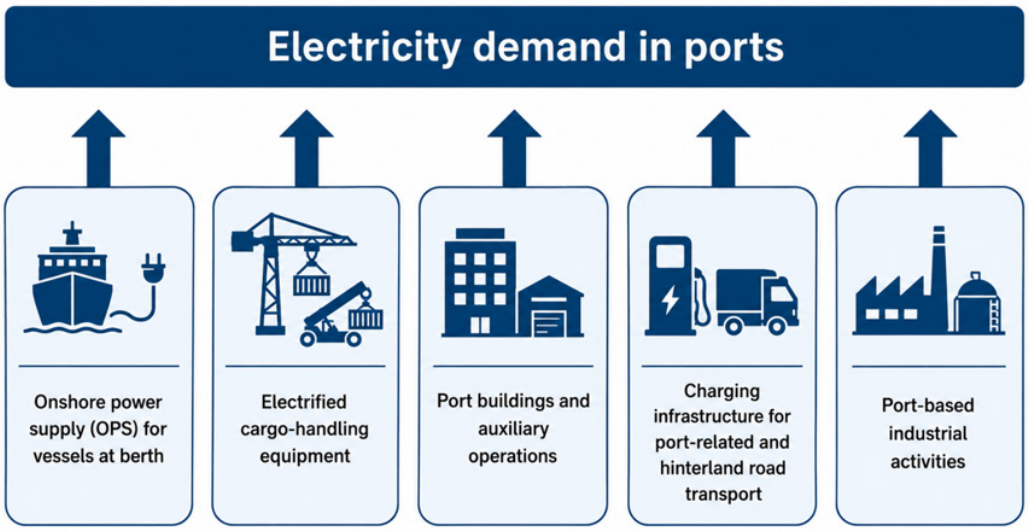
b. Grid capacity and network planning

Growing electricity demand in ports is not limited to OPS. It is also related to other port activities, **including terminal equipment and industrial activity**. This is supported by stakeholder input, which indicates that growing electricity demand will also result from the electrification of cargo-handling equipment and charging infrastructure for port-related and hinterland transport (EU Sector organisation 1, 3, 5, 7, & 8; Port administration 6 & 13). OPS, terminal electrification, and other sources of electricity demand in port areas should therefore be considered as **connected elements of port electrification**. This is particularly relevant where these demands develop simultaneously and **rely on the same local grid capacity**.

A key challenge is whether **port electricity infrastructure can keep pace with this growing demand in the face of grid capacity constraints** (Ramasan et al., 2025). The EU Ports Strategy states that sufficient grid capacity will be key while recognising that capacity constraints persist (EC, 2026c). In addition, stakeholder input indicates that insufficient grid capacity and grid congestion are practical barriers to port electrification (EU Sector organisation 1; Port administration 3 & 9; Expert 1). These constraints can **delay electrification projects or prevent newly installed infrastructure from being used** at its intended capacity.

Stakeholder input indicates that **smart management platforms** may help coordinate OPS, terminal equipment, charging infrastructure, renewable electricity generation and storage. They may reduce peak demand and make more effective use of available capacity, but they cannot replace grid reinforcement where structural capacity constraints remain (Port administration 6, 9 & 13).

Figure 11: Electricity demand in ports



Source: Authors.

On 10 December 2025, the European Commission presented the **European Grids Package**. Its legislative components comprise a proposal to revise the TEN-E Regulation and a proposal to accelerate permit-granting procedures for energy infrastructure (EC, 2025f). The package is complemented by non-legislative measures, including Commission guidance on efficient and timely grid connections (EC, 2025b). For ports, relevant elements include **stronger coordination of network planning, faster permitting, improved management of connection requests and more efficient use of existing grid capacity**. The legislative components have not yet been adopted. In June 2026, the Council agreed its negotiating position on both the revised TEN-E Regulation and the permitting directive. In July 2026, the European Parliament's ITRE Committee adopted its position on the permitting proposal and voted to open negotiations with the Council (EP, 2026a).

The EU Ports Strategy applies this wider framework to port electrification. It calls on Member States to **support smart-grid solutions, demand management, digitalised procedures and better use of existing grid assets** (EC, 2026c). It also stresses the need to integrate port electricity demand into wider network planning, including TEN-E, TEN-T, offshore network development plans and national transmission and distribution plans (EC, 2026c). Electricity-network development and connection decisions depend on the relevant transmission or distribution network and the national regulatory framework. Under Directive (EU) 2019/944, distribution and transmission system operators are responsible for operating, maintaining and developing their respective networks to meet reasonable demand (EP, 2025). For ports, this means that electrification **requires early coordination with grid operators** and integration of expected port electricity demand into network planning, while structural grid constraints cannot be resolved by ports alone.

OPS pricing structure and transparency cost of using OPS affects whether **vessels have an economic incentive to connect**, especially prior to the mandatory use of OPS (or equivalent zero-emission technology), which will come into effect in 2030 under FuelEU Maritime. **OPS pricing structures and transparency vary across EU ports**. The 2026 TRAN study finds that, at a given berth, a ship generally has only one OPS provider and characterises OPS as a **natural-monopoly** service because duplicating fixed infrastructure at the same berth is generally neither realistic nor efficient (EP, 2026b).

Once OPS use becomes mandatory for vessels within scope, limited competitive pressure may create a risk of excessive pricing where tariffs are not transparent or are not linked to identifiable cost drivers. **This could create the risk of vessels being charged excessively high electricity prices while at berth** when seeking to comply with FuelEU Maritime requirements. The EU Ports Strategy recognises this issue by stating the need to promote greater transparency for OPS pricing (EC, 2026a).

c. Remaining implementation issues

Three closely linked implementation issues have been identified: **matching OPS deployment to vessel demand, ensuring sufficient grid capacity for OPS alongside other sources of port electricity demand, and maintaining transparent and comparable OPS pricing**. The EU Ports Strategy addresses each of these areas through monitoring, demand forecasting, grid-access measures and greater pricing transparency (EC, 2026a). Implementation will nevertheless also depend on coordination between ports, ship operators, transmission and distribution system operators and Member States.

Policy for port electrification should consider OPS deployment and grid capacity as **connected implementation issues**. It should also account for electricity demand associated with terminal electrification and charging infrastructure for port-related transport. Growing electrification demand in ports can place substantial additional pressure on local electricity networks and may require grid

reinforcement where existing capacity is insufficient (Ramasan et al., 2025).The main responsibility for grid expansion lies with grid operators and Member States (**EP, 2025**).

OPS pricing transparency requires attention. **Policy should provide guidance on an OPS pricing framework that defines tariff transparency and a common method for comparing OPS prices** to ensure that prices are linked to identifiable cost drivers (EC, 2026a; EP, 2026). Greater transparency and comparability in OPS pricing could strengthen user confidence and support the uptake of OPS (EP, 2026b).

4.4. Energy efficiency in port operations and industrial clusters

4.4.1. Role of energy efficiency in port operations and industrial clusters

Energy efficiency can support the EU energy transition by **reducing the energy intensity of port operations, terminals and port-based industrial clusters** (Alzahrani et al., 2021; Fadiga et al., 2024).

It should be understood as complementary to, rather than separate from, electrification and alternative fuel deployment. Efficiency improvements can **reduce energy demand regardless of the energy carrier used**. Measures include more energy efficient terminal equipment, optimisation of cargo-handling and vessel-turnaround processes, reduced idling, improved building performance, energy-management systems and efficiency improvements in industrial processes (Alamoush et al., 2020; Fadiga et al., 2024).

For ports with substantial industrial activity, energy efficiency extends beyond the port operations themselves. Industrial firms located in port areas can reduce energy use through process efficiency and energy-management measures. At cluster level, additional efficiency gains may arise through cooperation between firms, for example, through **energy sharing and the reuse of waste heat** (Dhondt et al., 2025). The EU Ports Strategy confirms energy sharing, waste-heat reuse and integration with local heating and cooling networks as areas to strengthen cooperation between ports and industrials clusters (EC, 2026a).

Energy efficiency measures are especially relevant where electricity-network capacity is constrained. **Reducing electricity demand and managing peak loads can reduce pressure on existing network capacity**. Port-specific evidence from Oskarshamn also shows that optimised charging can reduce grid stress and defer network upgrades under the scenarios assessed (Ramasan et al., 2025). These measures can complement, but not replace, grid reinforcement where structural capacity constraints remain. As such, **efficiency measures should be implemented alongside grid expansion**.

4.4.2. EU framework and implementation barriers

a. EU energy efficiency framework and its relevance for ports

The **Energy Efficiency Directive** provides the primary EU framework for energy efficiency, setting obligations for EU energy efficiency targets (EC, 2023b). The directive creates a policy baseline for reducing energy demand across sectors, including transport infrastructure, industrial activity and buildings (EU, 2023a).

The EU Ports Strategy does not establish a dedicated energy efficiency framework for ports. However, **it includes energy efficiency within its broader agenda on the energy transition, clean industries and port innovation**. The EU Ports Strategy states that the Commission will organise **targeted workshops for ports** on several strategic topics, including the integration of energy efficiency (EC, 2026a).

b. Investment barriers for energy efficiency measures

Energy cost savings can strengthen the business case for efficiency measures, but **economically beneficial measures are not necessarily implemented automatically**. The European Commission identifies several persistent barriers to energy efficiency investment, **including high upfront costs, payback timeline uncertainty, limited knowledge, and split incentives** (EC, 2026g). Stakeholder input on wider green investment similarly points to high upfront costs, uncertain returns and limited organisational capacity as practical barriers (EU Sector organisation 2; Expert 7; Port administration 2 & 11). Difficulties in measuring and verifying energy savings can further increase uncertainty for investors.

Port-specific evidence points to an additional **organisation and information challenge**. Sdoukopoulos et al. (2019) found that more formal energy-management approaches in European ports, including energy-specific management and monitoring systems, remained relatively limited and **required substantial investment and organisational resources** (Sdoukopoulos et al., 2019). Reliable measurement of energy consumption is important because it provides the **baseline needed to identify high-consumption activities, compare possible measures and subsequently verify savings**. As such, in the face of investment barriers, the cost reductions can be insufficient for port actors to invest in energy efficiency measures.

4.5. Conclusions

The analysis shows that **ports can enable the energy transition across maritime transport, port operations and port-based industry**, but their role is mostly in a facilitating capacity. Alternative-fuel deployment remains affected by uncertainty over fuel-specific demand, while electrification depends increasingly on adequate grid capacity and effective use of OPS infrastructure. Energy efficiency can complement both pathways by reducing energy demand, although investment, organisational capacity and data availability can constrain implementation.

4.5.1. Thematic assessment of the EU Ports Strategy

The EU Ports Strategy places sustainability and the energy transition **at the centre of the future role of European ports** (EC, 2026c). It presents ports as transport nodes that need to reduce their own environmental footprint, as well as strategic energy hubs that can enable the decarbonisation of shipping, logistics, industry and energy systems.

The strategy identifies several **areas for action**. These include:

- accelerating port electrification;
- improving access to electricity grids;
- supporting the deployment of clean energy and alternative fuels, and promoting energy cooperation in and around port areas, including hydrogen-related initiatives;
- the need to accelerate permit-granting and assessment procedures for strategic energy and environmental port projects.

The EU Ports Strategy addresses each of the three main energy-transition components examined in this chapter: alternative fuels and port readiness, port electrification, and energy efficiency. It also addresses the role of port-based industrial clusters. Overall, the Strategy is broadly aligned with the main challenges identified in the literature and stakeholder consultations. The principal remaining issue is implementation. Table 6 summarises how the EU Ports Strategy addresses these main energy transition components and highlights the principal remaining implementation issues identified in this chapter.

Table 6: Assessment of the EU Ports Strategy for sustainability and the energy transition

Energy-transition component	EU Ports Strategy response and remaining implementation issue
Alternative fuels and port readiness	The Strategy recognises ports as multi-fuel production and supply hubs and acknowledges that uncertainty regarding demand for individual fuels can delay investment. It announces several follow-up actions, including the AFIR review, an assessment by the Renewable and Low-Carbon Fuels Alliance of future infrastructure needs, support for hydrogen-related initiatives and stronger cooperation between ports and industrial clusters (EC, 2026a). These measures do not fully remove the underlying coordination challenge. Fuel production, vessel-technology choices and critical elements of the investment in fuel infrastructure remain market-driven, while ports mainly facilitate implementation through land allocation, permitting, safety arrangements and infrastructure coordination. The remaining challenge is therefore to translate EU-wide demand signals into sufficiently credible port- and fuel-specific investment conditions.
Port electrification and OPS	The strategy covers OPS deployment, electricity-demand forecasting, grid capacity and planning, smart-grid and demand-management solutions, and greater transparency in OPS pricing (EC, 2026a). Implementation remains dependent on port-specific electricity demand, timely grid connections, and the development of transparent and fair OPS pricing arrangements.
Energy efficiency and port-based industrial clusters	The Strategy includes energy efficiency within its technological-leadership agenda and announces targeted workshops on the application of EU energy legislation. It also calls for structured cooperation between ports and industrial clusters on renewables, energy sharing, waste-heat reuse, storage and port-centred energy communities (EC, 2026a). The evidence reviewed in this chapter indicates that financing constraints, energy-management capacity and the availability of reliable energy-use data can still hinder uptake.

Source: Authors' own elaboration, based on EC (2026a).

4.5.2. Key takeaways

- **Ports are important to the energy transition because they bring together maritime transport, port operations, energy infrastructure and industrial activity**. This concentration of activities creates opportunities to reduce emissions within port areas and support decarbonisation across wider maritime, logistics and industrial value chains.
- **The energy transition has different implications for different ports and shipping segments**, so infrastructure needs associated with the energy transition cannot be addressed through a uniform approach. Vessel size, route length, operating patterns and cargo type affect the suitability of electrification, alternative fuels and energy efficiency measures, and therefore the infrastructure required.
- **Ports primarily hold an enabling role in alternative fuel deployment through infrastructure, land use, coordination and safety arrangement**s. Fuel demand, supply and investment remain largely market driven and face a 'chicken-and-egg' dilemma. This creates a coordination challenge, as ports may need to prepare infrastructure and safety arrangements before the future fuel mix and scale of demand are fully known.
- **Port electrification technology is mature and represents an important decarbonisation pathway**. However, OPS, terminal electrification and charging infrastructure can place simultaneous and excessive pressure on the local grid capacity, while limited competition at individual berths increases the importance of transparent OPS tariffs.

- **Energy efficiency can reduce energy demand across port operations and industrial clusters**, but investment and organisational barriers can limit uptake. Key barriers include high upfront costs, uncertain payback periods, limited organisational capacity and insufficient data to measure and verify savings.
- The EU Ports Strategy addresses the main issues identified in this chapter. The principal challenge is translating its objectives into implementation across different port contexts.

5. DIGITAL SYSTEMS

KEY FINDINGS

- **Digital solutions are transforming port operations** by improving planning, real-time monitoring, decision-making, coordination and automation.
- **Digitalisation** is a **key enabler of competitiveness, sustainability, resilience and security**, supporting more efficient, transparent and data-driven port operations.
- **Digitalisation increasingly extends beyond individual ports to the wider supply chain**, enabling information exchange, coordinated planning and more integrated management of cargo flows across maritime and hinterland transport networks.
- **The adoption of digital solutions remains uneven across European ports**, reflecting differences in governance arrangements, investment capacity, organisational capabilities and digital maturity.
- The technological building blocks for the digital transformation of European ports are already largely available. The principal challenge is no longer technological development, but rather the **achievement of interoperability, governance alignment and the large-scale deployment** of proven digital solutions across ports of different sizes and functions.
- The **EU Ports Strategy** broadly addresses these challenges, notably through its focus on interoperability, innovation deployment and public-private cooperation. Further attention could strengthen standardisation, interoperability governance and support the sustained uptake of proven solutions, particularly across ports with different levels of digital maturity.

5.1. Context

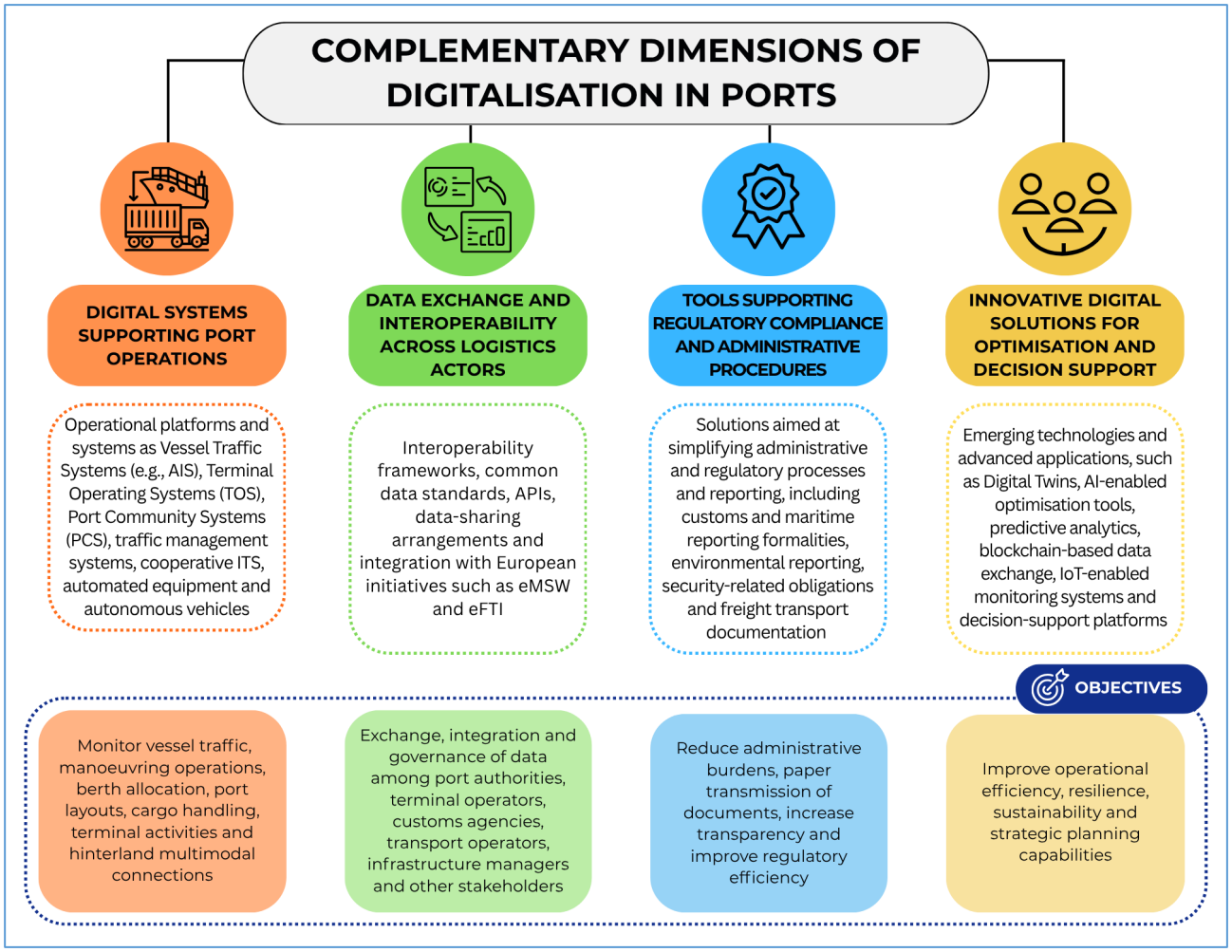
Digital solutions have significant potential to optimise port processes, operational conditions and efficiency (European Commission, 2020), streamline administrative procedures, and strengthen the competitiveness of the European maritime logistics system (European Parliament and Council of the European Union, 2019). At the same time, digitalisation raises strategic challenges related to data governance, ownership, standardisation and cross-border interoperability, particularly where ports act as gateways to EEA and non-EU hinterlands, where fragmented regulatory and digital frameworks can limit seamless data exchange across logistics chains. Therefore, interoperability and seamless data sharing are increasingly European policy issues rather than isolated local or national matters (European Parliament and Council of the European Union, 2020).

As ports increasingly compete globally as integral components of comprehensive logistics, energy, and data networks, it is essential to identify the governance, operational, and market drivers that can promote the widespread adoption of digital platforms, interoperable data sharing, and innovative tools. These elements are vital for achieving broader European objectives related to **competitiveness, safety, security, sustainability, and efficient multimodal connectivity**.

5.1.1. Relevant port digitalisation dimensions

Digitalisation in ports is a multidimensional process encompassing a wide range of technologies, systems and organisational changes. Existing literature often classifies digitalisation according to enabling technologies, such as artificial intelligence, Internet of Things (IoT), cloud computing, or cybersecurity (Sánchez-González et al., 2019). More recent studies have further highlighted the **importance of Digital Twins**, advanced connectivity solutions (including 5G), AI-enabled analytics, and federated data-sharing architectures as key enablers of digital transformation in port (Karlsson, M., et al., (2023), Gil-Pereira, R., et al., (2026), Saragani, C., et al., (2026). However, from a policy and strategic perspective, it is more useful to distinguish digital solutions according to their primary function within port ecosystems rather than the supporting technologies. Accordingly, four complementary dimensions of digitalisation in ports have been identified, as illustrated in Figure 12.

Figure 12: Complementary dimensions of digitalisation in ports



Source: Authors' own elaboration.

5.1.2. Drivers for ports digitalisation

According to Tijan, Jovic, Aksentijevic, & Pucihar (2021), port authorities and **port-related organisations are increasingly being engaged in digital systems motivated by organisational, technological, and external environmental drivers.** In line with these findings, the primary drivers identified across contemporary studies can be categorised into five major themes:

- **Operational efficiency and cost optimisation**
  The need to manage escalating logistics demand while reducing and optimising costs, calls for new digital solutions, such as, AI, Big Data analytics, and Digital Twins, to enable real-time tracking, predictive maintenance, and optimised vessel traffic flows, speeding up turnaround times, reducing congestion and increasing workforce efficiency (Gazzaneo et al., (2024); Min, H., (2022)). Consequently, digitalisation is no longer just an opportunity but a necessity for efficient global trade (Saragani et al., (2026)).
- **Carbon neutral transition and regulatory pressure**
  Environmental compliance has rapidly escalated from a corporate social responsibility initiative to an essential driver for digital transformation. International regulations, such as the International Maritime Organization's (IMO) 2023 GHG Strategy aiming for net-zero emissions by or around 2050, directly push ports to integrate digital tools. Digital systems allow ports to achieve better energy resource utilisation, optimize route tracking to lower emissions, integrate smart renewable grids, and deploy dock electrification (cold ironing) mechanisms seamlessly (Gazzaneo et al., (2024); Catana, E., et al., (2026)).
- **Market competitiveness and seamless supply chain**
  The persistent surge in global seaborne trade volume combined with sudden market shocks (e.g., pandemic, shipping bottlenecks) creates severe port congestion. Increased customer expectations for reliable, affordable, and cost-efficient transport services forces ports to adopt digital infrastructure to retain market share against highly advanced rival hubs, as modern shipping lines actively prioritise ports based on the reliability, visibility, and transparency of their information systems (Sakita, B. M., et al., 2024).
- **Interoperability, hinterland connectivity and data sharing**
  European ports do not operate in isolation; they are deeply bound to cross-border European rail, road, and inland waterway systems. Increasingly, the efficiency of these connections depends on the ability of stakeholders to exchange and process information seamlessly across organisational and national boundaries. Improving interoperability between port systems, customs authorities, infrastructure managers, logistics operators and transport service providers has therefore become a major driver of digitalisation, particularly along TEN-T corridors and cross-border freight chains (Paraskevas et al., 2024; Ollivier, P. et al., 2024).
- **Resilience, safety, and security**
  Recent disruptions, including cyberattacks, geopolitical tensions, extreme weather events and supply-chain disruptions have reinforced the need for greater operational resilience within port ecosystems. Cybersecurity is therefore a structural prerequisite for resilience and competitiveness, as also highlighted in the EU Maritime Security Strategy and the NIS2 Directive (European Parliament and Council of the European Union, 2022).
  As ports become increasingly critical infrastructures within European transport and energy systems, resilience and security considerations are emerging as key drivers of digital transformation.

For the purpose of this study, these issues are analysed through three complementary components:

- adoption of digital systems and solutions in ports;
- data sharing and governance; and
- innovative digital solutions for port operations.

5.2. Adoption of digital systems and solutions in ports

This component examines the current level of adoption of digital systems across EU ports, including terminal operating systems, Port Community Systems (PCS), customs and administrative digital platforms, traffic management systems, environmental monitoring tools and multimodal coordination platforms. The analysis maps differences in digital maturity across ports of different sizes, functions and macro-regions, while identifying the main organisational, financial, technological and governance drivers influencing digital uptake.

Various large-scale European ports are accelerating the deployment of integrated digital systems and smart port solutions, including PCS, Digital Twins, AI-enabled decision-support tools and IoT-based monitoring platforms (Port Technology International, 2024). Recent initiatives in ports such as Rotterdam, Antwerp-Bruges, Hamburg, and Livorno demonstrate growing focus on data-driven operations, predictive maintenance, traffic optimisation and digital ecosystem management (COREALIS, 2021). However, **significant disparities remain across smaller and medium-sized ports and across Member States** (EU Sector organisation 7,9, 10; Expert 5). Recent studies highlight that **digital maturity continues to vary considerably depending on financial resources, governance structures and organisational capabilities, creating a risk of an emerging digital divide within the European port system** (EC, 2025j; 2025k).

5.2.1. Analytical approach

The study assessed the adoption of digital solutions in European ports through selected evidence from academic literature, EU-funded projects and publicly available port-specific sources, focusing on digital system type, operational role, drivers and maturity. **The objective is not to provide a comprehensive assessment of all European ports, but rather an evidence-based illustrative benchmarking of selected ports representing different geographical areas, operational profiles and levels of digital maturity**.

Nine ports have been selected to ensure a representative coverage of European maritime regions, port functions and maturity levels, as summarised in the table below.

The main sources consulted for each port are reported in Annex 4.

Table 7: Adoption of digital systems: Criteria for the selection of ports

Geographical balance	Different sizes and functions
• Northern Range: Antwerp-Bruges, Rotterdam • Mediterranean: Livorno, Valencia, Piraeus • Nordic/Baltic: Gothenburg, HaminaKotka • Black Sea: Constanța • Inland: Vienna	• Global hubs: Rotterdam, Antwerp-Bruges • Major regional gateways: Valencia, Piraeus, Gothenburg • Medium-sized ports: Livorno, HaminaKotka • Inland logistics hub: Vienna • Strategic emerging gateway: Constanța

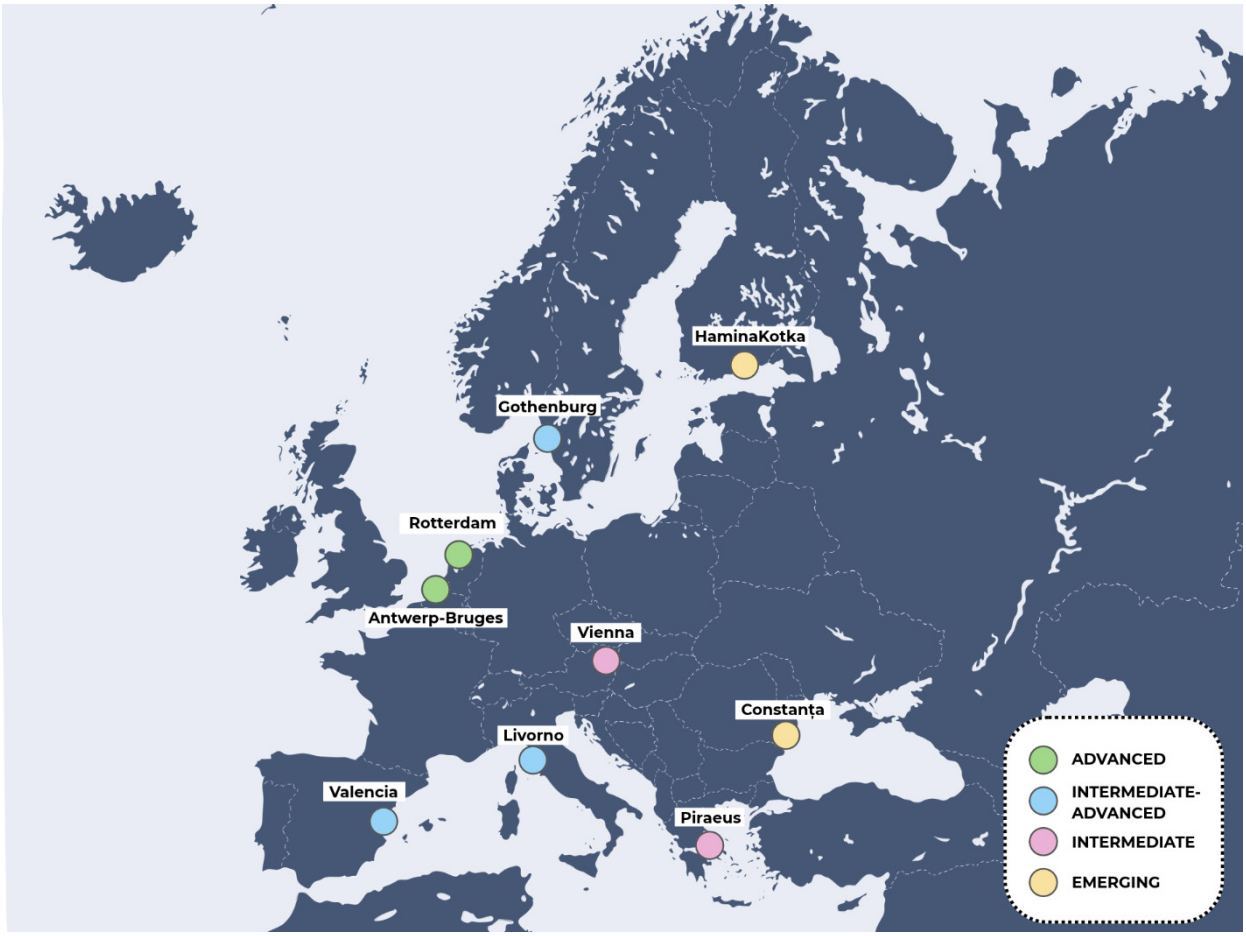
5.2.2. Synthesis of the analysis of the selected ports

Table 8 presents a summary of the comparative benchmarking exercise. The selected cases are used to illustrate different levels of digital maturity, from advanced smart-port ecosystems to emerging digitalisation pathways. The maturity level reflects a qualitative assessment based on evidence available in the literature and project documentation, taking into account three dimensions: (i) deployment of operational digital systems (e.g., TOS, PCS, VTMIS); (ii) implementation of data-sharing and interoperability mechanisms (e.g., PCS integration, customs integration, eMSW readiness); and (iii)

adoption of advanced and innovative digital solutions (e.g., Digital Twins, IoT platforms and AI-supported applications). Based on this assessment, **ports are classified as exhibiting advanced, intermediate or emerging levels of digital maturity** (Figure 13).

While all selected ports have undertaken digitalisation initiatives, the analysis reveals significant differences in the scope, integration and maturity of deployed solutions, reflecting variations in governance arrangements, investment capacity, strategic priorities and participation in innovation programmes.

Figure 13: Digital system maturity in selected ports



Source: Authors' own elaboration.

Table 8: Assessment of the adoption of digital solutions in selected ports

Port	Digital system and maturity	Main drivers and enablers	Operational and strategic benefits
Antwerp-Bruges	APICA Digital Twin platform; NxtPort data-sharing platform; Certified Pick up / Inbound Release Platform – secure container and customs-related data exchange; Smart cameras, drones, sensors and digital "iNoses". **Advanced**	Long-term smart-port strategy; Large-scale logistics and industrial integrated framework; Strong port community and data-governance model;	Flagship port for global trade; Improved situational awareness and decision-making; Secure and transparent container release; Enhanced data sharing across port stakeholders.

Port	Digital system and maturity	Main drivers and enablers	Operational and strategic benefits
		Participation in EU-backed innovation projects.	
Rotterdam	Portbase Port Community System; PortXchange / Pronto for port-call optimisation; Routescanner multimodal route-planning platform; Digital Twin, AI, and IoT/sensor-based data infrastructure. **Advanced**	Global hub scale; Long-term ambition to become a "smartest port"; Strong port-community governance through Portbase; Decarbonisation and just-in-time arrival objectives.	Improved port-call planning and vessel turnaround; reduced waiting and emissions; enhanced supply-chain visibility; better multimodal route planning.
Livorno	PCS enhancements (T-PCS); Control and monitoring platform (MONI.CA); Virtual Control Room for cargo management and C-ITS. **Intermediate -advanced**	Logistics optimisation needs; Digital Port strategy and sensorisation programme; Participation in EU-funded innovation projects.	Congestion reduction; Port-hinterland integration; Improved vessels and cargo visibility and emissions monitoring.
Gothenburg	"Digital Port Call" tool; "Port Optimizer Track & Trace" app; Digitalised port-call and cargo-tracking services; Integration with Railport Scandinavia and hinterland rail network. **Intermediate -Advanced**	Strong rail-port integration strategy; Decarbonisation and just-in-time arrival objectives; High share of rail-based hinterland transport; Cooperation with digital providers such as Awake.AI and Wabtec.	Improved port-call coordination and predictability; Reduced waiting times and emissions; Real-time cargo visibility from quayside to inland destination; Stronger coordination between maritime, terminal and inland transport actors.
Piraeus	Hellenic Port Community System / HPCS; Private 4G/LTE network; Smart-port digital transformation initiatives. **Intermediate**	Strong container growth and transhipment role – critical node in Belt and Road Initiative; COSCO/PCT operational model; EU-funded innovation projects.	Faster customs/container handling processes; Improved stakeholder coordination and data exchange; Enhanced operational efficiency.
Valencia	Valenciaport PCS; Digital Twin platform; Smart environmental monitoring platform (ECOPORT/Green C Ports); AI-based traffic prediction and IoT. **Intermediate -Advanced**	Long-term smart-port strategy; Strong governance through Fundación Valenciaport; Continuous participation in EU innovation projects; Environmental and decarbonisation objectives.	Improved interoperability; Enhanced environmental monitoring; AI-supported operational planning; Stronger port-city integration.

Port	Digital system and maturity	Main drivers and enablers	Operational and strategic benefits
HaminaKotka	3D digital port operating platform (VRT BIM); Digital asset and infrastructure management. **Emerging**	Need to improve operational efficiency despite peripheral location; Maintenance optimisation; Anchored in the national Finnish digitalisation strategy.	Improved logistics visibility; Increased operational resilience and support for future smart-port services.
Constanța	Port Community System developments; Digital customs and maritime reporting systems; Participation in EU digital and interoperability projects. **Emerging**	Black Sea gateway role; Growing geopolitical importance; Danube–Black Sea multimodal integration; EU innovation projects.	Improved customs efficiency; Enhanced multimodal coordination; Stronger interoperability with hinterland transport; Increased logistics resilience.
Vienna	Digital terminal and smart intermodal logistics systems at WienCont; Rail-side OCR gate for digital registration of wagons and loading units; River Information Services (RIS) supporting inland navigation. **Intermediate**	Trimodal role connecting rail, road and inland waterways; Rhine–Danube Corridor relevance; Inland-port decarbonisation and modal-shift objectives.	Improved rail-road-waterway coordination; Increased terminal efficiency; Improved reliability of inland logistics chains.

Source: Authors' own elaboration.

5.2.3. Cross-cutting findings

Several cross-cutting findings emerge from the benchmarking exercise:

- **Advanced digital ecosystems are concentrated in Europe's largest gateway ports**. Rotterdam and Antwerp-Bruges demonstrate the highest levels of digital maturity, characterised by integrated digital ecosystems combining Port Community Systems, Digital Twins, AI-supported decision-making, IoT-enabled monitoring and mature data-governance frameworks. Their experience confirms that **digital transformation depends not only on technology adoption, but also on strong governance structures** capable of orchestrating multiple stakeholders and digital platforms.
- **Different digitalisation pathways are emerging across European ports**. While leading ports pursue comprehensive smart-port ecosystems, medium-sized ports often specialise in digital solutions responding to their specific operational context. For example, Gothenburg focuses on digital port-call optimisation and rail integration, Livorno on logistics monitoring and innovative C-ITS pilots, Valencia on environmental intelligence and Digital Twin applications, Piraeus on terminal and container logistics, Vienna on intermodal inland logistics, and Constanța on multimodal interoperability and customs digitalisation.
- **EU-funded research and innovation programmes play a key enabling role**. Projects such as COREALIS, MAGPIE, PIONEERS and MultiRELOAD have enabled ports to test innovative

solutions including Digital Twins, AI-supported decision tools, IoT sensor networks and digital logistics platforms. **These initiatives have significantly accelerated experimentation and knowledge transfer, particularly for medium-sized ports with more limited internal innovation capacity**.

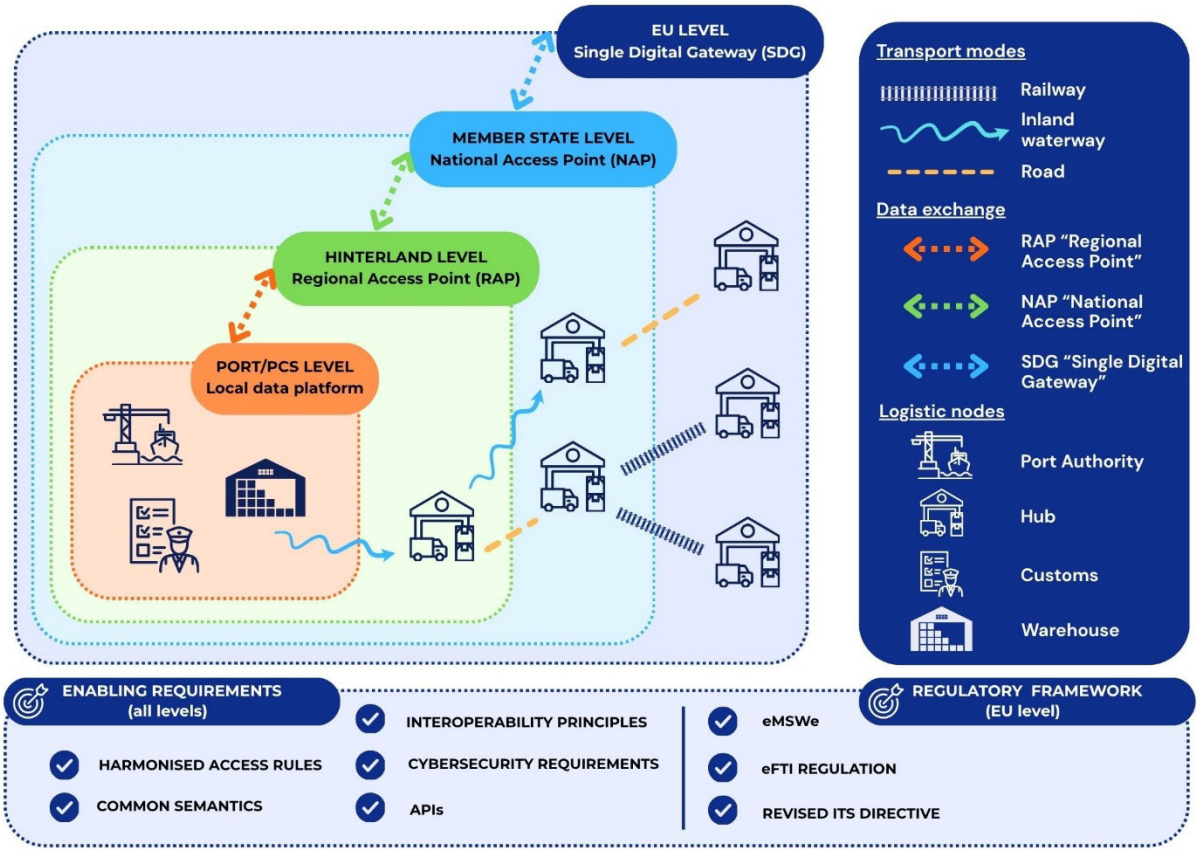
- **The main challenge is moving from pilot projects to large-scale deployment**. The experience of leading ports suggests considerable opportunities to replicate successful solutions both vertically, by transferring proven approaches from major gateways to medium-sized ports, and horizontally, through peer-learning, standardisation and cooperation across European port networks.

5.3. Data sharing and governance

A key challenge in modern port logistics is the fragmentation of information flows across multiple actors operating different IT systems and procedures (Digital Transport and Logistics Forum (DTLF), 2018). This component is therefore relevant because **efficient data sharing is increasingly becoming a prerequisite for competitiveness, resilience and sustainability across the European port system**, as confirmed by the recent developments of the EU regulatory framework, through initiatives such as eMSW, the eFTI Regulation and the revised ITS Directive.

Beyond the deployment of individual digital platforms, **effective digitalisation requires seamless data exchange across three complementary dimensions: across transport modes, across organisations, and across governance levels**. Digital systems should therefore not be regarded as isolated applications, but rather as **interconnected nodes within a wider digital ecosystem** linking local port operations with regional, national and European transport networks. This includes the exchange of information not only between different transport modes (e.g., maritime, rail, road and inland waterways), but also across different administrative and territorial levels, from port authorities and terminal operators to national authorities, customs administrations and European digital platforms (Figure 14). Achieving this level of integration requires interoperable architectures, common data models and harmonised exchange protocols that enable information to circulate efficiently across logistics chains while ensuring data quality, cybersecurity and appropriate governance arrangements. In this respect, European initiatives such as the European Maritime Single Window environment (eMSWe), the Electronic Freight Transport Information (eFTI) framework and the revised ITS Directive provide an important foundation for progressively connecting local port systems with wider national and European digital ecosystems.

Figure 14: Data exchange framework within the EU digital ecosystem



Source: Memex's own elaboration.

5.3.1. Port Community Systems as interoperability enablers

Significant progress in data sharing and interoperability has been made in large European ports, supported by the rollout of **Port Community Systems**, the implementation of the European Maritime Single Window environment (eMSW), and increasing integration of port and hinterland information systems.

The high number of stakeholders, operations, services, and organisation-based systems involved in the transport sector, has stressed the urgency of a rapid and efficient exchange of data and information. currently represent the most mature and widely deployed digital platforms supporting operational data sharing and interoperability across port communities (Ollivier, P. R. G., et al., 2024). **A Port Community System (PCS) is a neutral and open electronic platform that enables the intelligent and secure exchange of information between public and private stakeholders involved in port and logistics operations**. Its goal is to **enhance the competitive position of port communities**.

Different actors, each with unique competencies, participate in the PCS processes. At a high level, these actors can be categorised into two functional groups:

- **Operational stakeholders**: these are the actors who directly handle and transport goods or interact with them in some way. This group includes terminal operators, shipping companies, rail operators, and similar entities.

- **The institutional and regulatory stakeholders**: This group comprises those who oversee freight transport operations, providing control and management without being involved in maritime or on-site operations. Examples include port authorities and customs agencies.

Through interoperable and open system architectures, PCS enables participating organisations to trigger operational processes automatically based on digitally exchanged information. This **reduces duplication of data entry, minimises errors, accelerates administrative procedures and increases the reliability and transparency of logistics operations**. Consequently, both physical cargo flows and associated information flows become **more efficient and better coordinated**. Consequently, PCS have become the de facto digital backbone of many advanced European ports, providing the operational layer through which data exchange, administrative simplification and stakeholder coordination are increasingly achieved.

5.3.2. Persistent challenges and barriers

Despite significant progress, substantial fragmentation persists across smaller and medium-sized ports and across Member States. Existing studies and EU-funded initiatives continue to highlight uneven digital maturity and the need for stronger interoperability standards, governance alignment and shared semantics to support coordinated operations and harmonised environmental data collection across TEN-T ports (Gerlitz, L., Meyer, C., 2021; PRESPORT Project, 2026).

The benchmarking conducted by Ollivier, P. R. G., et al. (2024) also identified a digital and governance gap between developed and developing countries. The study shows that countries such as the Netherlands, Belgium, France, Germany, Spain, the United Kingdom, Singapore, Japan, and South Korea are among the leading countries in PCS adoption, while developing countries face challenges in adopting a PCS, arguing that this could be partially explained by the limited availability of financial resources and the lack of specialised technical expertise.

The key challenges identified in the stakeholder consultation for this study are summarised in Table 9. These findings align with the broader assessment of Almeida (2023) and González-Cancelas et al. (2024), who identifies governance fragmentation, limited interoperability between digital systems, cybersecurity and privacy concerns, organisational complexity and unequal technological capabilities as the principal barriers to digital transformation across ports worldwide.

Table 9: Key challenges and barriers for seamless data exchange

	Theme			
	Governance	**Interoperability across digital platforms**	**Digital maturity**	**Data governance, cybersecurity and trust**
Stakeholder recurrent and shared challenges	Different ownership models and governance fragmentation	Limited interoperability between PCS, customs, terminal, rail, road and inland-waterway systems, as well as with national and European digital platforms (eMSWe, eFTI)	Wide adoption in large ports compared to small and medium ports	Increasingly important issues related to data ownership, access rights, liability, cyber risks

	Theme			
	Governance	**Interoperability across digital platforms**	**Digital maturity**	**Data governance, cybersecurity and trust**
Stakeholder/ Source	*EU Sector organisation 6,8* *Port administration 6,9* *Expert 6,7,8*	*EU Sector organisation 7,9,10* *Port administration 1,6,9,12,13* *Expert 5*	*EU Sector organisation 7,8,9,10* *Expert 5*	*EU Sector organisation 5,6,8,9* *Port administration 6,9,13* *Expert 7*

Source: Authors' own elaboration based on stakeholder consultations.

5.4. Innovative digital solutions for port operations

Ports are increasingly evolving into highly connected and data-driven multimodal ecosystems, where operational efficiency, safety and resilience depend on the capability to collect, exchange and process information in real time (European Parliament and Council of the European Union, 2023; European Parliament and Council of the European Union, 2024b). Beyond improving individual port operations, digitalisation can support the coordination of wider supply chains by connecting information flows between ports, shipping lines, terminal operators, hinterland transport providers, shippers and industrial and commercial actors.

Greater visibility across these interconnected operations can support the synchronisation of cargo movements, transport capacity and logistics processes, enabling supply chains to be managed more efficiently under normal conditions and adapted more rapidly in response to disruptions (Caldeirinha et al., 2022). Innovative digital solutions have the potential to streamline operational processes by supporting predictive and automated decision-making, optimising traffic and terminal management, reducing delays and administrative procedures, and improving the overall competitiveness and reliability of logistics chains.

Recent innovation trends point to an increasing deployment of IoT devices, Digital Twins and AI-supported applications across major European ports and hinterland logistics and transport operations, particularly for traffic optimisation, predictive maintenance, emissions monitoring and operational management. Examples include Digital Twin initiatives and smart-port programmes in ports such as Rotterdam, Hamburg and Antwerp-Bruges, as well as the growing use of IoT-based monitoring systems and AI-supported decision-support tools for traffic and asset management.

Recent EU-funded projects further highlight the growing role of Digital Twins and AI technologies in supporting operational efficiency, resilience and sustainability objectives within port ecosystems (Gil-Pereira et al., 2026). However, implementation remains fragmented and uneven across ports and Member States. In this context, further EU-level guidance and coordination may be needed to support harmonised deployment, common technical standards and scalable C-ITS strategies across TEN-T ports and hinterland corridors.

5.4.1. Innovation ecosystems and operational transformation in ports and logistics supply chains

European ports are increasingly evolving into innovation ecosystems where public authorities, terminal operators, technology providers, research organisations and logistics stakeholders jointly develop, test and validate new digital solutions under real operational conditions. **Their combination of operational**

complexity, multimodal connectivity and measurable performance indicators makes ports particularly suitable environments for demonstrating innovative technologies before their wider deployment across the European transport system (EU Sector organisation 1; Port administration 9; Expert 4).

Innovation is not an objective in itself, but a means to improve port performance. Emerging digital technologies, including **Digital Twins, Artificial Intelligence (AI), the Internet of Things (IoT) and Cooperative Intelligent Transport Systems (C-ITS)**, are progressively transforming port operations by enabling predictive decision-making, optimising traffic and terminal management, improving environmental monitoring, strengthening safety and resilience, and reducing administrative burdens through automation.

The **controlled operational environment of ports** facilitates the generation of comparable performance data, supporting the evaluation, validation and replication of innovative solutions across different port typologies. Several characteristics make ports particularly suitable environments for innovation:

- controlled operational environments;
- multiple public and private stakeholders;
- multimodal transport interfaces;
- operational complexity requiring coordinated decision-making;
- measurable operational and environmental performance indicators;
- high potential for replication across the European port system.

The potential of these technologies extends beyond the optimisation of individual port functions. As ports form part of wider industrial, commercial and logistics supply chains, **digital solutions can increasingly connect operational information generated within the port with information from shipping, hinterland transport, logistics and cargo-owning actors**. Combining these information flows can provide greater end-to-end visibility over cargo movements and enable better coordination of vessel arrivals, terminal operations, storage capacity and onward transport (Inkinen et al., 2019).

Several of the consulted stakeholders emphasised a gradual shift from digitalisation as an instrument for information exchange towards **digitalisation as an enabler of supply-chain coordination and management**. By combining real-time and predictive information from different actors, digital platforms can support coordinated decisions across the logistics chain, rather than optimising individual operations in isolation (EU Sector Organisation 6, 7, 9).

The **main operational areas currently benefiting from innovative digital solutions** are summarised in Table 10. Ports are not only adopting innovation; they are contributing to shape and validate the next generation of digital technologies for the wider European transport system.

Table 10: Operational and supply-chain areas benefitting from innovative digital solutions

Operational area	Examples of innovative solutions	Benefits
Traffic management	Digital Twins, AI, C-ITS	Enabling predictive rather than reactive management
Asset management	IoT, predictive maintenance	Improved asset performance; reduced maintenance costs; increased infrastructure reliability

Operational area	Examples of innovative solutions	Benefits
Environmental monitoring	IoT sensors, Digital Twins	Real-time environmental monitoring; emissions management; support for sustainability objectives
Supply-chain coordination and visibility	AI, IoT, integrated digital platforms, real-time tracking	End-to-end cargo visibility; synchronisation of maritime, terminal and hinterland operations; improved reliability and resource allocation
Safety and emergency response	AI, Digital Twins	Enhanced risk assessment; faster incident response; improved operational resilience; coordinated response and rerouting across logistics chains
Administrative processes	AI, automation	Reduced administrative burden; faster procedures; improved decision-making

Source: Authors' own elaboration.

5.4.2. From innovation pilots to operational deployment

The challenge for Europe is no longer the development of innovative digital solutions, but their large-scale deployment across the wider port and logistic systems. Numerous technologies—including Digital Twins, AI-based decision-support tools, IoT sensor networks and C-ITS applications—have already demonstrated their technical feasibility through EU-funded research and innovation projects. However, their transition from pilot demonstrations to routine and scaled-up operations remains uneven across the full logistics chain (EU Sector organisation 9, Expert 5, Port administration 13).

Scaling up digital innovation depends on considerably more than technological readiness. Experience from leading ports shows that successful deployment requires supportive governance arrangements, sustainable business models, adequate investment, and close cooperation between public authorities, port communities and technology providers. **At the same time, interoperability between digital platforms, organisational readiness and the availability of digital skills remain essential prerequisites for integrating innovative solutions into day-to-day port operations** (European Commission, 2026j).

As a result, many innovations remain confined to individual pilot projects rather than becoming operational standards across the European port system. Bridging this gap therefore requires moving beyond technology demonstration towards coordinated implementation strategies capable of supporting replication, knowledge transfer and long-term investment across ports of different sizes and functions (EC, 2026a).

While scaling up innovative digital solutions remains an important priority, the next stage of digital transformation requires a broader systemic approach. The challenge is no longer only deploying digital technologies within individual ports, but ensuring that they operate as part of an integrated European digital ecosystem, where information can be exchanged seamlessly across ports, transport modes and administrative levels.

5.4.3. Towards an integrated European digital ecosystem

The benchmarking exercise, literature review and stakeholder consultations consistently indicate that **the European Union**, in cooperation with Member States, **has an important role in establishing the enabling framework for secure and interoperable data exchange across European ports** (EU Sector organisation 5, 6, 7, 8; Port administration 6,9,14; Expert 5, 6, 8, 7). Today, many ports continue to rely on different digital systems, governance arrangements and technical standards, limiting interoperability and reducing the efficiency of cross-border logistics chains. Building on existing initiatives such as the eMSWe, the eFTI framework and the revised ITS Directive, future European initiatives could further promote common data standards, interoperable architectures, secure APIs and harmonised governance principles covering data ownership, access rights, privacy and cybersecurity.

The objective of greater interoperability should therefore extend beyond facilitating data exchange between individual systems. A more integrated European digital ecosystem could enable information generated by ports, shipping lines, terminals, customs authorities, rail and road operators, logistics providers, shippers and industrial and commercial actors to support coordinated management of the wider supply chain. Ports can play an important role within this ecosystem as multimodal interfaces where maritime, cargo, transport and administrative information flows converge.

Such integration can support both day-to-day supply-chain optimisation and resilience under exceptional conditions. Under normal operations, greater visibility across the chain can improve synchronisation between vessel calls, terminal capacity, cargo availability and hinterland transport. During disruptions—including infrastructure failures, extreme weather events, congestion or geopolitical shocks—the same information environment can support shared situational awareness, identification of bottlenecks and alternative routes, and more coordinated responses between supply-chain actors (Urciuoli & Hintsa, 2021).

Stakeholders shared a general consensus that these integration issues do not necessarily require the creation of a single European platform or centralised governance model. Rather, the challenge is to **enable existing and future systems to interact within a federated and interoperable digital environment**, in which relevant information can flow securely across organisational, modal and geographical boundaries while respecting commercial confidentiality, data ownership and access rights.

Greater integration also increases the importance of **cybersecurity** and **digital resilience**. As discussed in Section 3.2, expanding connectivity between port, transport and supply-chain systems can increase the attack surface and create **interdependencies** through which **vulnerabilities** affecting one organisation or system **may propagate across the wider logistics ecosystem**. An integrated European digital ecosystem should therefore be developed on a **security- and resilience-by-design basis**, combining interoperability with appropriate access controls, cybersecurity requirements, third-party risk management and clear responsibilities across organisational interfaces. These requirements are particularly important where digital systems support critical infrastructure, business continuity or other strategically sensitive functions, including the dual-use and military-mobility functions discussed in Sections 3.4 and 6.

At the same time, closer cooperation between port authorities, transport operators, technology providers, research organisations and logistics stakeholders will remain essential to reduce fragmentation, improve operational efficiency and enable ports of different sizes and functions to fully benefit from digitalisation, multimodal integration and cross-border connectivity.

Particular efforts should therefore focus on **strengthening secure and resilient interoperability** between Port Community Systems, supply-chain platforms, and wider European digital frameworks, promoting common data governance principles, harmonised semantics, APIs and secure data-sharing arrangements across logistics chains. This would allow interoperability to support not only the exchange of information, but also more coordinated planning, management and resilience of European freight and logistics chains.

5.5. Conclusions

5.5.1. Thematic assessment of the EU Ports Strategy

The EU Ports Strategy recognises **digitalisation as a key enabler of port competitiveness, operational efficiency, market development and sustainability**. Its overall direction is consistent with the findings of this chapter, particularly regarding the need to move beyond individual technological applications towards wider deployment, stronger interoperability and greater cooperation across the port ecosystem.

A first important issue concerns the **transition from innovation pilots to operational deployment at scale**. The Strategy acknowledges that, despite substantial EU investment in research and innovation, many innovative solutions do not progress beyond the pilot phase. It therefore places greater emphasis on market deployment, including through reinforced public-private cooperation under the 2028–2034 Horizon Europe Framework Programme, building on existing initiatives and supporting synergies between decarbonisation, digitalisation, automation and circularity. This responds to an important barrier identified in the analysis. However, **more specific mechanisms supporting the transition from successful demonstration to sustained operational adoption could further strengthen this approach**, including funding and investment models that support implementation beyond the initial testing phase.

A second priority is **interoperability and integration of information flows across port and logistics systems**. The Strategy recognises that fragmented business-to-business (B2B) data exchange and insufficient interoperability can reduce logistics-chain efficiency. Rather than promoting centralised platforms, it supports better integration between existing systems through common guidance on data sharing, while seeking to preserve existing IT investments and strengthen cooperation between Member States and industry stakeholders. This approach is broadly aligned with the findings of this chapter. **Its implementation could nevertheless benefit from clearer governance and accountability arrangements**, including responsibilities for coordinating and maintaining standards, assessing interoperability, and addressing data governance, quality, access and security.

Finally, the analysis identifies **uneven digital maturity across European ports as a continuing challenge**. Major gateway ports generally benefit from greater investment capacity, stronger digital governance and more advanced technology deployment, while smaller and medium-sized ports often adopt more targeted solutions reflecting local operational needs and available resources. The Strategy acknowledges this diversity and promotes public-private cooperation, dissemination of EU-funded innovation, exchange of good practices, partnerships and new business models. Its emphasis on supporting innovation uptake in smaller ports is therefore particularly relevant. **Continued attention will nevertheless be needed to ensure that the expansion of digitalisation does not widen existing differences in digital capacity and that proven solutions can be adapted and transferred across ports of different sizes, functions and levels of maturity**.

5.5.2. Key takeaways

- **Digitalisation has become a strategic enabler for European ports**. Digital solutions increasingly support operational efficiency, competitiveness, sustainability, safety and resilience by improving planning, monitoring, decision-making and coordination. Port digitalisation is multidimensional, encompassing operational systems, data-sharing platforms, automation and emerging technologies such as AI, IoT and Digital Twins. Its development is driven not only by technological progress, but also by growing logistics complexity, decarbonisation requirements, security needs and increasing demand for real-time information.
- **The adoption of digital solutions remains uneven across the European port system**. The benchmarking shows that major gateway ports such as Rotterdam and Antwerp-Bruges have developed highly integrated digital ecosystems, supported by mature governance arrangements, Port Community Systems and extensive deployment of innovative technologies. Other ports are following different digitalisation pathways, often focusing on solutions responding to specific operational needs. EU-funded research and innovation projects have played an important role in supporting experimentation, but differences in investment capacity, governance and organisational capabilities continue to influence the pace and scope of digital transformation.
- **Data sharing and interoperability are becoming as important as the individual digital solutions themselves**. Port Community Systems provide an established basis for connecting public and private stakeholders, but fragmentation persists between systems, platforms, transport modes and administrative levels. Effective digitalisation therefore increasingly depends on common semantics, interoperable architectures and APIs, alongside clear arrangements for data ownership, access, quality, cybersecurity and accountability. The EU Ports Strategy recognises these challenges and appropriately emphasises better integration of existing systems rather than the creation of new centralised platforms; however, the governance and accountability mechanisms underpinning interoperability could be further clarified.
- **Digitalisation increasingly extends beyond the port boundary to the management of end-to-end logistics chains**. Ports form part of wider networks connecting shipping, terminals, rail and road operators, inland terminals, shippers and commercial actors. Digital platforms can therefore evolve from mechanisms for exchanging information towards tools supporting coordinated planning and supply-chain orchestration, including the anticipation of disruptions, optimisation of cargo flows and adaptation of logistics operations in both normal and exceptional situations. This requires seamless information exchange across ports, transport modes and geographical and administrative levels.
- **Emerging technologies are further expanding the role of digitalisation in port operations**. AI, IoT, Digital Twins, C-ITS and advanced analytics are increasingly being applied to traffic and terminal management, predictive maintenance, environmental monitoring, safety and emergency response. The technological building blocks are therefore largely available; the principal challenge is increasingly to move successful innovations from demonstration to sustained operational deployment. This requires viable business models, adequate investment, digital skills, public-private cooperation and solutions that can be adapted to ports of different sizes and functions.
- **Overall, the next phase of European port digitalisation is primarily a challenge of integration, governance and deployment at scale**. The EU Ports Strategy is broadly aligned with this direction through its focus on interoperability, public-private cooperation and

innovation uptake, including under the 2028–2034 Horizon Europe Framework Programme. The analysis nevertheless points to three areas requiring continued EU-level attention: supporting the deployment and transfer of proven solutions across ports with different levels of digital maturity; strengthening interoperable port-hinterland and supply-chain data exchange; and providing stable governance and investment conditions for sustained digital transformation.

6. HINTERLAND CONNECTIVITY

KEY FINDINGS

- **Port-hinterland connectivity is a core determinant of EU port competitiveness, decarbonisation and resilience**. Formal TEN-T connection is insufficient where last-mile access, terminal capacity, interoperability or cross-border coordination remain weak.
- **Multimodal integration remains uneven**. Performance depends on reliable interfaces among rail, inland waterways, road, terminals, data exchange and corridor coordination, including the conditions for synchromodal operation.
- **Stakeholders identify recurring bottlenecks in rail and last-mile access, back-port and intermodal-terminal capacity, data exchange and shared-infrastructure coordination**.
- **Dual-use requirements create specific infrastructure needs at strategic ports and corridors**, including heavy-load capacity, staging and marshalling space, technical compatibility, route continuity and redundancy.
- **EU funding instruments are relevant but fragmented**. Smaller ports and integrated port-access packages face access and project-preparation barriers.
- The **EU Ports Strategy** provides a strong policy basis, addressing rail and inland waterway access, multimodality, data sharing, resilience, dual-use infrastructure and access to finance. However, it remains broad on how these elements should be integrated, implemented and monitored at corridor level.

6.1. Context

6.1.1. Scope and policy relevance

This chapter examines **port-hinterland connectivity as a key infrastructure dimension** of the European port system and focuses on how ports are integrated with road, rail and inland waterway networks through transport corridors, intermodal infrastructure and logistics systems that support freight movements between ports and inland markets. The analysis emphasises effective multimodal integration, including the conditions that can enable more coordinated and synchromodal use of available transport models. It also considers the transport infrastructure requirements created by dual-use and resilience needs, where port access routes and hinterland links are strategically relevant, while finally examining whether existing EU financial instruments are sufficient to support multimodal, resilient and strategically relevant port-hinterland connectivity.

Port-hinterland connectivity is relevant to three policy objectives that are central to the EU port agenda, namely **competitiveness, decarbonisation and resilience**. Efficient inland links allow ports to serve markets and logistics chains, while interfaces with rail, inland waterways and short sea shipping support modal shift, and recent disruptions have increased the strategic relevance of ports and hinterland corridors for continuity of supply and military mobility (European Commission, 2020; European Commission, 2022b; European Commission, 2026b).

6.1.2. EU policy framework and implementation gap

The EU policy framework is shaped by the revised TEN-T Regulation, the 2026 EU Ports Strategy, the Sustainable and Smart Mobility Strategy, the Action Plan on Military Mobility 2.0, the Critical Entities Resilience Directive and the NIS2 Directive. At the same time, the 2026 EU Ports Strategy represents the main policy anchor for this chapter because it places hinterland links, rail and inland waterway access, small and medium-sized ports, digital data exchange, dual-use infrastructure and access to finance within the same competitiveness and resilience agenda (European Commission, 2026b).

These instruments collectively link port-hinterland connectivity to corridor integration, modal shift, interoperability, dual-use readiness, infrastructure resilience and cybersecurity preparedness (European Parliament & Council of the European Union, 2022a, 2022b, 2024a), although implementation gaps remain regarding terminal information, cross-border coordination, and monitoring of modal-shift outcomes and the **difference between formal TEN-T connection and effective multimodal performance** (European Court of Auditors, 2023).

More broadly, direct connectivity alone does not capture effective multimodal hinterland connectivity, which also depends on transfer connections and multimodal routes (Harter et al., 2022). The growing role of real-time information and coordinated capacity use also means that effective connectivity increasingly depends on operational and digital integration across modes, not only on physical access. The main EU instruments therefore perform complementary functions:

- **TEN-T:** physical connectivity, network standards and interoperability;
- **Critical Entities Resilience** (CER): resilience and continuity of critical infrastructure and services;
- **NIS2**: cybersecurity of port and corridor digital systems;
- **CEF and Cohesion Policy**: financing and implementation of infrastructure and connectivity improvements.

The **EU Ports Strategy** therefore provides a relevant and substantially stronger policy basis for port-hinterland connectivity. It recognises importance of rail and inland waterway connections, European Maritime Space coordination, transport-chain data sharing, resilience, dual-use infrastructure and access to finance, and it announces concrete follow-up actions in several of these areas.

At the same time, it remains relatively broad on **how these separate measures should be combined and how effective hinterland performance should be assessed, monitored and linked to investment priorities**. In particular, the Strategy does not provide a common operational framework for distinguishing formal network connection from actual multimodal port-corridor performance or for assessing syncromodal coordination across available models. From a European Parliament perspective, the main relevance of this chapter is therefore the scrutiny of whether EU legislation, funding instruments and Commission follow-up actions translate the Strategy's objectives into measurable improvements in connectivity, interoperability and resilience.

6.1.3. Dimensions of port-hinterland connectivity

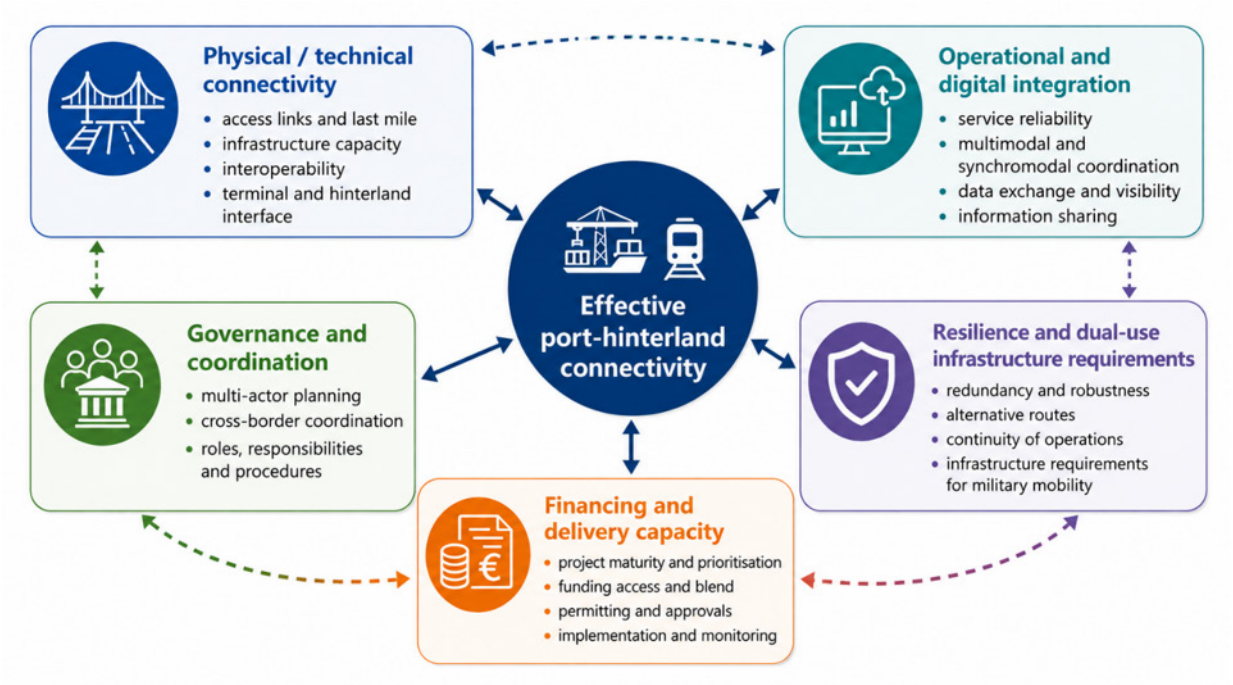
Port-hinterland connectivity is multidimensional and **cannot be assessed only by the existence of a road, rail or inland waterway link** A recent work on multimodal hinterland service networks shows that connectivity is not only a local property of direct links but also depends on transfer opportunities, multimodal routes and the position of ports within wider hinterland networks (Harter et al., 2022). More generally, port connectivity depends on the integration and capacity of maritime, port and hinterland transport components (Indriastiwi et al., 2021). A port may therefore be formally connected to the TEN-

T network but still face practical limitations if access routes are congested, terminal and transhipment capacity is insufficient, technical standards are incomplete, or logistics actors are poorly coordinated (European Court of Auditors, 2023). For this reason, the assessment of hinterland connectivity needs to combine physical, technical, operational, digital governance, resilience and financing considerations.

Physical and technical connectivity concern the availability, capacity and interoperability of inland links. Operational performance can be assessed through measures of transport-chain and terminal efficiency (Saeedi et al., 2019; Saeedi et al., 2022), while effective digital and operational performance also depends on accessible terminal and network-capacity information and coordination among relevant actors (European Court of Auditors, 2023).

These are also the conditions that can enable more flexible synchromodal use of transport modes where sufficient information and capacity are available. Resilience and dual-use readiness concern the infrastructure capacity of selected corridors to absorb disruption, provide alternative routing options and support strategic movements where required, whereas financing and delivery capacity determine whether identified bottlenecks can realistically be addressed. These dimensions and their interaction are summarised in Figure 15, which provides the assessment framework used in the following sections.

Figure 15: Port-hinterland connectivity assessment framework



Source: Authors' own elaboration.

Against this background, the chapter first examines the practical integration of ports with rail, road and inland waterway systems, with particular attention to multimodal and synchromodal coordination. It then considers the transport infrastructure arising from dual-use and resilience needs on strategically relevant port-hinterland corridors before assessing whether existing EU financial instruments and investment mechanisms are sufficient to deliver the required connectivity, interoperability and resilience upgrades.

6.2. Multimodal port connectivity and hinterland integration

6.2.1. Policy and analytical framing

Hinterland connectivity is widely recognised as a key determinant of port competitiveness, as the quality, efficiency and integration of inland transport and logistics networks strongly influence port performance and accessibility to inland markets (Deshmukh & Song, 2025; Sdoukopoulos & Boile, 2020). This analysis focuses on the connectivity of EU ports, including both TEN-T and non-TEN-T ports, with road, rail and inland waterway systems, as components of an integrated multimodal network.

Port connectivity can be assessed across maritime connectivity, port-hinterland connectivity and connectivity at the port, considering infrastructure and service-network characteristics such as time, capacity and accessibility (Indriastiwi et al., 2021). Two related concepts are particularly relevant to the analysis:

- **Multimodality** combines the strengths of different transport modes within the same freight chain, enabling maritime, road, rail and inland-waterway transport to perform complementary functions.
- **Synchromodality** goes further by coordinating the use of available modes, routes and capacity and, where operationally feasible, allowing flows to be adjusted in response to real-time information and changing network conditions (Zhang & Pel, 2016).

Ports are particularly suitable nodes for this approach, because maritime, road, rail and inland-waterway flows converge terminal and logistics operations. In this context, the revised TEN-T Regulation and the 2026 EU Ports Strategy highlight the need for investments addressing hinterland bottlenecks, cross-border connectivity gaps and interoperability standards across European port and logistics networks (European Commission, 2026b, 2026d; European Parliament & Council of the European Union, 2024a).

The **EU Ports Strategy** is particularly explicit on this operational dimension, linking port performance to the upcoming European Maritime Space work plan, stronger rules on access to rail service facilities, a future Action Plan on Inland Waterway Transport for 2028–2034 and EU guidelines for efficient data sharing in the transport chain. The Strategy therefore covers most of the main building blocks of multimodal port-hinterland connectivity. However, these actions are still largely presented through individual modes or instruments, and the Strategy is less specific on how they should be combined and monitored as a single port-hinterland system. In particular, it does not establish common indicators for effective multimodal corridor performance or explicitly develop the synchromodal use of real-time data and available capacity across modes.

The European Court of Auditors, (2023) had already identified implementation weaknesses in EU intermodal freight transport. Against this background, although the 2026 Ports Strategy addresses several relevant components, it does not establish a common framework for assessing synchromodal corridor performance.

The Critical Entities Resilience Directive broadens the resilience frame for transport-related critical entities by requiring Member States to identify and strengthen critical entities across key sectors, including transport, energy and digital infrastructure (European Parliament & Council of the European Union, 2022b).

The analysis of multimodal port connectivity needs to account for **the diversity of the European port system and the different connectivity functions performed by different types of ports and nodes**:

- **Large gateway ports** generally require high-capacity rail and inland waterway links to serve deep hinterlands and maintain reliable access to international supply chains.
- **Inland ports and inland terminals** function as consolidation and distribution nodes within longer logistics chains, often extending the operational reach of maritime ports (Gleser et al., 2023; Rožić et al., 2025).
- **Small and medium-sized ports** remain important for island, remote and outermost regions and specialised markets (European Commission, 2026b), although some may face difficulties generating sufficient volumes for frequent dedicated rail or barge services.

The assessment below therefore considers modal infrastructure together with the **interfaces, terminals, data and coordination** that determine whether those modes can function as an integrated system.

6.2.2. Modal and port-corridor integration

Effective multimodal integration depends not only on the availability of road, rail and inland waterway connections, but on how effectively these modes interact across the port–hinterland corridor. The critical points are therefore the interfaces between port terminals, inland terminals, transport services and corridor infrastructure, where capacity, interoperability, reliability and coordination determine whether different modes can function as an integrated system (Karam et al., 2023).

- **Rail** is particularly relevant for high-volume and long-distance hinterland flows. Effective port–rail integration requires coordination between terminal handling, train formation, timetabling and hinterland operations (Hu et al., 2019), together with adequate port rail infrastructure, operational capacity and path allocation (ERA, 2022). The revised TEN-T Regulation strengthens relevant network requirements, including 740 m freight-train capability, ERTMS deployment, electrification and axle-load standards (European Parliament & Council of the European Union, 2024a). However, short tracks, constrained terminal layouts and insufficient last-mile capacity can prevent wider corridor upgrades from translating into improved multimodal performance (ERA, 2022).
- **Inland waterways**, where geographical conditions allow, complement rail and road by providing high-capacity connections between seaports, inland terminals and industrial regions (Calderón-Rivera et al., 2024). Their contribution depends on reliable navigability, terminal interfaces and service availability. Water-level variability and limited predictability can reduce operational reliability, reinforcing the value of forecasting, information exchange and alternative routing options within the wider multimodal network (Czermański et al., 2026; Lamei et al., 2026).
- **Road** remains essential for first- and last-mile movements, short-distance distribution and flows for which rail or inland waterways are operationally or commercially unsuitable.

The policy challenge is therefore not to optimise each mode in isolation, but to ensure that modes can operate as complementary components of the same logistics system. This requires efficient transfer points, sufficient terminal and corridor capacity, interoperable infrastructure, reliable services and accessible information on available routes and capacity. The European Court of Auditors (2023) identified gaps in information on intermodal terminals and real-time capacity as barriers to effective intermodal transport. Strengthening these interfaces also creates the operational basis for synchromodal transport, where cargo can, where feasible, be allocated or redirected across modes according to capacity, reliability and network conditions.

6.2.3. Inland terminals and synchromodal coordination

Dry ports, inland terminals and intermodal logistics platforms are important instruments for improving port-hinterland integration as they extend port functions inland, enable consolidation of cargo flows, reduce pressure on port land and support more regular rail and inland waterway services. Their successful integration depends on effective multimodal connections, cargo aggregation and logistics functions, customs services and collaboration between ports, terminal operators, transport operators and other stakeholders (Rožić et al., 2025). These nodes are also key interfaces for synchromodal operation, because they can combine cargo consolidation with information on available rail, barge and road services.

At ports and inland terminals, synchromodal coordination depends in particular on:

- visibility of terminal slots and expected arrival times;
- information on available transport capacity and disruptions;
- interoperable data exchange; and
- sufficient operational flexibility to adjust routing.

This does not mean that every flow can be switched dynamically between modes; **synchromodal flexibility remains constrained by available services, schedules and network capacity** (Zhang & Pel, 2016). In this sense, multimodal integration is not only an infrastructure issue but also a logistics and governance issue. A key limitation in current policy assessment is that modal split is often used as a proxy for multimodal performance, although it does not fully explain why some ports achieve stronger rail or inland waterway shares than others, and modal split should therefore be interpreted together with indicators of infrastructure quality, technical compliance, service reliability, terminal capacity, information availability and corridor integration. A port with low rail share may face physical bottlenecks, weak demand aggregation, limited-service frequency, regulatory barriers or poor coordination with infrastructure managers, whereas a port with high rail or inland waterway share may still face resilience risks if it relies on a limited number of corridors or lacks alternative routes.

6.2.4. Effective multimodal integration and remaining bottlenecks

Overall, port infrastructure integration with road, rail and inland waterways remains uneven across the European port system. Many major ports are formally connected to rail and inland networks, and some seaports achieve high rail shares in hinterland traffic. However, **formal network connectivity does not necessarily translate into effective multimodal integration**, which continues to be affected by infrastructure, operational, coordination and information constraints.

Evidence from the literature and existing assessments highlights several recurring issues:

- **Rail and last-mile infrastructure remain important constraints**. Bottlenecks include insufficient terminal and shunting capacity, incomplete electrification and uneven interoperability. The European Court of Auditors (2023) similarly identified delays in meeting TEN-T technical requirements as an EU-wide barrier.
- **Available infrastructure is not always translated into its full modal-shift potential**. Between 2019 and 2022, the actual rail share was 47% for Koper and above 50% for Trieste, whereas the modelled economically optimal shares were substantially higher at 72% and 64% respectively (Zgonc & Jakšič, 2025). More broadly, North Adriatic ports such as Koper, Rijeka and Trieste have expanded towards more distant hinterland markets where combined transport should be

economically attractive, but underdeveloped rail infrastructure continues to limit actual modal-shift potential.

- **Information and coordination gaps affect effective integration**. Incomplete information on intermodal terminals and real-time capacity, fragmented corridor coordination and limited availability of reliable modal-split and terminal-capacity data constrain both planning and operations (European Court of Auditors, 2023).
- **The nature of the bottleneck differs across port regions**. Inland-waterway reliability is particularly relevant for ports dependent on river systems (Calderón-Rivera et al., 2024; Czermański et al., 2026), whereas rail and last-mile capacity may constitute the more important constraint in other regions (ERA, 2022; European Court of Auditors, 2023).

Stakeholder consultation for this study reinforced these findings across different port regions and stakeholder groups. Recurring bottlenecks identified by stakeholders included (Port administration 9, 11 & 12; EU Sector organisation 7 & 9):

- **insufficient railway infrastructure and electrification**, together with weak last-mile access in port cities;
- **poor coordination with the TEN-T network**, limited backport and intermodal-terminal capacity, terminal congestion; and
- **fragmented data exchange**.

Stakeholders also emphasised (EU Sector organisation 1 & 9, Port administration 17):

- the need to **focus on the weakest link across the transport network** rather than on isolated infrastructure assets; and
- the difficulty of applying **uniform EU-level modal-shift targets** across ports with different geography, cargo mixes, ownership structures and hinterland options.

Taken together, literature, the European Court of Auditors (2023) and the stakeholder evidence indicate a remaining **implementation gap between formal network connection from effective port-hinterland integration**. A port may be connected to the TEN-T network but still face practical constraints in last-mile rail access, terminal capacity, shunting operations, inland terminal links, data exchange or cross-border coordination.

The 2026 EU Ports Strategy addresses several of these components through stronger rail-service access rules, an inland-waterway action plan, European Maritime Space coordination and transport-chain data-sharing guidelines, but it does not yet provide a common framework for monitoring whether these measures translate into reliable multimodal or synchromodal corridor performance. This supports a more integrated monitoring and investment logic that focuses on **the weakest links in the whole port-hinterland chain rather than on isolated infrastructure assets**.

6.3. Dual-use Infrastructure and strategic resilience

6.3.1. Infrastructure requirements for military mobility

European ports and hinterland transport networks need to support both commercial logistics and, where strategically relevant, military mobility requirements. Since the Russian war of aggression against Ukraine, the EU military mobility agenda has accelerated, shifting attention from general dual-use planning towards the practical ability to move troops, equipment and military assets quickly across borders (European Commission, 2022b; EPRS, 2025). The 2025 Military Mobility Package further

develops this agenda through harmonised rules for cross-border military movements, shorter processing time and streamlined customs formalities (EC, 2025e).

The infrastructure scale of the challenge is also significant: the White Paper for European Defence Readiness 2030 identifies four priority multimodal corridors and around 500 urgent hot-spot projects, including railway tunnels, widening reinforcement of road and railway bridges and expansion of port and airport terminals (European Commission & High Representative, 2025). Academic work likewise points to rail-gauge compatibility, interoperability and infrastructure-capacity constraints in military transport networks (Manolache, 2024). The revised TEN-T Regulation strengthens the link between TEN-T infrastructure and dual-use requirements (European Parliament & Council of the European Union, 2024a). These developments translate into specific technical and capacity requirement for ports and their connecting corridors.

Box 6: Dual-use requirements for ports

For ports, **dual-use requirements primarily concern whether existing or planned civilian infrastructure can accommodate strategic military movements under specific conditions**. Three aspects are particularly relevant:

- **Infrastructure and handling capacity**. Relevant assets include port access roads, rail links, quays and terminals, marshalling and staging areas, bridges, tunnels, loading facilities, inland terminals and the connecting cross-border corridors. Military mobility can impose requirements that differ from regular commercial freight, including load-bearing capacity, loading gauge and axle-load requirements, capacity for abnormal or outsized movements, and sufficient infrastructure resilience and routing options (European Commission & High Representative, 2025; EC, 2025e).
- **Rail and technical interoperability**. Rail is particularly important for moving large volumes of heavy equipment over long distances, but its effectiveness depends on technical compatibility across the full route, including last-mile port access, terminals and cross-border sections. Where these requirements are not met, movements may require transhipment, rerouting or infrastructure adaptations (EPRS, 2025; Manolache & Manolache, 2024).
- **Corridor-level coordination**. Infrastructure upgrades need to be coordinated across the corridor, so that improvements to individual port assets do not leave bottlenecks on connecting road or rail sections, as also emphasised by the Action Plan on Military Mobility 2.0 (European Commission, 2022b).

Source: Authors.

Table 11 summarises the main infrastructure requirements and their implications for planning and funding. The **policy challenge is to ensure that infrastructure designed for commercial freight efficiency can also contribute to defence readiness and crisis response where strategically relevant, without undermining the normal functioning of civilian logistics**. Dual-use readiness is also affected by administrative and procedural barriers, since cross-border permissions, customs procedures, dangerous goods rules, abnormal-load authorisations and priority arrangements may create delays even where the infrastructure itself is technically adequate.

Table 11: Dual-use requirements and implications for port-hinterland infrastructure

Requirement	Infrastructure/governance implication	Strategic funding use
Heavy or oversized movements	Reinforced bridges, quays, roads and rail access; suitable loading gauge, axle load and handling equipment.	Assess dual-use needs at design stage to avoid costly retrofits.
Secure separated operations	Dedicated areas, controlled access and traffic management to avoid conflicts between civilian freight and strategic movements.	Use grants for capacity that serves public infrastructure resilience needs.
Rapid cross-border movement	Simplified authorisations, customs coordination, dangerous-goods procedures and predictable corridor routing.	Combine TEN-T, CEF and military mobility appraisal for infrastructure and procedural readiness.
Network redundancy and cyber-secure coordination	Alternative routes, modal options and protected data exchange between port, infrastructure, logistics and public authorities.	Prioritise corridors where upgrades improve civilian resilience and strategic mobility simultaneously.

Source: Synthesis using European Commission (2022), European Commission & High Representative (2025), European Court of Auditors (2025), Manolache & Manolache (2024) and stakeholders' interviews.

6.3.2. Port- corridor planning and proportionality

Dual-use capability depends on the continuity of the whole route, not on the port alone. A port or terminal may be technically capable of handling military equipment, but movements can still be constrained by downstream bridge capacity, tunnel or loading-gauge limitations, rail compatibility, last-mile access or unavailable alternative routes.

The European Court of Auditors (2025) found design, coordination and monitoring weaknesses in the EU military mobility framework, reinforcing the need to assess infrastructure at corridor level. The EU Ports Strategy partly addresses this through the European Maritime Space coordinator, who is expected to facilitate resilience planning for maritime and hinterland connectivity with other European Transport Corridor Coordinators, while the revised TEN-T framework provides the principal basis for aligning port and corridor infrastructure. The Critical Entities Resilience Directive also reinforces prevention, business continuity and recovery capacity for critical transport entities, including measures to maintain essential services during and after disruptive incidents (European Parliament & Council of the European Union, 2022b). **The infrastructure implication is that dual-use requirements should be considered at corridor level and, where relevant, at project-design stage rather than through isolated port upgrades**.

Stakeholder consultation for this study confirmed that **the main port-hinterland implications of dual use concern infrastructure capacity and corridor continuity**. Stakeholders highlighted corridor redundancy, storage and marshalling space, reinforced quay and bridge infrastructure, suitable rail equipment and cross-border route continuity, while also noting that some military-mobility adaptations create strategic public benefits without direct commercial returns (EU Sector organisation 1, 6, 7 & 9; Expert 6; Port administration 3, 12 & 14). These findings reinforce the importance of integrating relevant dual-use requirements into normal infrastructure planning and of ensuring that funding can cover strategically necessary adaptations that may not be commercially bankable.

The infrastructure approach also requires proportionality because not every port or hinterland corridor needs the same level of military-mobility readiness. This conclusion is supported by the

stakeholder consultation, which stressed that port functions, geography, infrastructure conditions and strategic roles differ significantly (EU Sector organisation 1; Port administration 12 & 14). Dual-use planning may also need to consider the potential security and resilience implications of concentrating civilian and military functions within the same infrastructure. In periods of heightened geopolitical tension or conflict, the strategic use of major commercial ports and corridors could alter their risk profile, particularly where critical civilian supply chains or nearby populations may also be affected. This further reinforces the importance of redundancy, alternative routes and continuity arrangements when assessing dual-use infrastructure needs. Prioritisation should therefore reflect:

- strategic location and corridor relevance;
- connection to external borders;
- proximity to relevant military logistics routes;
- availability of alternative routes; and
- the role of the port in critical supply chains.

This helps concentrate limited funding on infrastructure where dual-use adaptations produce corridor-level benefits rather than dispersing resources across ports with limited strategic relevance.

6.4. Financial instruments and investments

6.4.1. Investment needs and funding landscape

A structured review of EU financial instruments shows how existing funding mechanisms support multimodal port integration, dual use infrastructure, and port-hinterland connectivity across TEN-T and non-TEN-T ports, although current evidence suggests that **funding remains unevenly accessible, particularly for smaller ports** (de Langen, 2025; ESPO, 2024; European Commission, 2026c, 2026n).

The EU Ports Strategy also recognises access-to-finance and advisory needs, with particular attention to small and medium-sized ports (European Commission, 2026b, 2026n). The 2026 EU Ports Strategy cites ESPO's estimate of around **EUR 80 billion in investment needs of European port managing bodies for the period 2024–2034** (European Commission, 2026b; ESPO, 2024) This represents an estimate of the investment pipeline of port managing bodies rather than an EU budget envelope and does not include the full scale of private-sector port investment or maintenance expenditure.

These needs cover port capacity, sustainability, energy transition, digitalisation, resilience and connectivity. Earlier ESPO analysis shows that **18% of planned port investment projects relate specifically to transport connectivity to the hinterland**, including road, rail, inland waterway connections and intermodal/multimodal terminals, while rail-related investment needs may account for up to 20% of total port needs (ESPO, 2019; ESPO & EFIP, 2019).

Recent years have seen a relative shift in the composition of planned investments with sustainability and energy-transition projects taking a larger share of the pipeline, while hinterland-connectivity categories represent a smaller share in the more recent investment pipeline, (ESPO, 2024), as summarised in Table 12.

Table 12: Main changes in planned port investment priorities

Investment area	Main observation
Port basin, quay and terminal expansion	Remains one of the largest investment priorities.
Sustainability and energy-transition infrastructure	Has become much more prominent in recent investment plans.
Rail, road and inland waterway connections	Remain relevant but appear less dominant than core port capacity and energy-transition investments.
Intermodal terminals and digital infrastructure	Important supporting areas for more efficient and multimodal port operations.

Source: Synthesis using ESPO (2019; 2024) and ESPO & EFIP (2019).

Since 2014, EU instruments have supported port-related projects across energy, sustainability, connectivity, innovation and other areas. The main funding figures relevant to the assessment include:

- **EU support to port-related projects since 2014**: approximately EUR 10 billion for deployment and more than €200 million for research and innovation, as reported in the 2026 EU Ports Strategy (European Commission, 2026b).
- **CEF Transport 2021-2027**: EUR 25.8 billion is available under the current Connecting Europe Facility for Transport, including a EUR 1.69 billion Military Mobility envelope, which was fully allocated through the 2021–2023 calls (CINEA, 2022, DG MOVE, 2024).
- **Proposed CEF 2028-2034**: for the next Multiannual Financing Framework (MFF), the Commission proposal foresees EUR 51.5 billion for transport, including EUR 17.5 billion for military mobility. These financial provisions remain subject to the MFF negotiations (DG MOVE, 2025).

Overall, the scale of the identified port investment pipeline compared with available EU instruments reinforces the need to prioritise projects with clear European added value and to combine EU, national and private financing where appropriate.

6.4.2. From separate instruments to integrated port-access packages

The investment challenge involves not only the overall volume of funding but also the **alignment between funding instruments and the type of port-hinterland projects** that need to be delivered, and this alignment is particularly important because port managing bodies face changing investment drivers, financial bottlenecks and different levels of dependence on public funding depending on their ownership and governance model (de Langen, 2025).

Port-hinterland connectivity projects are often complex because they involve multiple assets, promoters and jurisdictions, as an integrated port-access package may combine rail or inland waterway access, road last-mile links, terminal interfaces and digital traffic management, involving a port managing body, terminal operator, infrastructure manager, municipality and corridor authority. **This multi-actor structure makes project preparation more demanding and can delay implementation**, particularly where benefits are distributed across several users while costs are concentrated on one infrastructure owner.

Table 13: Role of EU funding instruments in integrated port-access packages

Funding instrument	Potential role in port-hinterland connectivity	Main considerations
CEF Transport / TEN-T	Bottleneck removal, cross-border connectivity, interoperability, rail and last-mile access, inland-waterway infrastructure, multimodal terminals and TEN-T-related digital traffic management.	Particularly relevant where projects demonstrate clear European added value. Competitive and administratively demanding procedures may create challenges for smaller and medium-sized ports in project preparation, co-financing and demonstrating European added value (European Commission, 2026n; European Parliament & Council of the European Union, 2024a).
Cohesion Policy / ERDF	Port access, regional rail and road links, multimodal terminals and inland connections addressing accessibility and territorial-cohesion needs.	Particularly relevant for peripheral, island, eastern and south-eastern regions. Port-hinterland projects need to be sufficiently embedded in national transport plans, TEN-T implementation strategies or regional development priorities.
Military mobility funding	Adaptation of roads, railways, bridges, terminals and ports to proportionate civilian-defence dual-use requirements on strategically relevant corridors	Particularly relevant for strategic corridors, external borders and routes towards the EU's eastern flank. Future appraisal could better integrate civilian transport benefits, military requirements and resilience objectives (European Commission & High Representative, 2022; European Court of Auditors, 2025).
EIB / InvestEU and blending	Financing of bankable components of integrated infrastructure packages and mobilisation of complementary investment.	Can complement grants and other public support, particularly where projects combine commercially viable components with wider public benefits.

Source: Authors' own elaboration.

The resulting policy challenge is therefore not simply to increase funding, but to combine instruments around the function of each project within the wider port-hinterland corridor. An integrated approach could:

- use **TEN-T and CEF as the main framework for bottleneck removal, interoperability and cross-border port access**;
- use **Cohesion Policy and ERDF to address accessibility gaps**, particularly in peripheral, island, eastern and smaller-port regions;
- **target military mobility funding at proportionate dual-use requirements** on strategically relevant corridors;
- **mobilise EIB/InvestEU and blending for bankable components**, complemented by grants and technical assistance where projects generate high public value but limited direct revenue; and
- **link funding more closely to corridor-level outcomes**, including effective multimodal integration and modal-shift performance, rather than focusing primarily on individual project outputs.

This approach would also respond to the European Court of Auditors' finding that EU-funded intermodal projects were not sufficiently linked to modal-shift results and that monitoring often focused on outputs rather than long-term impacts (European Court of Auditors, 2023).

6.4.3. Funding barriers and future alignment needs

Stakeholder consultation for this study confirmed that funding barriers are not only financial. Stakeholders (EU Sector organisation 1, 2 & 7; Port administration 3, 9 & 14; Expert 1 & 2) referred in particular to:

- unclear eligibility rules;
- long state-aid and permitting procedures;
- limited administrative capacity in smaller ports; and
- difficulties financing integrated port-access packages combining last-mile rail, retroport facilities, digital systems and energy infrastructure.

However, the financing gap is **not only a question of funding volume**, but also of how EU instruments are aligned with the type of projects that need to be delivered. Port-hinterland projects often combine commercial, environmental, territorial-cohesion, resilience and dual-use benefits, while the costs and responsibilities are spread across different actors, and consequently some strategically important projects may not be sufficiently bankable, mature or eligible under existing funding routes.

Future EU support therefore needs to move beyond a simple list of instruments and focus on how CEF, Cohesion Policy, military mobility funding, EIB/InvestEU, grants and technical assistance can be combined to deliver integrated port-access packages.

The 2026 EU Ports Strategy moves in this direction by recognising access-to-finance constraints and capacity-building needs, particularly for small and medium-sized ports. However, it remains less specific on how funding prioritisation will assess whole-corridor multimodal performance and link project outputs to outcomes such as modal shift, service reliability and resilience. This remains important in light of the European Court of Auditors' finding that EU-funded intermodal projects were not systematically linked to modal-shift results or monitored for long-term impacts (European Court of Auditors, 2023).

6.5. Conclusions

6.5.1. Thematic assessment of the EU Ports Strategy

The EU Ports Strategy provides a strong policy basis for improving port-hinterland connectivity by addressing rail and inland waterway access, multimodality, data sharing, resilience, dual-use infrastructure and access to finance. However, **it remains broad on how these elements should be integrated, implemented and monitored at corridor level**.

Formal TEN-T connection does not necessarily translate into effective connectivity. Performance also depends on last-mile access, terminal capacity, technical interoperability, service reliability, data exchange and cross-border coordination. The Strategy would therefore benefit from a common monitoring framework distinguishing network inclusion from effective multimodal performance, with indicators covering reliability, modal shift, interoperability and resilience.

Dual-use requirements similarly need to be considered across the whole port-hinterland corridor, since **isolated port upgrades may have limited value where downstream infrastructure remains**

constrained. Investment should therefore be proportionate and targeted at strategically relevant ports and corridors.

Finally, existing EU financial instruments are relevant, but **funding remains fragmented across instruments and implementation routes**, while project-preparation requirements can disadvantage smaller ports. Better coordination between CEF, Cohesion Policy, military mobility funding, EIB/InvestEU, grants and technical assistance could support more integrated port-access investments.

6.5.2. Key takeaways

- **Effective port-hinterland connectivity depends on the performance of the entire transport chain**, not simply on whether a port is formally connected to the TEN-T network. Last-mile access, terminal and shunting capacity, technical interoperability, service reliability, data exchange and cross-border coordination all influence whether infrastructure connections translate into effective multimodal access. **Investment should therefore focus on the weakest links in port-hinterland corridors**. Improvements within the port have limited value where rail access, inland-waterway connections, intermodal terminals or downstream infrastructure remain constrained, making coordinated corridor-level planning essential for improving overall performance.
- **Multimodal and, where feasible, synchromodal integration requires more than physical infrastructure**. Reliable interfaces between rail, road, inland waterways, terminals and logistics operators need to be supported by operational coordination and timely information exchange so that cargo flows can be managed efficiently across modes and adapted when disruptions occur.
- **Monitoring should move beyond formal network connection and modal-split indicators towards a broader assessment of effective connectivity**. Capacity, service reliability, technical and operational interoperability, cross-border performance and resilience provide a more complete basis for identifying bottlenecks and assessing whether investment improves corridor performance.
- **Dual-use infrastructure requirements should be assessed across complete port-hinterland corridors and applied proportionately according to strategic relevance**. Upgrading individual port assets will provide limited additional capability if connecting rail, road or inland-waterway infrastructure remains constrained; dual-use considerations should therefore be integrated into wider TEN-T, resilience and investment planning.
- **Existing EU financial instruments provide a substantial basis for port-hinterland investment, but fragmentation across funding sources and project-preparation requirements can hinder integrated delivery, particularly for smaller ports**. Better coordination between CEF, Cohesion Policy, military-mobility funding, EIB/InvestEU, grants and technical assistance could support integrated port-access packages addressing infrastructure, terminals and digital systems together.
- **The EU Ports Strategy provides a strong policy basis for improving hinterland access, multimodality, resilience, dual-use infrastructure and financing**. Its effectiveness will depend on translating these objectives into measurable corridor-level implementation, supported by clearer performance monitoring, coordinated investment and attention to the varying needs and capacities of European ports.

7. STRATEGIC FRAMEWORK FOR STRENGTHENING THE COMPETITIVENESS OF EU PORTS AND COMPARATIVE ASSESSMENT

KEY FINDINGS

- **Port competitiveness extends beyond cargo volumes** to shipping services, logistics and industrial functions, investment, connectivity, resilience and energy-transition capabilities.
- **Three strategic priorities structure the assessment**: integrated governance and long-term planning; coordinated investment, digitalisation and innovation; and logistics ecosystems, industrial integration and resilient connectivity.
- **Singapore and Tanger Med illustrate different competitiveness models**, combining maritime connectivity with, respectively, integrated planning and maritime services, and coordinated port–logistics–industrial development.
- **Leading EU ports already demonstrate many comparable capabilities**, but often through different institutional arrangements and mature infrastructure systems; the key challenge is stronger coordination, sequencing, interoperability and deployment.
- **Transferability varies by port function, cargo market and region;** the framework therefore supports differentiated EU action rather than a single port-development model.

7.1. Strategic framework for strengthening the competitiveness of EU ports

Drawing on Chapter 2's assessment of global competitiveness, stakeholder consultation and literature on port competitiveness, governance and port regionalization, the framework translates terminal offerings, management strategies and the external environment into three mutually reinforcing priorities (Table 14). These cover competition for cargo and shipping services and ports' capacity to attract logistics activities, industrial and energy investment, innovation and strategic supply-chain functions (Notteboom & Rodrigue, 2005; Parola et al., 2017; European Commission, 2026; Yu et al., 2025).

Table 14: Strategic framework for strengthening EU port competitiveness

Strategic priority	Chapter 2 basis	Purpose	Principal policy and competitiveness levers
Integrated governance, competitiveness monitoring and long-term planning	Management strategies and external environment	Establish the institutional and strategic capacity to coordinate port development, anticipate changes in competitive conditions and maintain a coherent long-term development direction.	Governance and responsibilities; multilevel coordination; strategic and spatial planning; concession and land policy; market intelligence; stakeholder coordination; skills and risk management.

Strategic priority	Chapter 2 basis	Purpose	Principal policy and competitiveness levers
Coordinated investment, digital transformation and innovation deployment	Terminal offerings and management strategies	Develop physical, digital, energy and resilience capabilities as complementary components of port development and facilitate the transition of innovation from testing to operational use.	Infrastructure and superstructure; digital systems; Port Community Systems; automation; interoperability; cybersecurity; innovation ecosystems; financing and permitting; energy and grid access.
Logistics ecosystems, industrial integration and resilient connectivity	External environment and terminal offerings, supported by supply-chain management	Position ports within wider maritime, hinterland, logistics, industrial and energy systems in order to strengthen connectivity, generate value beyond cargo handling and support resilient supply chains.	Maritime and hinterland connectivity; rail, inland-waterway and pipeline access; logistics services and zones; industrial clusters and land; storage and utilities; route reliability; regional port cooperation.

Source: Authors' elaboration based on de Langen (2004), Merk and Notteboom (2015), Parola et al. (2017), Mendes Constante et al. (2023), Yu et al. (2025), ESPO (2024) and European Commission (2026).

The priorities are applied to Singapore and Tanger Med and interpreted across cargo markets, port functions and European maritime regions; they identify strategic capabilities rather than prescribe a uniform development model.

7.1.1. Integrated governance, competitiveness monitoring and long-term planning.

Port competitiveness depends on coordination among port authorities, terminal and infrastructure operators, shipping and logistics companies, customs, industrial firms, energy-network operators and public administrations (de Langen, 2004; OECD, 2014). Four capabilities are relevant:

- **Clear governance and responsibilities**. Responsibilities and cooperation mechanisms should coordinate commercial development with public-policy objectives, irrespective of institutional model.
- **Alignment of port and wider planning**. Development should align with TEN-T corridors, logistics strategies, industrial and energy policies, spatial planning and environmental objectives where infrastructure, hinterland, energy and industrial development are interdependent (OECD, 2014; European Sea Ports Organisation, 2024; European Commission, 2026).
- **Long-term but adaptable strategic planning**. Strategies should provide certainty for long-lived infrastructure and investment while adapting to changing trade, technologies, energy systems and geopolitical conditions.
- **Competitiveness monitoring**. Throughput and market share should be complemented, according to port function, by connectivity, reliability, modal integration, industrial and logistics activity, energy readiness and resilience, with different indicators for container, bulk, Ro-Ro and general-cargo markets.

7.1.2. Coordinated investment, digital transformation and innovation deployment.

Long-term competitiveness also requires coordination between long-cycle infrastructure and faster-evolving digital technologies, energy systems and operating practices, while retaining adaptability to vessel characteristics, cargo patterns, energy carriers, environmental requirements and operational technologies (OECD, 2014; European Sea Ports Organisation, 2024):

- **Coordinated investment planning**. Nautical access, quays, terminals and storage should be planned with hinterland infrastructure, energy networks, digital systems and workforce requirements as one interconnected system (European Commission, 2026).
- **Digital transformation**. Port Community Systems, Maritime Single Windows, terminal operating systems, automation, artificial intelligence, digital twins and data-sharing platforms can improve coordination and visibility when supported by interoperability, data quality, cybersecurity and port-community participation (Klar et al., 2023; Mendes Constante et al., 2023).
- **Solutions adapted to port functions**. Container, bulk, Ro-Ro and general-cargo operations require different combinations of digital coordination, visibility and operational support.
- **Innovation deployment**. Cooperation among port authorities, operators, shipping companies, industrial firms, technology providers and research organisations supports experimentation, but gains depend on moving successful pilots and demonstrations into sustained operation (Mendes Constante et al., 2023; European Commission, 2026).

7.1.3. Logistics ecosystems, industrial integration and resilient connectivity.

Ports increasingly compete within transport corridors, supply chains and industrial ecosystems. Terminal performance also depends on market access, hinterland connections, logistics services, industrial activity and energy infrastructure (Robinson, 2002; Notteboom & Rodrigue, 2005; Merk & Notteboom, 2015):

- **Connectivity beyond the terminal.** Maritime services require rail, road, inland-waterway and pipeline connections, inland terminals, logistics platforms and supporting infrastructure.
- **Logistics and industrial integration.** Ports compete for cargo and vessel calls and for logistics services, manufacturing, industrial and energy investment and other supply-chain functions that can generate stable cargo and strengthen locational attractiveness (de Langen, 2004; Parola et al., 2017).
- **Cargo- and region-specific ecosystems.** Container ports depend on liner connectivity and hinterland reach; bulk ports on storage, pipelines, commodity corridors and industrial demand; Ro-Ro ports on service frequency and corridor reliability; and general-cargo ports on flexible, specialised handling and industrial supply-chain links (Merk & Dang, 2012; de Langen et al., 2016; Turbaningsih, 2022). Geography further differentiates Mediterranean, Northern Range, Baltic, North Sea, Atlantic and Black Sea systems (Eurostat, 2025; UN Trade and Development, 2025; European Commission, 2026).
- **System resilience.** Corridor infrastructure, energy systems, logistics platforms and inter-port cooperation affect the capacity to maintain connectivity and supply chains during disruption.

7.2. Comparative assessment conceptual and methodological approach

The comparative assessment applies the three strategic priorities established in Section 7.1 to Singapore and Tanger Med and compares their approaches with selected EU ports. It first defines international port competitiveness, then considers differences across cargo markets and maritime regions, and finally sets out the comparative method, indicators and case-selection criteria.

7.2.1. International port competitiveness as market position and system capability

International port competitiveness is defined as the capacity of a port and its associated transport, industrial and institutional system to attract, retain and create economically and strategically valuable

cargo flows, shipping services, logistics functions and investment while providing reliable, efficient, resilient and increasingly low-carbon services. This reflects the evolution of ports from cargo-handling locations into nodes within value-driven supply chains and port-industrial systems (Robinson, 2002; Notteboom & Rodrigue, 2005; OECD, 2014).

Competitiveness therefore extends beyond throughput. Cargo volumes remain important, but should be assessed together with connectivity, reliability, value-added functions, investment, industrial activity, resilience and environmental performance (OECD, 2014; Parola et al., 2017).

Two interconnected forms of competition are considered:

- **Traffic- and service-market competitiveness**: competition for contestable cargo, vessel calls, transshipment flows, ferry services and gateway traffic where shipping lines or cargo owners can redirect flows between alternative ports.
- **Ecosystem and strategic-function competitiveness**: competition for logistics activities, maritime services, manufacturing, industrial and energy investment, technology deployment and other supply-chain functions. Connectivity can attract such activities, while industrial and logistics activity can generate cargo and reinforce maritime connectivity (de Langen, 2004; Notteboom & Rodrigue, 2005; Parola et al., 2017).

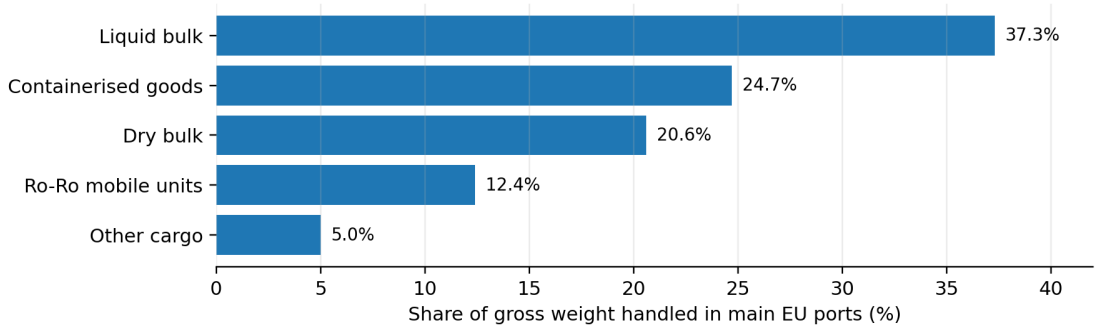
Box 7: International competitiveness and cargo types

International competitiveness does not imply that every port competes globally for the same cargo.

Depending on the port function, international competition may concern mobile cargo and maritime services, access to overlapping hinterlands, or the ability of the wider port system to support internationally competitive industrial, logistics, energy and supply-chain activities.

The structure of EU port traffic (Figure 16) confirms the need for this broader perspective. In 2024, liquid bulk accounted for 37.3% of gross weight handled in the main EU ports, containerised goods 24.7%, dry bulk 20.6% and Ro-Ro mobile units 12.4% (Eurostat, 2025). A framework centred on one cargo type, such as containers, would therefore fail to capture a substantial share of the European port system.

Figure 16: Composition of cargo handled in the main EU ports, 2024



Source: Authors' own elaboration based on Eurostat (2025). Shares refer to gross weight handled in main EU ports.

The three strategic priorities provide a common framework across cargo segments, but their relative importance and practical expression vary by cargo, port function and geographical context (de Langen, 2004; Merk & Dang, 2012; Parola et al., 2017).

7.2.2. Cargo-market and regional differentiation

Cargo markets differ in competitive geography, operational requirements, relevant decision-makers and critical infrastructure. Table 15 summarises how competitiveness is expressed across the principal cargo segments.

Table 15: Competitive arenas across principal cargo segments

Cargo segment	Principal object of competition	Cargo-specific expression of competitiveness
Containers	Liner calls, transhipment flows, gateway cargo and logistics functions within global liner networks, regional hub ranges and overlapping hinterlands.	Nautical access; berth reliability; productivity; service frequency; feeder and inland connectivity; costs; digital coordination; carrier relationships.
Liquid bulk	Energy and chemical flows, storage, refining, bunkering and transition infrastructure, combining global sourcing with regional energy systems and port-industrial clusters.	Pipelines; tank storage; product flexibility; safety; refinery/chemical integration; grid access; alternative-fuel capability; long-term demand certainty.
Dry bulk	Commodity flows and industrial or agricultural corridors, generally linked to particular producers, consumers or hinterlands.	Silos and stockyards; loading systems; rail/inland-waterway capacity; seasonal reliability; environmental controls; proximity to producers or industrial users.
Ro-Ro	Paired ferry services, accompanied/unaccompanied freight and automotive flows within regional routes and multimodal corridors.	Frequency; timetable reliability; sailing time; road/rail access; border processes; yard fluidity; driver conditions; door-to-door cost.
General cargo	General and specialised/project cargo flows, industrial supply chains and associated logistics services in regional, corridor- and industry-specific markets.	Flexible handling and storage; suitable terminal equipment; inland access; skilled labour; cargo visibility; coordination with industrial and logistics supply chains.

Source: Authors' elaboration based on Kaluza et al. (2010), Merk and Dang (2012), Balci et al. (2018), de Langen et al. (2016), Mangan et al. (2002) and Turbaningsih (2022).

These distinctions materially affect port choice and performance. Container shipping operates through comparatively regular liner networks, whereas tanker and dry-bulk movements depend more strongly on commodity and industrial flows (Kaluza et al., 2010). Dry-bulk terminal choice gives particular weight to handling cost, cargo integrity, location, speed, responsiveness and storage capability (Balci et al., 2018); Ro-Ro competitiveness depends strongly on direct connectivity, frequency and route configuration (de Langen et al., 2016; Mangan et al., 2002); and general/project cargo places greater emphasis on specialised handling, inland-route feasibility and operational coordination (Turbaningsih, 2022).

Geography creates a second layer of differentiation. Ports handling similar cargoes may face different competitive conditions because of hinterland structure, neighbouring competitors, industrial specialisation, corridor position and exposure to energy, security or resilience constraints. Table 16 summarises these conditions across the main EU maritime regions.

Table 16: Regional expression of EU port competitiveness

Maritime region	Principal functions	Characteristic competitive conditions and policy issues
Mediterranean	Deep-sea gateways and transhipment; Ro-Ro links; energy imports; industrial and passenger functions.	Competition with North African and eastern Mediterranean hubs; hinterland rail access; Suez/Red Sea exposure; regulatory differences at the EU external maritime boundary.

Maritime region	Principal functions	Characteristic competitive conditions and policy issues
Northern Range	Continental gateways; containers, chemicals, petroleum and dry bulk; dense logistics and industrial clusters.	Overlapping hinterlands; congestion and land scarcity; Rhine and rail resilience; grid capacity; industrial decarbonisation; competition for logistics and energy investment.
Baltic Sea	Ro-Ro and ferries; feeder containers; forest products, grain, fertilisers and energy flows.	Service continuity; winter navigation; feeder dependence; security conditions; rail-gauge and border issues; ferry decarbonisation.
North Sea	Offshore-energy and industrial supply chains; specialised terminal and storage capacity; short-sea services.	Heavy-duty quays and laydown land; grid, hydrogen and CO_2 networks; specialist skills; coordination of construction, fabrication and operational capacity.
Atlantic	Deep-sea and regional gateways; LNG and energy; Ro-Ro, fisheries and multipurpose cargo.	Service frequency and hinterland reach; Iberian and transatlantic corridors; peripheral/island connectivity; energy projects; port-city spatial constraints.
Black Sea	Grain and agricultural bulk; oil products; containers, Ro-Ro and Danube-linked traffic.	Commodity-corridor reliability; Danube, rail and border capacity; security, sanctions and insurance; resilience of trade routes serving the EU's eastern neighbourhood.

Source: Authors' elaboration based on Eurostat (2025), European Commission (2026), ESPO (2024), Merk and Notteboom (2015) and the cargo-specific literature cited in Table 15.

Table 15 and Table 16 are complementary: the first differentiates competitiveness by cargo market, while the second captures the geographical and corridor conditions in which those markets operate. The three strategic priorities remain common, but their relative importance, indicators and implementation must reflect these differences.

7.2.3. Comparative method, indicators and case selection

The assessment applies the same three strategic priorities to Singapore and Tanger Med (Table 17), combining quantitative indicators of market position and operating context with qualitative evidence on governance, investment, digitalisation, connectivity and industrial integration.

The evidence base includes:

- peer-reviewed literature on port competitiveness, governance, connectivity and innovation;
- EU and international policy documents;
- Eurostat and UNCTAD transport and connectivity data;
- official port and terminal statistics;
- port-authority strategies, master plans and investment programmes; and
- evidence on digital systems, industrial/logistics clusters and energy-transition initiatives.

Quantitative indicators characterise competitive position rather than produce a single ranking across fundamentally different port types, since production processes, markets and relevant outputs vary substantially between cargo segments (Merk & Dang, 2012).

Table 17: Application of the strategic framework in the comparative assessment

Strategic priority	Main questions examined	Indicative evidence
Integrated governance, competitiveness monitoring and long-term planning	How is port development coordinated? How is long-term direction established? How are competitive and regulatory changes monitored?	Governance and institutional structure; port-authority mandate; planning; land and concession arrangements; coordination mechanisms; investment pipelines; regulatory and risk-management context.
Coordinated investment, digital transformation and innovation deployment	How are infrastructure, digitalisation, innovation and transition-related investments developed and coordinated?	Terminal and infrastructure capacity; port-call performance; Port Community Systems and other digital platforms; automation; interoperability; innovation programmes; financing; grid and energy-related infrastructure.
Logistics ecosystems, industrial integration and resilient connectivity	How is the port connected to maritime networks, hinterland corridors, logistics systems and industrial or energy clusters?	Throughput and market role; maritime connectivity; rail, road, inland-waterway and pipeline access; logistics zones; industrial clusters; storage and utilities; cargo-generating economic activity.

Source: Authors' methodology, structured according to the strategic framework presented in Table 14. Principal evidence sources include peer-reviewed literature, OECD/ITF studies, Eurostat, UNCTAD, ESPO, the EU Ports Strategy and associated policy documentation, and official port-authority statistics and strategies. Quantitative indicators are interpreted according to cargo and port function (Merk & Dang, 2012).

Selection of the international reference cases

Singapore and Tanger Med were selected as **complementary port models**, based on four criteria:

- international significance and competitive relevance;
- availability of reliable and sufficiently detailed evidence;
- contrasting governance and development pathways;
- relevance to the competitive challenges addressed by the EU Ports Strategy.

The cases are **not treated as models for direct replication**. Rather, they are used to examine how internationally competitive port systems perform against the three strategic priorities, how their practices compare with selected EU ports, and how their relevance changes across the cargo-market and regional conditions identified above (Table 18).

Table 18: Relevance of the use cases selected for the study goals

Singapore	Tanger Med
• Mature global maritime hub with extensive international connectivity. • Major container-transhipment function, but also substantial tanker, bulk, bunkering and maritime-service activities. • Strong integration of long-term planning, infrastructure development, digitalisation, automation and maritime innovation. • Provides a reference for examining global-hub capabilities against leading EU Northern Range gateway and industrial ports.	• Rapidly developed international hub immediately adjacent to the EU. • Major container-transhipment role combined with Ro-Ro, vehicle logistics, bulk activities and manufacturing. • Close integration of port infrastructure, logistics zones, industrial development and investment attraction. • Provides a reference for both direct competition with EU Mediterranean ports and wider competition for logistics and industrial investment.

Source: Authors' own elaboration.

This distinguishes context-specific practices in Singapore and Tanger Med from capabilities already demonstrated by leading EU ports and practices with wider EU relevance. The following sections apply the framework to both cases, with transferability and EU implications assessed jointly in Section 7.5.

7.3. Use case: Port of Singapore

7.3.1. Context and competitive position

The Port of Singapore is a major global transhipment, bunkering and maritime-services hub located at the intersection of the main East–West shipping routes (Figure 17). In 2024, it handled 622.67 million tonnes of cargo and 41.12 million TEU, around 90% of which was transhipment; bulk carriers, container ships and tankers each accounted for about one-third of vessel-arrival tonnage and together over 90% of the total (Maritime and Port Authority of Singapore, 2025).

Figure 17: Main maritime routes and global connectivity of the Port of Singapore



Source: Authors' visualisation based on Maritime and Port Authority of Singapore (MPA) and UNCTAD liner shipping connectivity data.

Its competitive position combines a central location in global shipping networks, extensive feeder connectivity, large-scale container transhipment, rapid vessel servicing, a major bunkering function and a concentration of maritime, professional and technology-related services.

Rotterdam, Antwerp-Bruges and Hamburg are used as EU reference ports because they combine major international gateway functions with extensive hinterland, logistics and industrial activities. The comparison recognises their different roles: Singapore is considerably more transhipment-oriented, whereas the Northern Range ports derive greater competitive value from European hinterland access, industrial clusters and regional cargo generation. This contrast allows the same three strategic priorities to be examined across different competitive models.

Table 19: Comparative positioning of Singapore and major EU Northern Range ports

Indicator	Singapore	Rotterdam	Antwerp-Bruges	Hamburg
2024 cargo scale	622.67 million tonnes; 41.12 million TEU	435.8 million tonnes; 13.8 million TEU	278 million tonnes; 13.5 million TEU	111.8 million tonnes; 7.8 million TEU
Main system role	Global transhipment, bunkering and maritime-services hub; around 90% of container throughput is transhipment	Major European gateway, logistics hub and port-industrial complex handling containers, liquid and dry bulk and breakbulk	Major gateway and integrated maritime-logistics-industrial system; strong container, vehicle, general-cargo, liquid- and dry-bulk functions	Major European gateway with a strong hinterland orientation and significant container, conventional general-cargo and bulk activities
Governance and long-term planning	MPA combines port regulation and planning with development of the international maritime centre and responsibility for digitalisation and decarbonisation initiatives	Port Authority develops and manages the port and industrial area; publicly owned by the municipality of Rotterdam and Dutch State	Public-law port authority owned by the cities of Antwerp and Bruges, managing the Antwerp and Zeebrugge port platforms	HPA is an institution under public law responsible for port infrastructure and related sovereign functions; development guided by the Port Development Plan 2040
Connectivity and wider ecosystem	Global maritime and feeder connectivity; major bunkering role; more than 200 international shipping groups	Extensive rail, road, inland-waterway and pipeline connections to European markets; integrated petrochemical, energy and logistics cluster	More than 300 liner services and 800 destinations; extensive multimodal and pipeline connections; Europe's largest integrated chemical cluster	5.2 million TEU of hinterland traffic in 2024 versus 2.6 million TEU of transhipment; rail accounted for 50.2% of container hinterland transport
Investment, digitalisation and transition	Tuas Port developed towards 65 million TEU annual capacity and 66 berths; automation and digitalPORT@SG, including Maritime Single Window and Just-in-Time functions	Portbase Port Community System and Secure Chain; infrastructure, digital-resilience and industrial/energy-transition investments including Porthos	Digital-twin and smart-port applications, NxtPort and industrial-transition initiatives including NextGen District	Port Development Plan 2040 and smartPORT approach integrating digital traffic, infrastructure and information-management solutions
Principal comparative value	Integrated global hub model	Gateway-industrial benchmark	Gateway-industrial and cluster benchmark	Gateway-hinterland benchmark

Sources: Maritime and Port Authority of Singapore (2025; n.d.-a; n.d.-b; n.d.-c); Port of Rotterdam Authority (2021a, 2021b, 2021c, 2025, n.d.); Port of Antwerp-Bruges (2025; n.d.-a; n.d.-b; n.d.-c); Hafen Hamburg Marketing e.V. (2025); Hamburg Port Authority (2024a, 2024b). Container-throughput comparison corroborated by Hamburger Hafen und Logistik AG (2025).

The four ports therefore provide distinct reference points: Singapore as a global transhipment and maritime-services hub; Rotterdam and Antwerp-Bruges as gateway-industrial systems; and Hamburg as a strongly hinterland-oriented gateway. The following assessment applies the three strategic priorities to these different models.

7.3.2. Integrated governance, competitiveness monitoring and long-term planning

Singapore

- Maritime and Port Authority of Singapore (MPA) combines maritime and port regulation and planning with development of Singapore's international maritime centre and responsibility for major digitalisation and decarbonisation initiatives (Maritime and Port Authority of Singapore, n.d.-a).
- Terminal operations are undertaken by operators including PSA and Jurong Port, while strategic maritime functions remain closely coordinated with government agencies, industry and research organisations.
- Tuas Port illustrates long-term planning: it is being developed in four phases towards completion in the 2040s, with 66 berths and annual capacity of 65 million TEU, while allowing technologies and operating practices to evolve during implementation (Maritime and Port Authority of Singapore, n.d.-c).

EU reference ports

- **Rotterdam**: the Port of Rotterdam Authority develops, manages and operates the port and industrial area and is publicly owned by the Municipality of Rotterdam and the Dutch State (Port of Rotterdam Authority, 2021a).
- **Antwerp-Bruges**: a public-law authority owned by the cities of Antwerp and Bruges manages both port platforms as a combined logistics and industrial system (Port of Antwerp-Bruges, 2025).
- **Hamburg**: Hamburg Port Authority manages major water- and landside infrastructure and the port railway, while the Port Development Plan 2040 provides the long-term development framework (Hamburg Port Authority, 2024b).

Comparative observation

The EU reference ports perform comparable planning, infrastructure and development functions through different public ownership and multi-level institutional arrangements. The main distinction is therefore how strategic coordination is organised, rather than whether long-term planning capacity exists.

7.3.3. Coordinated investment, digital transformation and innovation deployment

Singapore

- Tuas Port combines major physical expansion with automation and digital infrastructure. At completion, it is planned to cover approximately 1,337 hectares, provide 66 berths and reach 65 million TEU annual capacity (Maritime and Port Authority of Singapore, n.d.-c).
- digitalPORT@SG™ serves as Singapore's Maritime Single Window and includes Just-in-Time functions for coordinating vessel arrivals and departures (Maritime and Port Authority of Singapore, n.d.-b).
- MPA also works with industry and research organisations on automation, digitalisation, decarbonisation, alternative fuels and green and digital shipping corridors.

EU reference ports

- **Rotterdam**: Portbase supports the port community, complemented by initiatives such as Secure Chain and transition investments including Porthos (Port of Rotterdam Authority, 2021b, 2021c).

- **Antwerp-Bruges**: digital-twin, sensor and smart-port technologies and NxtPort complement industrial-transition initiatives including the NextGen District (Port of Antwerp-Bruges, n.d.-a, n.d.-b).
- **Hamburg**: the smartPORT approach integrates digital traffic management, infrastructure monitoring and information management within the Port Development Plan 2040 (Hamburg Port Authority, 2024a, 2024b).

Comparative observation

Advanced digitalisation and transition-related investment are evident in both Singapore and the leading EU reference ports. The principal difference lies in the development setting: Singapore integrates new capacity, automation and digital systems within the largely consolidated Tuas development programme, whereas the Northern Range ports deploy comparable capabilities across existing terminals, infrastructure networks and mature industrial areas.

7.3.4. Logistics ecosystems, industrial integration and resilient connectivity

Singapore

- Singapore's competitiveness extends beyond container handling. In 2024, it remained the world's largest bunkering port, supplying 54.92 million tonnes of marine fuel (Maritime and Port Authority of Singapore, 2025).
- More than 200 international shipping groups operate in Singapore alongside ship management, finance, insurance, legal, technical and technology-related maritime services.
- Dense global and regional connectivity supports the concentration of cargo handling, feeder operations, bunkering and specialised maritime services within one ecosystem.

EU reference ports

- **Rotterdam**: combines global maritime access with extensive rail, road, inland-waterway and pipeline connections and a major chemical, petrochemical and energy cluster; inland shipping provides daily connections to more than 100 European destinations (Port of Rotterdam Authority, 2021b, n.d.).
- **Antwerp-Bruges**: combines more than 300 liner services and around 800 destinations with rail, road, inland-waterway and pipeline links and Europe's largest integrated chemical cluster (Port of Antwerp-Bruges, n.d.-c).
- **Hamburg**: has a particularly strong gateway role; in 2024, 5.2 million TEU moved in hinterland traffic compared with 2.6 million TEU of transhipment, while rail accounted for 50.2% of container hinterland transport (Hafen Hamburg Marketing e.V., 2025).
- The comparison also extends beyond containers: Rotterdam handled approximately 200 million tonnes of liquid bulk in 2024; Antwerp-Bruges combines container activity with Ro-Ro, conventional general cargo and major liquid- and dry-bulk functions; and Hamburg handled 33.1 million tonnes of bulk cargo alongside container and conventional general-cargo traffic (Port of Rotterdam Authority, 2025; Port of Antwerp-Bruges, 2025; Hafen Hamburg Marketing e.V., 2025).

Comparative observation

The ports rely on different ecosystem configurations: Singapore combines maritime-network centrality, transshipment, bunkering and maritime services; Rotterdam and Antwerp-Bruges integrate maritime accessibility with extensive industrial, energy and inland-transport systems; and Hamburg represents a strongly hinterland-oriented gateway model.

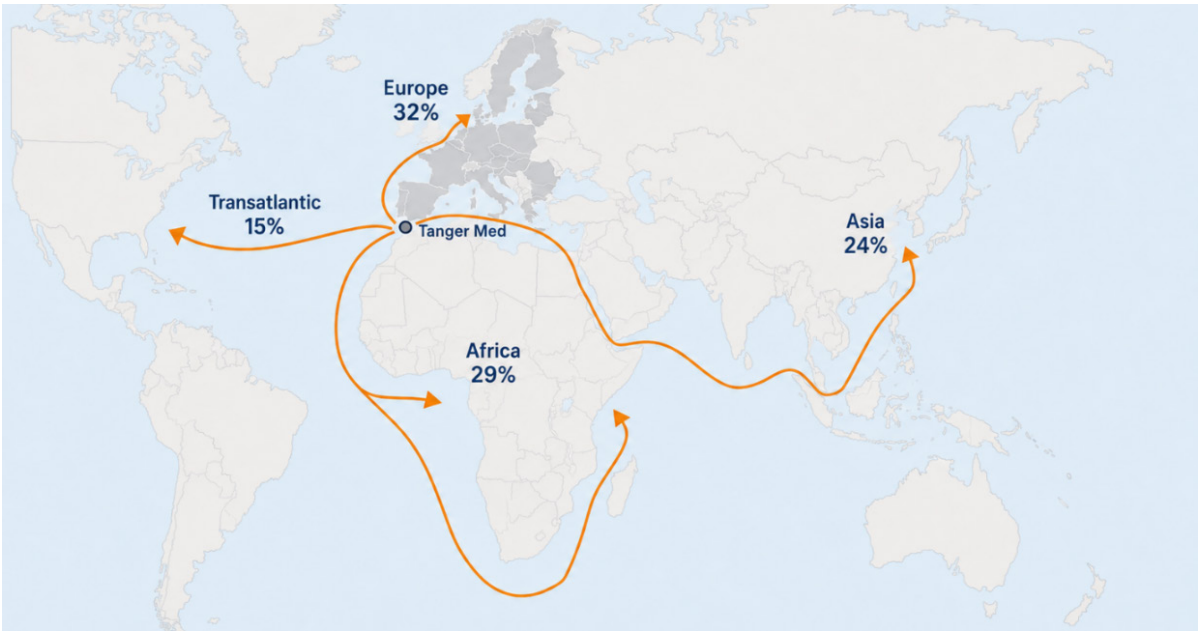
Their transferability across EU cargo markets and maritime regions, and the implications for EU port competitiveness, are assessed jointly with the Tanger Med findings in Section 7.5.

Use case: Tanger Med

7.3.5. Context and competitive position

Tanger Med occupies a strategic position on the Strait of Gibraltar, directly adjacent to the main East–West maritime route and opposite the southern Spanish port system (Figure 18). Its competitive position combines large-scale container transhipment with Ro-Ro links to Europe, vehicle logistics, liquid- and dry-bulk activities and an extensive logistics and industrial platform.

Figure 18: Main maritime routes and geographical distribution of traffic from Tanger Med



Source: Authors' visualisation based on Tanger Med Group (2025), Key Figures 2024. Percentages represent the geographical distribution of container traffic by tonnage.

In 2024, the port complex handled 10.24 million TEU, 142 million tonnes of goods, 516,842 Ro-Ro trucks, 600,872 vehicles and 17,479 vessel calls. Container performance benefited from upgraded facilities, new equipment and optimisation of maritime calls, while Ro-Ro and vehicle traffic is closely linked to Moroccan industrial and agri-food production (Tanger Med Port Authority, 2024).

Algeciras, Valencia, Gioia Tauro and Piraeus are used as the principal EU Mediterranean reference ports (Figure 19): Algeciras as the closest direct competitor across the Strait of Gibraltar; Valencia as a Western Mediterranean gateway and transhipment port; Gioia Tauro as a predominantly transhipment-oriented Central Mediterranean hub; and Piraeus as an Eastern Mediterranean container, gateway and multipurpose port.

Tanger Med's relevance also extends beyond Mediterranean container competition. Its development integrates port capacity with export-oriented logistics and industrial activities, linking maritime connectivity, manufacturing, cargo generation and investment attraction (Tanger Med Special Agency, 2024a). Rotterdam and Antwerp-Bruges therefore provide additional functional references for industrial integration because both combine maritime gateway functions with major industrial, energy and logistics clusters (Port of Rotterdam Authority, 2021b; Port of Antwerp-Bruges, n.d.-c).

Figure 19: Location of Tanger Med and selected EU ports in the Mediterranean



Source: Authors' visualisation.

The assessment consequently operates at two levels: the four Mediterranean ports provide the direct reference group for container services, transhipment and gateway competition (Table 20), while Rotterdam and Antwerp-Bruges provide functional benchmarks for the wider port–industrial ecosystem dimension established in Section 7.2.

Table 20: Comparative positioning of Tanger Med and selected EU Mediterranean reference ports

Comparative dimension	Tanger Med	Algeciras	Valencia	Gioia Tauro	Piraeus
Container throughput, 2024	10.24 m TEU	4.71 m TEU	5.48 m TEU	3.94 m TEU	4.68 m TEU
Main role	Transhipment, Ro-Ro and integrated industrial/logistics hub	Strait transhipment/ gateway hub with energy traffic	Gateway and transhipment port	Predominantly transhipment hub	Eastern Mediterranean gateway/ transhipment and multipurpose port
Transhipment share	>90%	~85%	~50%	>90%	~75%
Connectivity / corridor position	Main East-West routes; ~180 ports in 70 countries; Ro-Ro links to Europe	Gibraltar Strait; mainline and North Africa connections	Western Mediterranean; strong Spanish hinterland	Central Mediterranean hub; developing rail links	Suez-facing gateway; feeder links and access towards Balkans/Central Europe
Governance/ development context	Integrated port-logistics-industrial group structure	Spanish public port authority	Spanish public port authority	Italian multi-port system authority	Corporate port-authority and concession model

Comparative dimension	Tanger Med	Algeciras	Valencia	Gioia Tauro	Piraeus
Investment/ digital focus	PCS, call optimisation and coordinated terminal/industrial development	Digital and port-call innovation initiatives	PAULA platform; rail and digital investment	Equipment renewal, PCS and rail integration	Car-terminal expansion, e-services and logistics development
Principal comparative value	Neighbouring non-EU integrated benchmark	Closest direct EU competitor	Gateway/ transhipment benchmark	Transhipment benchmark	Eastern Mediterranean multipurpose benchmark

Sources: Tanger Med Port Authority (2024; n.d.-a; n.d.-b; n.d.-c), Tanger Med Special Agency (n.d.-a; n.d.-b), Tanger Med Group (2025), Puertos del Estado (2025), Port Authority of the Bay of Algeciras (2025), Valencia port (2024; n.d.), Autorità di Sistema Portuale dei Mari Tirreno Meridionale e Ionio (2024; 2025; n.d.), Piraeus Port Authority S.A. (2025; n.d.-a; n.d.-b), and Eurostat (2025). Spanish 2024 traffic statistics are from the official Puertos del Estado Statistical Yearbook.

The Mediterranean reference group captures distinct models: Algeciras provides the closest spatial and market comparison, Valencia combines hub and gateway functions, Gioia Tauro isolates the transhipment model more clearly, and Piraeus adds an Eastern Mediterranean multipurpose perspective. This helps distinguish Tanger Med's location- and transhipment-related advantages from its wider institutional, investment and industrial capabilities.

7.3.6. Integrated governance, competitiveness monitoring and long-term planning

Tanger Med

- Development is characterised by close institutional coordination between port, logistics and industrial functions.
- Tanger Med Special Agency (TMSA) was established with public prerogatives covering the port and free zones, including port and logistics development, industrial activity zones, investment mobilisation, concessions and port-authority functions (Tanger Med Special Agency, n.d.-a; n.d.-b).
- The Group links port and logistics, industrial and services activities, integrating maritime infrastructure, land development, investment attraction and cargo-generating economic activity.
- Its comparatively recent and largely greenfield development allowed port capacity, logistics areas, industrial zones and supporting infrastructure to be planned as interconnected components.

EU Mediterranean reference ports

- **Algeciras** and **Valencia** operate through Spanish public port authorities within the national governance framework.
- **Gioia Tauro** forms part of an Italian multi-port system authority.
- **Piraeus** operates through a corporate port-authority and concession structure.
- These ports therefore coordinate development within more established infrastructure systems and national and EU regulatory frameworks.

Comparative observation

Tanger Med combines port, logistics-zone and industrial development within a comparatively integrated institutional structure. The EU reference ports operate through different governance models and generally within more mature spatial and infrastructure environments. The key contrast is therefore

the degree of institutional and spatial integration through which long-term development is organised, rather than the existence of strategic planning.

7.3.7. Coordinated investment, digital transformation and innovation deployment

Tanger Med

- Investment extends beyond terminal capacity to port infrastructure, logistics areas, industrial zones and supporting services.
- In 2024, the industrial platform attracted MAD 10.06 billion in investment and 95 new projects were confirmed in Tanger Med Zones (Tanger Med Special Agency, 2024c).
- The Tanger Med Port Community System supports maritime and cargo information exchange across the port ecosystem (Tanger Med Port Authority, n.d.-b).
- Digitalisation also covers industrial-development procedures: in 2024, the e-ONE platform enabled investors to manage installation permits, building permits and operating licences digitally through the Zones Community System (Tanger Med Special Agency, 2024b).

EU reference ports

The Mediterranean reference ports also pursue digital and infrastructure development, although with different emphases:

- **Algeciras**: digital and port-call innovation initiatives (Port Authority of the Bay of Algeciras, 2025).
- **Valencia**: digital development, including PAULA, alongside rail and broader infrastructure investment (Valenciaport, 2024).
- **Gioia Tauro**: equipment renewal, Port Community System development and improved rail integration (Autorità di Sistema Portuale dei Mari Tirreno Meridionale e Ionio, 2024; n.d.).
- **Piraeus**: terminal and logistics investment, e-services and expansion of specialised facilities, including vehicle-handling capacity (Piraeus Port Authority S.A., 2025; n.d.-a).

For the **port-industrial dimension**, **Rotterdam** and **Antwerp-Bruges** provide additional comparison. Rotterdam's transition includes shared CO_2 infrastructure such as Porthos and development of hydrogen and pipeline systems, while Antwerp-Bruges combines digital and industrial-transition initiatives with hydrogen, CO_2 and circular-economy development (Port of Rotterdam Authority, 2021b; Port of Antwerp-Bruges, n.d.-a; n.d.-b).

Comparative observation

Tanger Med's distinctive feature is the parallel development of terminals, logistics facilities, industrial zones and digital administrative processes within an integrated platform. EU reference ports also demonstrate substantial digital, infrastructure and transition investment, but generally within existing port, transport and industrial systems and across several programmes and institutional actors.

7.3.8. Logistics ecosystems, industrial integration and resilient connectivity

Tanger Med

Industrial integration is central to the Tanger Med model. In 2024, its wider business and industrial platform covered approximately 3,000 hectares, hosted more than 1,400 companies, supported almost 130,000 jobs and generated MAD 174 billion in business volume. Activities included automotive, aeronautics, textiles, healthcare, agri-food, electronics, renewable energy, packaging, services and

logistics, with MAD 117 billion generated by automotive activities and MAD 46 billion by logistics (Tanger Med Special Agency, 2024a).

The platform is closely integrated with maritime and logistics functions. Automotive manufacturing and suppliers generate vehicle, Ro-Ro and container flows, while maritime connectivity provides access to European and global markets. Continued expansion by automotive suppliers, logistics operators and emerging manufacturing activities further strengthens the cargo-generating economic base.

EU reference ports

The Mediterranean comparators combine these ecosystem functions differently:

- **Algeciras** is the closest direct maritime competitor because of its position across the Strait.
- **Valencia** combines Mediterranean connectivity with a substantial Spanish hinterland.
- **Gioia Tauro** remains more concentrated on transhipment.
- **Piraeus** combines container activity with ferry, vehicle and other multipurpose functions.

For industrial integration, Rotterdam and Antwerp-Bruges provide particularly relevant EU examples:

- **Rotterdam** combines its gateway role with an extensive petrochemical, industrial and energy cluster and multimodal and pipeline connections (Port of Rotterdam Authority, 2021b; n.d.).
- **Antwerp-Bruges** combines global maritime connectivity with Europe's largest integrated chemical cluster, linking production, terminals, tank storage, logistics and distribution (Port of Antwerp-Bruges, n.d.-c).

Comparative observation

Tanger Med combines maritime connectivity with a growing export-oriented industrial and logistics platform that directly generates cargo. Rotterdam and Antwerp-Bruges demonstrate a related port–industrial relationship within larger and more mature European clusters, while the Mediterranean reference ports represent different combinations of transhipment, gateway and multipurpose functions.

The comparison therefore identifies distinct competitive configurations rather than a single port model. Their transferability across EU port and cargo contexts, and the conditions under which they are relevant, are assessed jointly with the Singapore findings in Section 7.5.

7.4. Comparative findings and relevance for the EU port system

The comparison of Singapore and Tanger Med with selected EU ports confirms the three strategic priorities established in Section 7.1, but also shows that no single model defines international port competitiveness. Competitive strength reflects different combinations of governance, maritime and hinterland connectivity, infrastructure, digitalisation, industrial integration and specialised services.

The international cases should therefore be interpreted by distinguishing between broadly transferable capabilities; practices whose relevance depends on cargo market, geography, institutional conditions or development stage; and advantages specific to Singapore or Tanger Med that cannot readily be reproduced in the EU. Table 21 translates these distinctions into implications for EU competitiveness and reconnects them with the Chapter 2 dimensions of terminal offerings, management strategies and the external environment.

Table 21: Cross-case comparative findings and implications for EU port competitiveness

Strategic priority	Main comparative finding	Transferability to the EU context	Direction for strengthening EU competitiveness
Integrated governance, competitiveness monitoring and long-term planning	Singapore: strategic maritime functions concentrated within an integrated national system. Tanger Med: coordinated port–logistics–industrial development. EU reference ports: comparable planning and development functions delivered through diverse public, corporate and multi-level governance arrangements.	High for the underlying capabilities; limited for institutional replication. Singapore's city-state structure and Tanger Med's integrated greenfield model are not directly transferable.	Strengthen coordination capacity, clear responsibilities, long-term adaptable planning and systematic competitiveness monitoring, without prescribing a uniform governance model.
Coordinated investment, digital transformation and innovation deployment	Singapore: Tuas integrates capacity expansion, automation and digitalisation within one long-term programme. Tanger Med: terminal, logistics, industrial and digital development progress in parallel. EU reference ports: advanced infrastructure, digital and transition projects are already widespread, but mostly across mature systems and multiple programmes.	High for coordination, sequencing, interoperability and deployment principles; conditional for greenfield-style integration.	Improve sequencing of physical, digital, energy and resilience investments, interoperability across actors and systems, and progression from pilots to sustained operational deployment.
Logistics ecosystems, industrial integration and resilient connectivity	Singapore: transhipment, bunkering, global connectivity and maritime services. Tanger Med: maritime accessibility integrated with logistics zones and export-oriented manufacturing. EU reference ports: strong gateway, hinterland, industrial and energy-cluster models.	High as a strategic principle, but strongly dependent on cargo market, port function and local conditions.	Strengthen the ecosystem appropriate to each port function, combining maritime and hinterland connectivity, logistics and industrial integration, energy systems and specialised supply-chain capabilities.

Source: Authors' comparative synthesis based on Maritime and Port Authority of Singapore (2025; n.d.-a; n.d.-b; n.d.-c); Port of Rotterdam Authority (2021a, 2021b, 2021c, 2025; n.d.); Port of Antwerp-Bruges (2025; n.d.-a; n.d.-b; n.d.-c); Hamburg Port Authority (2024a, 2024b); Hafen Hamburg Marketing e.V. (2025); Tanger Med Special Agency (2024a, 2024b, 2024c; n.d.-a; n.d.-b); Tanger Med Port Authority (2024; n.d.-a; n.d.-b; n.d.-c); ESPO (2024); and European Commission (2026).

7.4.1. Integrated governance, competitiveness monitoring and long-term planning

The comparison indicates that **effective coordination matters more than institutional form**. Singapore concentrates maritime planning and regulatory responsibilities, while Tanger Med links port development with logistics zones, industrial land and investment attraction. Rotterdam, Antwerp-Bruges, Hamburg and the Mediterranean reference ports demonstrate that comparable strategic functions can also be delivered through public, corporate and multi-level governance arrangements.

For the EU, three directions follow:

- **Coordinate port development with transport, industrial, energy and spatial planning**, particularly where hinterland corridors, electricity and fuel infrastructure and industrial land lie outside port-authority control.
- **Strengthen competitiveness monitoring** using market-specific comparator groups and indicators: liner connectivity, service performance and neighbouring hubs for transhipment ports; hinterland and corridor performance for gateways; storage, pipelines, rail/inland-waterway access and industrial conditions for bulk and industrial ports; and frequency and corridor reliability for Ro-Ro.

- **Monitor the external competitive environment**, particularly at EU maritime boundaries, including regulatory and cost conditions, infrastructure, service performance and potential traffic or investment diversion alongside conventional throughput indicators.

The objective is therefore stronger strategic capacity to anticipate and respond to competitive change, rather than harmonisation of governance structures, consistent with the management-strategy and external-environment dimensions of Chapter 2.

7.4.2. Coordinated investment, digital transformation and innovation deployment

The cases do not indicate a general technological deficit in leading EU ports: Rotterdam, Antwerp-Bruges, Hamburg, Valencia, Algeciras, Gioia Tauro and Piraeus already invest substantially in digital systems, terminal infrastructure, rail integration, energy-transition projects and smart-port applications. The main comparative issue is how such investments are combined and deployed.

Singapore integrates capacity, automation and digitalisation within the long-term Tuas programme, while Tanger Med develops terminal, logistics, industrial and digital capabilities in parallel. EU ports face the additional challenge of integrating comparable investments within established terminals, cities, transport networks and industrial areas.

Four priorities emerge:

- **sequence terminal expansion** with required rail, road, inland-waterway, storage and logistics capacity;
- **integrate** grids, pipelines and other energy infrastructure needed for electrification, alternative fuels and industrial decarbonisation into port investment planning;
- **prioritise interoperability** among Port Community Systems, Maritime Single Windows, terminal systems and the wider logistics community; and
- **strengthen progression** from pilots to scaled, sustained operational deployment.

The transferable lesson is integrated deployment rather than replication of particular technologies or infrastructure models. Tuas itself is not reproducible in most mature EU ports; its relevance lies in coordinated infrastructure, automation and digitalisation over a long planning horizon. This supports the terminal-offerings and management-strategy dimensions of Chapter 2 while recognising different investment conditions in expanding and mature ports.

7.4.3. Logistics ecosystems, industrial integration and resilient connectivity

The strongest cross-case finding is that internationally competitive **ports create value beyond the terminal** through different ecosystem configurations: Singapore through network centrality, transhipment, bunkering and maritime services; Tanger Med through logistics zones and export-oriented manufacturing; Rotterdam and Antwerp-Bruges through gateway, hinterland and industrial-energy clusters; Hamburg through gateway activity and rail integration; and Mediterranean reference ports through varying transhipment, gateway, Ro-Ro and multipurpose functions.

Competitiveness therefore extends beyond throughput and terminal productivity: maritime connectivity attracts logistics and industrial activity, which in turn generates cargo, services and investment. EU action should strengthen the ecosystem appropriate to each port function:

- **container gateways**: liner and feeder connectivity with reliable hinterland corridors;
- **liquid-bulk and energy ports**: storage, pipelines, industrial demand, energy infrastructure and industrial-cluster transformation;

- **dry-bulk ports**: commodity corridors, rail/inland-waterway access, storage and proximity to producers or users;
- **Ro-Ro ports**: service frequency, border performance and reliable door-to-door corridors;
- **general and project-cargo ports**: specialised infrastructure, industrial land, skills and coordination with project and manufacturing supply chains.

This ecosystem perspective reflects the diversity of the EU port system and links the comparison to the external-environment, terminal-offerings and supply-chain dimensions of Chapter 2.

7.4.4. Transferability across EU maritime regions and cargo markets

The relevance of the international cases varies across the European port system. Table 22 identifies the principal applications and the conditions under which they should be interpreted.

Table 22: Regional and cargo-market transferability of the comparative findings

EU port context	Principal relevance of the international cases
Mediterranean container and Ro-Ro ports	Tanger Med provides the most direct competitive reference. Priority should be given to reliable operations, maritime and feeder connectivity, hinterland performance and monitoring of regulatory and cost asymmetries and potential traffic diversion. Singapore provides additional lessons on port-call coordination and integrated digital processes.
Northern Range and industrial ports	Singapore and Tanger Med reinforce the importance of coordinating maritime capacity with industrial and logistics functions, but Rotterdam and Antwerp-Bruges demonstrate that the EU already possesses highly developed port-industrial models. The central challenge is maintaining and transforming these clusters through coordinated land, grid, pipeline, low-carbon energy and transport investment.
Baltic, Atlantic and Black Sea gateways	The strongest transfer concerns system integration rather than transhipment. Maritime services need to be connected with resilient hinterland corridors, industrial and commodity flows, border performance, energy infrastructure and security requirements.
North Sea and general-cargo ports	Relevant findings concern the coordination of industrial land, heavy-duty and specialised infrastructure, energy networks, logistics services, skills and project supply chains required to attract and retain specialised activities.
Dry- and liquid-bulk ports across EU regions	The ecosystem perspective is particularly relevant: terminal competitiveness depends on integration with storage, pipelines, rail or inland waterways, industrial demand and the transition requirements of the industries and energy systems served.
Container transhipment hubs and major gateways	Singapore and Tanger Med demonstrate the importance of maritime connectivity, service reliability and efficient port calls, but their exceptionally favourable geographical positions cannot be replicated. EU ports should therefore combine maritime performance with those gateway, hinterland, logistics or industrial functions that strengthen their own competitive position.

Source: Authors' synthesis based on Tanger Med Special Agency and Tanger Med Port Authority; Maritime and Port Authority of Singapore; Port of Rotterdam Authority; Port of Antwerp-Bruges; Hamburg Port Authority; Hafen Hamburg Marketing e.V.; ESPO (2024); and European Commission (2026).

The assessment **distinguishes transferable capabilities from context-specific models**. Coordination, long-term planning, interoperable digital systems, investment sequencing, resilient connectivity and logistics and industrial integration have broad relevance. Singapore's institutional concentration and transhipment scale, Tanger Med's greenfield development conditions and both ports' geographical advantages are context specific.

The three priorities should therefore be applied differentially according to cargo market, port function, industrial structure, hinterland conditions and regional competitive geography. Strengthening EU port competitiveness does not require replication of a single global-hub model, but the capacity of EU ports

to combine effective governance, coordinated investment and digital deployment, and strong logistics, industrial and connectivity ecosystems in ways appropriate to their competitive functions.

7.5. Conclusions

The comparative assessment confirms that **there is no single model of international port competitiveness**. Competitive strength results from how effectively ports combine governance and long-term planning, coordinated investment and technological deployment, and integration with wider logistics, industrial, energy and hinterland systems.

The Singapore and Tanger Med cases, together with the EU reference ports, show that these capabilities can be developed through different institutional, spatial and market configurations. The strategic framework should therefore be applied as a common basis for assessment, while allowing differentiated implementation according to port function, cargo market and regional context.

7.5.1. Key takeaways

- **Port competitiveness extends beyond cargo volumes and terminal performance**. It depends on the interaction between governance, long-term planning, infrastructure, digitalisation, maritime and hinterland connectivity, and the wider logistics, industrial and energy ecosystems in which ports operate.
- The comparative assessment identifies three mutually reinforcing priorities for strengthening competitiveness: **integrated governance, competitiveness monitoring and long-term planning; coordinated investment, digital transformation and innovation deployment; and logistics ecosystems, industrial integration and resilient connectivity**. These priorities provide a common framework across different port types, while their practical expression varies according to cargo market, port function and regional context.
- **Singapore** and **Tanger Med** illustrate different competitive models. Singapore combines global maritime connectivity, transhipment, bunkering and maritime services with integrated long-term planning and digital development, while Tanger Med combines maritime accessibility with coordinated port, logistics and export-oriented industrial development.
- **Leading EU ports already demonstrate many comparable capabilities**. Rotterdam, Antwerp-Bruges, Hamburg and the Mediterranean reference ports show that strong governance, digitalisation, industrial integration, hinterland connectivity and transition-related investment can be achieved through different institutional arrangements and within mature infrastructure systems. The main comparative issue is therefore less the absence of capabilities than how effectively they are coordinated, sequenced and deployed.
- The most transferable lessons concern strategic coordination, long-term adaptable planning, investment sequencing, digital interoperability, progression from innovation pilots to sustained deployment, and stronger integration between ports and their logistics, industrial, energy and hinterland systems. These capabilities can strengthen competitiveness without requiring replication of the institutional or spatial characteristics of Singapore or Tanger Med.
- **Transferability remains highly context-dependent**. Container hubs, gateway ports, bulk and energy ports, Ro-Ro ports and general- or project-cargo ports face different competitive conditions and infrastructure requirements, while regional factors such as hinterland structure, neighbouring competitors, industrial specialisation and regulatory exposure further shape their needs.
- **EU action should therefore strengthen common strategic capabilities while allowing differentiated implementation across the European port system**. A single global-hub model

would not reflect the diversity of EU ports; the more relevant objective is to enable each port to combine governance, investment, connectivity and ecosystem integration in ways that match its competitive function and regional context.

8. ALTERNATIVE FUTURE SCENARIOS

KEY FINDINGS

- **Four medium-term scenarios** up to 2040 are defined along two axes: the pace of decarbonisation and the degree of global trade and geopolitical cooperation.
- **S1 Fragmented Fossil Security** reflects low decarbonisation and high geopolitical fragmentation, with strong pressures on competitiveness, resilience and strategic autonomy.
- **S2 Green Competition** reflects high but fragmented decarbonisation, with strong competition over green technologies, standards, subsidies and investment.
- **S3 Open trade, weak global action** reflects open trade but limited global climate ambition, creating uncertainty around decarbonisation and long-term investment.
- **S4 Green Cooperation** reflects open trade and coordinated decarbonisation, with greater regulatory convergence and stronger opportunities for green technology deployment.

European ports are exposed to geopolitical, macroeconomic, technological and environmental shifts that could alter their operating context by 2040. This chapter, therefore, explores how different combinations of external developments could affect the strategic priorities identified in the previous chapters.

8.1. Scenario framework

This chapter applies a scenario matrix based on two critical uncertainties, an approach widely used in strategic foresight to explore plausible future operating environments (Ramirez & Wilkinson, 2014). For EU ports, two uncertainties are considered particularly decisive for the period to 2040:

- **Future of global trade and geopolitical competition**. This uncertainty concerns whether global trade will remain relatively open, rules-based and interconnected, or become more fragmented due to geopolitical rivalry, protectionism and strategic dependencies.
- **The pace and coordination of global decarbonisation**. This uncertainty concerns whether the transition to low-carbon transport, energy and industry will proceed rapidly and in a coordinated manner, or more slowly and unevenly across regions.

These two uncertainties were selected because they combine three characteristics. First, they are highly consequential for all five analytical topics of the study: competitiveness, security, sustainability, digitalisation and hinterland connectivity. Global trade and geopolitical competition affect cargo flows, investment patterns, critical infrastructure risks, supply-chain resilience and strategic dependencies. The pace and coordination of decarbonisation affect fuel choices, energy infrastructure, regulatory exposure, investment needs and the risk of carbon or business leakage. Second, both uncertainties remain highly uncertain up to 2040. Neither future trade relations nor the speed and international coordination of decarbonisation can be assumed with confidence. Third, they are largely external to individual port authorities, meaning that ports and EU policymakers must prepare for them rather than control them directly.

Other uncertainties are also relevant to the future of European ports, including **automation and digitalisation, labour market trends, energy prices, fuel availability and social developments**. These are not excluded from the analysis. Rather, they are treated as developments within the scenarios, because their implications depend strongly on the broader geopolitical and decarbonisation context.

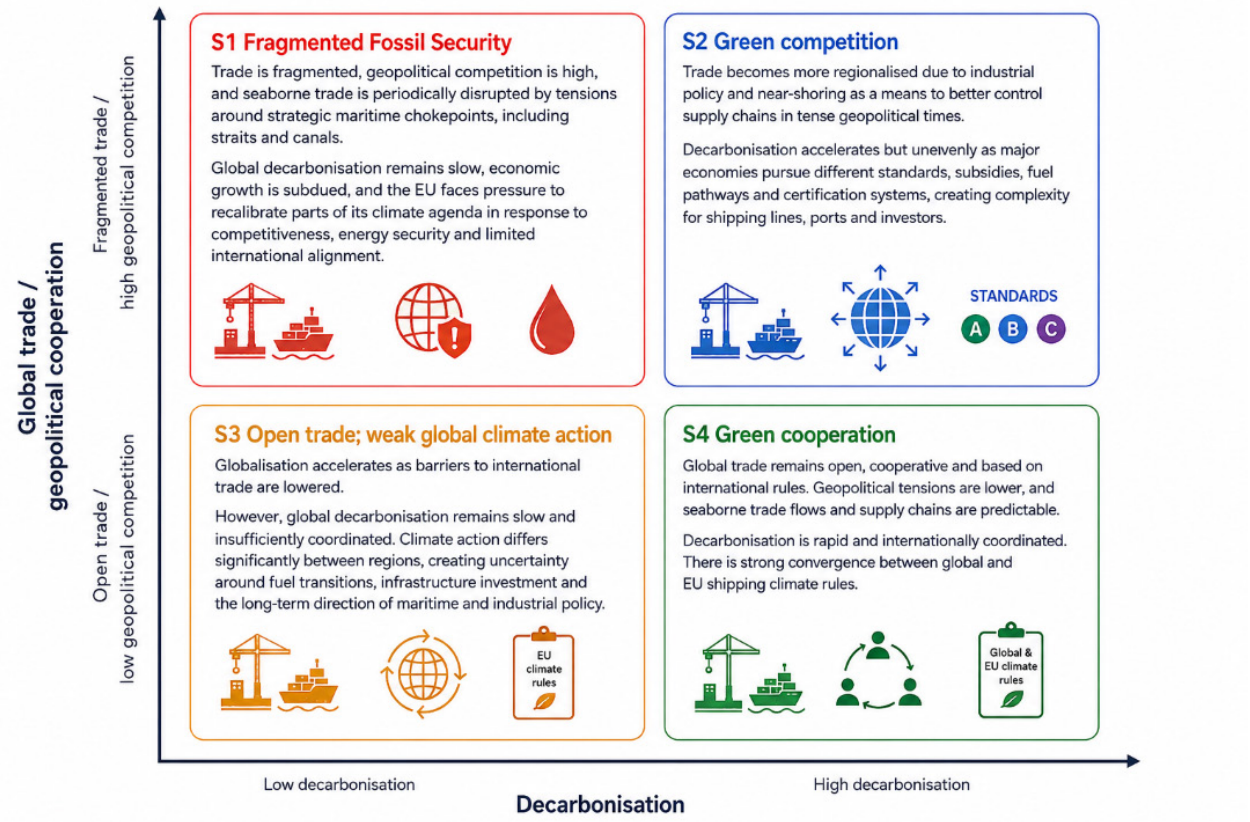
For example, digitalisation and automation may support efficiency and resilience in all futures, but their strategic meaning differs depending on whether global markets are open and cooperative or fragmented and strategically contested. Similarly, alternative-fuel availability depends strongly on the pace and coordination of global decarbonisation.

Moreover, the proposed two uncertainties are **consistent with existing maritime and port foresight exercises**. The Port of Barcelona's 2040 maritime traffic scenarios, for example, also use the 2x2 scenario matrix along the axis of geopolitical/global growth context and Europe's ability to move towards a sustainable economic model (Barcelona Port Authority, 2021). Similarly, global cooperation and decarbonisation are also central to the four 2050 scenarios developed by the Port of Rotterdam. *Global Maritime Trends 2050*, developed by Economist Impact, builds four maritime futures around global cooperation versus fragmentation and the speed of technological uptake (Economic Impact, 2023).

The two selected axes therefore do not imply that other uncertainties are unimportant. Rather, they provide the most useful structure for testing how robust the study's recommendations are under different external conditions. Other uncertainties are reflected within the scenario narratives and in the assessment of individual policy recommendations.

Figure 20 presents four plausible scenarios for European ports towards 2040. The scenarios are developed by combining the two critical uncertainties identified above: the future of global trade and geopolitical competition, and the pace and coordination of global decarbonisation.

Figure 20: Overview of future scenarios



Source: Authors.

In the following section, the logic behind the four scenarios is explained in more detail.

8.1.1. S1: Fragmented Fossil Security

Recent disruptions in the Strait of Hormuz and in the southern entrance to the Red Sea have underscored the **vulnerability of critical maritime chokepoints to geopolitical tensions** and their potential to transmit shocks across supply chains and commodity and energy markets (UNCTAD, 2026b). In a more geopolitically tense world, as foreseen in this scenario, such disruptions become more frequent and global trade becomes less predictable. EU efforts in the 2020s to revitalise the World Trade Organisation's effectiveness (European Commission, 2026) are unsuccessful. Unilateral sanctions from key economies further disrupt global trade.

This geopolitical environment also slows global decarbonisation. Governments give greater priority to short-term competitiveness, energy security and industrial resilience, while international alignment on climate policy weakens. As a result, EU gives less priority to climate ambitions. Investment in low-carbon transport and energy systems slows, and fossil fuels retain a larger role in global energy and trade flows. Economic growth is subdued in most regions, further constraining public and private investment in the transition.

As a result, global emissions do not fall sharply enough to meet the Paris Agreement objective of keeping the increase in global average temperature well below 2°C above pre-industrial levels, and ideally no more than 1.5°C.

In this geopolitically tense scenario, safety and security concerns in the maritime sector increase as international cooperation and enforcement become less effective. Weaker coordination between countries and international organisations makes it more difficult to enforce effectively. Fraudulent ship registrations and registries, as well as a "dark fleet" of ships that operate under the radar, remain a pressing issue. Such practices can undermine safety, security, pollution control, and seafarer welfare in the maritime industry (UNCTAD, 2024c).

For EU ports, S1 implies a highly uncertain operating environment. Periodic disruptions around strategic chokepoints lead to shifts in cargo flows between ports and transport corridors. Ports face higher costs for physical security, cybersecurity, monitoring, contingency planning and enforcement. At the same time, several port and coastal regions require substantial investment in climate-resilient infrastructure, even though low growth and competing budgetary priorities make such investment more difficult. In this scenario, resilience, security and operational flexibility become central concerns for EU port policy.

8.1.2. S2: Green competition

In this scenario, ambitious global decarbonisation regulations – including for the shipping industry – are adopted after many years of negotiations. However, the delay in agreeing to global regulations now requires urgent action, which is not well coordinated internationally, with different regions each favouring their own decarbonisation technologies and standards in line with national priorities.

In a tense geopolitical world, the EU seek to favour their own national/regional industries via state aid, including in clean technology R&D and manufacturing industrial policies. In light of frequent disruption to key maritime chokepoints, national/regional governments seek to gain greater control of supply chains, encouraging re-shoring or near-shoring. Competition for access to critical energy transition materials intensifies. These minerals, including lithium, cobalt, nickel, copper and rare earth elements, are essential for clean energy technologies, electrification and digitalisation (UNCTAD, 2026a). Already since the 2020s, there has been a surge in export-restrictive measures applied by critical-mineral rich countries such as export bans, monitoring or taxes (UNCTAD, 2026a).

For the shipping sector, ambitious and enforceable IMO decarbonisation regulations enable the EU to align its shipping decarbonisation regulations with those of the IMO, reducing the risk that European ports face a competitive disadvantage relative to neighbouring regions. However, a growing concern is competition from non-EU ports receiving generous state subsidies in support of national clean-tech industrial policy goals.

For ports, S2 implies a complex investment environment, as ports may need to accommodate multiple fuel and energy pathways to remain competitive in serving the shipping industry, while facing competition from neighbouring port regions which benefit from higher levels of state aid. Reshoring or near-shoring of certain manufacturing segments results in strong intra-regional/European trade with growth in shortsea volumes, while global deep sea shipping decreases. Late but fast decarbonisation also requires the use of technologies like CO_2 capture and storage, including storage in or near port areas – requiring associated infrastructure.

8.1.3. S3: Open Trade, Weak Global Climate Action

In this scenario, a multilateral trading system based on predictable and clear rules from a reformed WTO enables global trade to flourish. Economic growth is high. However, global consensus on tackling climate change dissipates. The EU maintains its objective of climate neutrality by 2050 and achieves a 90% reduction in emissions by 2040 compared to 1990 levels, in line with the European Climate Law (European Commission, 2026). This supports the development of new clean technology industries in Europe. In the EU, climate resilience and adaptation were carefully planned, but global temperatures rise well beyond the aims of the Paris Agreement. Already in 2022, studies estimated that 86% of ports internationally faced exposure to their infrastructure from more than three natural hazards such as flooding.

For ports, S3 implies solid global trade volumes and use of existing infrastructure (e.g. continued fossil fuel usage by ships; fossil fuel storage infrastructure). The imbalance of strong decarbonisation regulations in Europe, while not necessarily in neighbouring regions, threatens the competitive position of European ports. The threat of military escalation is low. However, ports and coastal areas increasingly need to invest in climate resilience and adaptation to rising sea levels.

8.1.4. S4: Green Cooperation

In this scenario, ambitious global decarbonisation regulations are adopted and implemented in a timely and coordinated way across regions, including for the shipping industry. There is also high convergence on low carbon fuels/energy systems technical standards and certification rules. Clean technologies foster industrial activity and economic growth around the world. The shipping sector benefits from greater policy certainty. Strong global climate rules also reduce the risk of carbon leakage, traffic diversion, and competitive disadvantages between ports in different regions.

For ports, S4 implies international trade remains strong across various cargo segments, but the cargoes being transported are different from today. For example, liquid e-fuels replace petroleum products, requiring substantial investment and adaptation of terminal infrastructure. In some cases, the strong implementation of circular economy principles, such as the re-use of steel or aluminium, may reduce import needs for certain cargoes. The demand from ships for alternative fuels and clean energy requires strong coordination with national/regional government to ensure sufficient infrastructure – including substantial electrical grid capacity - in the port area.

8.2. Conclusions

The scenario framework shows that the operating context for European ports could change by 2040. This chapter uses two critical uncertainties to illustrate these possible changes: the **degree of global trade and geopolitical cooperation**, and the **pace and coordination of decarbonisation**. Combining these uncertainties results in four scenarios. Other futures are possible, but these scenarios capture key external developments that are likely to shape the strategic position of EU ports. The four scenarios are as follows:

- In **S1 Fragmented Fossil Security**, EU ports would face stronger geopolitical disruption, higher security risks and slower progress on decarbonisation.
- In **S2 Green Competition**, rapid but fragmented decarbonisation would create strong competition over technologies, standards, fuels and industrial investment.
- In **S3 Open Trade, Weak Global Climate Action**, trade volumes would remain strong, but EU ports could face competitiveness risks from uneven climate ambition and growing climate-adaptation needs.
- In **S4 Green Cooperation**, coordinated decarbonisation and open trade would create a more favourable environment, but still require major investments in clean energy, grid capacity and adapted port infrastructure.

These scenarios are used to assess the robustness of the policy recommendations presented in the next chapter. The detailed assessment is included in Annex 3. The overall conclusions are summarised in section 9.3, which explains how the future uncertainties set out in this chapter influence the urgency and relevance of the policy recommendations derived from the study.

9. CONCLUSIONS AND POLICY RECOMMENDATIONS

KEY FINDINGS

- **The EU Ports Strategy provides a sound and relevant strategic foundation, but implementation is now the central challenge**. The Strategy broadly addresses the main challenges identified by the study across competitiveness, security and resilience, energy transition, digitalisation and hinterland connectivity. The principal need is therefore not a fundamentally different policy framework, but clearer implementation pathways, responsibilities, monitoring and supporting instruments, while reflecting the diversity of the European port system.
- **Stronger coordination is a recurring requirement across all policy areas**. The five analytical topics are closely interconnected, while implementation involves multiple EU and national policies, governance levels and public and private actors. Effective implementation therefore depends on better coordination across transport corridors, security and resilience frameworks, energy and industrial actors, digital systems and data governance, and regulatory and funding instruments.
- The study identifies 16 recommendations aimed primarily at **operationalising and reinforcing the direction of the EU Ports Strategy**. **Selected priorities for EU action include**:
  - **establishing a robust, evidence-based framework for monitoring the global competitiveness of EU ports**, including potential leakage risks and emerging competitiveness gaps;
  - **strengthening the resilience and security of European ports** through coordinated risk assessment, preparedness, implementation capacity and cooperation across the logistics chain;
  - **creating predictable and coordinated investment conditions for the maritime energy transition**, reducing uncertainty around alternative-fuel demand and infrastructure while maintaining a flexible long-term decarbonisation framework and promoting international alignment through the IMO;
  - **accelerating the deployment and replication of proven digital solutions while strengthening interoperability**, coordination and trusted data exchange between existing and emerging port, maritime, freight and hinterland systems;
  - **strengthening port-hinterland connectivity and resilience**, including through integrated investment planning and the mainstreaming of proportionate dual-use and resilience considerations in strategically relevant corridors.
- **The recommendations remain relevant across different futures, but their urgency is strongly influenced by geopolitical and competitive conditions**. The scenario analysis finds particularly high urgency under futures characterised by geopolitical fragmentation, regulatory divergence and stronger international competition, whereas greater international cooperation and regulatory convergence reduce but do not eliminate the need for EU action.

This chapter first provides a synopsis of the assessment of the EU Ports Strategy bringing together the assessment developed throughout the thematic chapters. Afterwards, it lists concrete and actionable to meet the identified policy gaps. The conclusions and recommendations are based on all research methods used to conduct the study.

9.1. Synopsis of the assessment of the EU Ports Strategy

The EU Ports Strategy, published by EC in March 2026, reflects and consolidates a broader understanding of the role of ports within European policy. While ports have traditionally been viewed primarily as logistics nodes, the Strategy increasingly recognises their wider strategic functions in relation to competitiveness, security and resilience, the energy transition, digitalisation and European connectivity.

Overall, **the thematic assessment finds the EU Ports Strategy timely and relevant and broadly aligned with the evidence reviewed in this study**. Its main added value lies in establishing an integrated strategic direction for a highly heterogeneous European port system. It recognises the major challenges identified across the five analytical topics and provides a broad policy basis for action on competitiveness, safety and security, sustainability and the energy transition, digitalisation and hinterland connectivity. The main issue emerging from the assessment is therefore not a fundamental gap in strategic objectives, but the transition from strategic direction to effective implementation.

The thematic assessment identifies a number of recurring strengths, as well as areas where the Strategy may need to be further operationalised, specified or complemented during implementation, as summarised in Table 23.

Table 23: Recurring strengths and areas where the Strategy needs to be further operationalised

Cross-cutting strengths	Areas for further development
Comprehensive and relevant strategic foundation The Strategy recognises the major challenges currently affecting European ports and treats ports not merely as transport infrastructure, but as strategic nodes for competitiveness, security, energy transition, digitalisation and European connectivity.	**From strategic objectives to operational implementation** The Strategy establishes a clear overall direction, but implementation will require more specific pathways, responsibilities, monitoring arrangements, investment mechanisms and/or instruments depending on the thematic area.
Broad alignment with the evidence base Across the five analytical dimensions, the Strategy's priorities are broadly consistent with the challenges identified through the literature review, port analysis and benchmarking, and stakeholder consultation.	**Implementation across a highly diverse European port system** Ports differ considerably in size, function, geography, governance, investment capacity, digital maturity and strategic role. Effective implementation therefore needs to reflect these differences and allow measures and support mechanisms to be adapted to different port contexts.
Integration with the wider EU policy architecture The Strategy generally builds upon rather than replaces existing EU instruments — TEN-T, energy and climate legislation, security/resilience frameworks, digital initiatives, R&I and financing mechanisms.	**Coordination across policies, actors and geographical scales** Effective implementation requires coordination across multiple policy domains and governance levels, including corridor-level coordination for hinterland connectivity, public-private and multi-agency cooperation for security, port-industry-energy coordination for the energy transition, interoperability and data governance for digitalisation, and coordination between funding and regulatory instruments.

Source: Authors' own elaboration.

The assessment also highlights that the five analytical topics are strongly interconnected. Digitalisation affects competitiveness and security; energy infrastructure affects competitiveness and sustainability; hinterland connectivity influences competitiveness, resilience and military mobility; and investment

and governance recur across all analytical dimensions. The Strategy's value therefore lies partly in providing an overarching port-focused policy direction across these interconnected challenges. **Its effectiveness will depend on the ability to translate this direction into coordinated implementation across policy domains, governance levels and different parts of the European port system**.

Overall, the EU Ports Strategy provides a sound strategic foundation for the future development of European ports. The assessment points to implementation, coordination and adaptation to different port contexts as the principal areas requiring further attention. Accordingly, the policy recommendations presented in Section 9.2 are primarily intended to operationalise and reinforce the direction established by the Strategy, rather than to propose an alternative policy framework.

9.2. Consolidated policy recommendations

9.2.1. Global competitiveness

Policy Recommendation P1-1: Ensure credible monitoring of leakage risks under EU maritime climate legislation

The EU policy makers should **closely scrutinise the methodological approach used to assess possible business leakage and competitiveness loss linked to EU climate legislation**, in particular in view of the update of the EU Emissions Trading System in Q3 2026 and the planned review of FuelEU Maritime.

- Ensure that the methodology used to detect business leakage is robust, transparent and supported by stakeholders, using the upcoming review of the maritime EU ETS as an opportunity to further strengthen the monitoring approach.
- Call on the Commission to consult **ports, EU sector organisations, Member States representatives, and other relevant stakeholders** when further developing the methodology.
- Ensure that the monitoring approach can distinguish between normal changes in liner networks, temporary disruptions, commercial investment decisions and genuine competitiveness losses linked to regulatory or investment conditions in the EU.
- As a key element in assessing impacts on global competitiveness, investigate **whether investments taking place in non-EU ports would otherwise have taken place in EU ports**.

Policy Recommendation P1-2: Strengthen the evidence base on EU port competitiveness and in ongoing EU policy processes

The **available evidence does not allow for firm conclusions on the scale of the impact of permitting procedures, state aid, funding, energy prices and electricity grid capacity on EU port competitiveness**. EU policymakers should therefore strengthen the evidence base and ensure that port competitiveness is adequately considered in relevant ongoing EU policy processes.

- Consider **carrying out systematic and periodic assessments of the competitiveness of EU ports**, identifying emerging competitiveness gaps and, where relevant, comparing conditions in EU ports with those in nearby non-EU ports.
- **Pay close attention to ongoing EU policy processes relevant to port competitiveness**, including the Environmental Omnibus package, the European Grids Package, the design of upcoming EU funding schemes under the next Multiannual Financial Framework, and the proposal for the European Competitiveness Fund, COM(2025) 555.
- **Monitor the forthcoming review of the State aid framework for ports** to assess whether is sufficiently reflects the specific nature of port investments.

Policy Recommendation P1-3: Translate the EU Ports Strategy's technological leadership objective into a concrete port innovation deployment agenda

EU policy makers could **make the EU Ports Strategy's objective on technological leadership more concrete**, as the Strategy remains relatively broad on how this ambition will be achieved in practice.

- Monitor the **Industrial Accelerator Act, COM(2026)100** (EU, 2026), and assess whether port-industrial clusters and port-related technologies are sufficiently reflected in the Act's provisions on industrial acceleration areas.
- Promote the development of a **Port Innovation Deployment Roadmap**, identifying priority technologies, the EU instruments to support their deployment, and milestones towards 2030 and 2040.
- Provide for periodic assessment of progress towards its objectives, allowing implementation gaps to be identified and the approach adjusted where necessary.
- Complement the Roadmap with an **innovation monitoring framework for EU ports**. This would help assess whether the EU ports system is actually gaining technological capabilities compared with non-EU ports, for example through deployment levels, standard-setting influence, investment attraction and market uptake.

9.2.2. Safety and security

Policy Recommendation P2-1: Strengthening cybersecurity and digital resilience through consistent and operational implementation of existing EU requirements

The EU should support the practical implementation of NIS2 and related requirements in port environments, taking account of the specific interdependencies between IT, OT and physical operations.

- Promote maritime-specific guidance under NIS2, where appropriate, and common/interoperable approaches to cyber-risk assessment, incident response and preparedness testing.
- Strengthen secure information sharing between port authorities, terminal operators, customs, logistics operators and relevant digital service providers.
- Promote regular cyber-resilience exercises, including scenarios involving cascading effects between digital systems and physical port operations.
- Provide targeted technical assistance and skills development for smaller, peripheral and island ports with limited specialised capacity.

Policy Recommendation P2-2: Strengthening critical port infrastructure resilience through common risk assessment and preparedness approaches

The EU should support more consistent approaches to identifying vulnerabilities and preparing for disruptions affecting interconnected transport, energy, digital and logistics infrastructure.

- Develop common principles and interoperable methodologies for risk assessment, resilience benchmarking and continuity planning, while respecting Member States' responsibilities for national security.
- Promote multi-agency exercises covering cyber incidents, organised crime, critical infrastructure disruption and complex multi-hazard scenarios.
- Strengthen cross-border crisis communication and continuity arrangements, particularly where disruptions affect wider transport and logistics networks.

- Encourage resilience-by-design in port investments, including redundancy and coordinated planning of transport, energy and digital infrastructure.

Policy Recommendation P2-3: Strengthen the fight against organised crime through whole-logistics-chain intelligence and risk-based security

The EU should strengthen operational cooperation against drug trafficking, cargo-related fraud, insider threats and the exploitation of digital and logistical vulnerabilities across the wider logistics chain.

- Strengthen structured intelligence sharing between customs, law-enforcement authorities, port authorities and relevant private operators on high-risk cargo, emerging criminal patterns and vulnerabilities.
- Extend risk-based security monitoring beyond the port perimeter to inland terminals, logistics centres and strategically important hinterland corridors.
- Promote interoperable digital tools for cargo traceability, monitoring and risk analysis to support intelligence-led inspections and enforcement.
- Strengthen insider-risk management, including personnel awareness, appropriate vetting and corruption-prevention measures.
- Improve coordination between physical-security, customs, law-enforcement and cybersecurity functions, while ensuring that controls remain risk-based and proportionate to avoid unnecessary delays to legitimate trade.

Policy Recommendation P2-4: Strengthen governance, implementation capacity and access to support

The EU should strengthen the capacity of Member States, port authorities and relevant private operators to implement safety, security and resilience measures consistently, while recognising differences in port size, governance and strategic role.

- Support technical assistance, peer learning, capacity building and specialised workforce development, particularly for smaller, peripheral and island ports.
- Strengthen coordination between public authorities, port authorities, infrastructure managers, terminal operators and other relevant private actors.
- Promote systematic post-incident learning and structured sharing of lessons from significant disruptions and security incidents.
- Improve access to relevant EU funding instruments, including CEF, Horizon Europe and the Internal Security Fund, for eligible investments in cybersecurity, critical infrastructure protection, preparedness and resilience.
- Where relevant, ensure that the security and resilience dimensions of dual-use infrastructure and military mobility can be considered in investment appraisal and prioritisation, integrated proportionately into TEN-T, resilience and corridor planning rather than through a separate regulatory regime.

9.2.3. Energy transition

Policy Recommendation P3-1: Target alternative fuel policy at conditions that determine demand, supply and investment

EU Policy should recognise that ports are important implementation locations for alternative fuels, but are not likely to be the main enabling actors for their uptake in maritime transport. Demand and investment decisions are mainly shaped by shipping companies, fuel suppliers, fuel producers,

cargo owners and the wider regulatory framework. Policy support should focus on reducing the investment uncertainty and facilitating coordinated investment across the fuel value chain, rather than expecting port authorities to create demand.

- **Build on the demand signals provided by FuelEU Maritime and the EU ETS** to reduce remaining uncertainty around the location, scale and timing of alternative-fuel demand and supply.
- **Use targeted instruments to facilitate coordination between market actors**, improve visibility of expected demand and reduce investment risk where infrastructure, fuel supply and vessel uptake depend on each other**.**
- **Enable ports to support implementation through their spatial planning and landlord functions**, including spatial planning, land allocation, permitting, safety frameworks, training and coordination with market actors. Where appropriate, concession conditions can help influence where and how alternative-fuel infrastructure is developed.
- **Assess whether EU-level mechanisms comparable to the European Hydrogen Bank could support other alternative fuels relevant to maritime transport**, subject to market conditions and sector-specific needs.

Policy Recommendation P3-2: Translate long-term EU decarbonisation targets into predictable investment conditions for ports

The European Parliament should support a **predictable long-term policy direction for the energy transition in ports**, building on existing EU climate and maritime decarbonisation objectives. Rather than introducing additional high-level targets, policy should provide sufficient continuity and clarity to support investment in alternative fuels, port electrification and energy efficiency, while retaining flexibility as technologies, markets and local conditions evolve.

- Provide a stable and concrete long-term **policy framework** that enables ports and market actors to anticipate future requirements, plan investments and mobilise private **financing for green port infrastructure**.
- Maintain flexibility for a multi-fuel approach, recognising the uncertainty surrounding the future role of hydrogen, ammonia, methanol, methane, produced as either biofuel or synthetic fuels. The overall direction towards reducing the greenhouse gas intensity of energy used in ports and maritime transport should remain clear and stable, while market and technological conditions determine the most suitable energy carriers.
- Avoid premature technological lock-in by combining certainty over long-term decarbonisation objectives with flexibility in the technologies and fuels used to achieve them.
- Support energy efficiency investment through clear long-term targets and more consistent emissions reporting, helping **port actors to identify priorities and assess expected benefits where investment is constrained by upfront costs, uncertain payback periods, limited knowledge or split incentives**.
- Translate the sustainability ambitions of the EU Ports Strategy into credible investment signals, providing ports, grid operators, shipping companies, fuel suppliers and industrial actors with confidence in the stability of future policy direction.

Policy Recommendation P3-3: Support international alignment through IMO

The European Parliament should support international alignment through **IMO** to promote globally coordinated policy action to reduce GHG emissions from maritime transport. From the perspective of avoiding regulatory fragmentation and maintaining a global level playing field, globally coordinated

measures offer advantages over exclusively regional approaches, while not replacing the need for EU-level action.

- Encourage the Commission and Member States to pursue coherent positions at IMO, aligned with EU objectives on global GHG standards, fuel requirements and market-based measures.
- Use international alignment to reduce investment uncertainty for shipping companies, fuel suppliers and ports taking decisions on fuel supply, bunkering infrastructure, safety procedures and training.
- Continue supporting EU action through existing instruments, including AFIR, FuelEU Maritime and the EU ETS, rather than delaying EU measures pending international agreement.
- Use the European Parliament's institutional role to support and scrutinise the EU's international policy direction. While the Parliament has no formal negotiating role at IMO, it may send parliamentary delegations to relevant meetings and assess whether international outcomes provide sufficient environmental ambition and a level playing field.

9.2.4. Digitalisation

Policy Recommendation P4-1: Establish mechanisms for scaling up and replicating proven digital solutions across European ports

The implementation of the EU Ports Strategy could place greater emphasis on **establishing mechanisms to support the deployment and replication of innovative digital solutions beyond the pilot phase**. While the Strategy rightly places greater emphasis on market uptake through Horizon Europe, strengthened public-private cooperation and targeted support for innovation, additional attention should be given to scaling up mature digital solutions across ports with different operational characteristics and levels of digital maturity.

- **Develop dedicated scale-up programmes** supporting the deployment of mature and proven digital solutions beyond individual pilot projects;
- **Promote peer-learning initiatives and knowledge-sharing** mechanisms enabling successful solutions demonstrated in leading ports to be replicated across the wider European port system.

Policy Recommendation P4-2: Strengthen the EU policy and governance framework for interoperable port, hinterland and supply-chain data exchange

The analysis and stakeholders' interviews highlight an opportunity to **strengthen interoperability across the existing EU regulatory and digital environment for maritime and freight transport**. This does not require the creation of a new centralised European platform, but rather stronger coordination and interoperability between existing and emerging systems and frameworks, including the European Maritime Single Window environment (EMSWe), the electronic Freight Transport Information (eFTI) framework, Port Community Systems and other national, port and hinterland transport platforms.

- **Promote common standards, interoperable architectures, secure APIs** (Application Programming Interfaces) and harmonised governance principles supporting trusted data exchange between Port Community Systems, maritime and freight information systems, hinterland transport operators and the wider logistics ecosystem.
- **Develop harmonised governance principles for data exchange**, with clear arrangements for data access and usage rights, commercially sensitive information, data quality, cybersecurity and accountability.

- **Strengthen interoperability between existing and emerging systems and frameworks**, rather than creating a new centralised European platform.
- **Improve end-to-end visibility and coordinated planning of cargo flows** connecting port, maritime, terminal and hinterland information across logistics chains
- **Exploit interoperable data exchange to strengthen disruption management and resilience**, including by supporting the identification of alternative routes, modes or logistics capacity.

Policy Recommendation P4-3: Build investment and implementation capacity for port digitalisation

Future implementation of the EU Ports Strategy could **strengthen the capacity of European ports to invest in, implement and maintain digital solutions over time**, building on existing EU and national funding instruments.

- **Promote coordinated investment in digital infrastructure and public-private cooperation** to support the implementation and long-term operation of digital solutions;
- **Strengthen digital skills and organisational capabilities** required to deploy, operate and maintain increasingly complex digital systems
- **Provide targeted support for smaller and medium-sized ports and other ports with lower levels of digital maturity**, recognising differences in investment and implementation capacity.

9.2.5. Hinterland connectivity

Policy Recommendation P5-1: Develop a European port-hinterland connectivity and resilience observatory

The EU should develop a **common monitoring framework to assess whether ports are effectively integrated into multimodal and resilient hinterland corridors rather than only formally connected to the TEN-T network**. This would support the objective of the EU Ports Strategy of strengthening reliable hinterland links by creating a practical evidence base for identifying bottlenecks, prioritising investments and monitoring delivery.

- **Monitor the availability and capacity of road, rail and inland waterway connections**, together with TEN-T and interoperability compliance.
- **Track the performance of terminals, dry-ports and logistics-platforms**, as well as modal split, service reliability and cross-border integration.
- **Assess the resilience of port-hinterland connections**, including the availability of alternative routes and modes.
- **Include selected dual-use indicators where strategically appropriate**, while avoiding the disclosure of operationally sensitive information.
- **Use the observatory to strengthen corridor-level oversight of port-hinterland performance**, moving beyond fragmented project-level reporting and providing a stronger evidence base for CEF prioritisation, the identification of critical transport entities under the CER Directive, and European Parliament scrutiny of whether EU funding is improving actual port-hinterland connectivity.

Policy Recommendation P5-2: Use EU funding instruments strategically for integrated port-access packages

Future EU funding support **integrated port-access packages addressing the weakest links across the whole logistics chain, rather than isolated infrastructure assets**. This would translate the EU

Ports Strategy's emphasis on finance, smaller ports and project preparation into a more targeted investment logic.

- **Prioritise port-hinterland bottlenecks that constrain corridor performance**, including last-mile rail access, terminal tracks, marshalling capacity, retroport facilities, inland waterway links, cross-border sections, digital coordination and, where relevant, energy infrastructure.
- **Link funding eligibility and the choice of financing instrument to the function of each project within the wider corridor**, using CEF Transport for TEN-T bottleneck removal and interoperability, Cohesion Policy for peripheral, island, eastern and smaller-port connectivity, military mobility funding for proportionate dual-use requirements and EIB/InvestEU or blending for bankable components.
- **Complement financing with grants and technical assistance where public benefits are high but direct revenues are weak**.
- **Improve coordination between funding streams** to reduce the risk that strategically important projects remain unsupported because of unclear eligibility, fragmented instruments, limited administrative capacity or slow permitting.

Policy Recommendation P5-3: Mainstream dual-use and resilience appraisal in strategic port-hinterland corridors

Dual-use and resilience requirements should be **integrated early into the planning and appraisal of strategically relevant port-hinterland infrastructure**, using a proportionate and risk-based way so that additional requirements are targeted to corridors and ports where they provide clear civilian and strategic value.

- **Screen strategically relevant infrastructures for dual-use and resilience requirements**, including heavy-load capacity, loading-gauge and rail-gauge constraints, bridge and tunnel suitability, quay and terminal handling capacity, secure staging areas, cyber-secure coordination, alternative routes, cross-border procedures and administrative readiness.
- **Prioritise investments that generate both civilian and strategic value**, strengthening commercial freight operations, supply-chain continuity, crisis response and strategic preparedness rather than treating dual-use requirements as a separate objective.
- **Align TEN-T, CEF, CER and military mobility instruments around common appraisal criteria for selected strategic corridors, where appropriate**.
- **Integrate these requirements early enough in infrastructure planning to reduce the need for costly subsequent retrofits** and help ensure that EU-funded infrastructure can serve both normal logistics operations and exceptional crisis requirements.

9.3. Scenario sensitivity of policy recommendations

This study assesses how the urgency of the policy recommendations varies under different future scenarios. In total, the study identifies 16 policy recommendations. For each recommendation, the assessment considers whether the need for EU-level attention, prioritisation or implementation increases under each scenario. The full assessment is included in Annex 3.

The four scenarios differ in terms of the pace and coordination of decarbonisation, and the degree of global trade and geopolitical cooperation. The purpose of the assessment is therefore to test how the recommendations perform under different external conditions, ranging from more fragmented and competitive futures to more cooperative and coordinated futures. The assessment shows that EU action becomes particularly important in futures characterised by greater global competition and

geopolitical fragmentation. In both **S1 Fragmented Fossil Security** and **S2 Green Competition**, most recommendations are assessed as critically urgent. This suggests that, if the medium-term environment moves towards more fragmented trade, regulatory divergence and strategic competition, the EU would need to act more decisively to protect port competitiveness, strengthen resilience, support investment and avoid dependency on non-EU actors or technologies.

In **S3 Open trade, weak global action**, the recommendations remain relevant, but most are assessed as having higher rather than critical urgency. Open trade reduces some geopolitical pressures, but weak global climate action continues to create uncertainty around decarbonisation, investment and competitiveness.

In **S4 Green Cooperation**, the urgency of many recommendations is lower because open trade, coordinated decarbonisation and regulatory convergence reduce some of the risks facing EU ports. However, this does not make EU action unnecessary. In such a scenario, policy should focus more on enabling EU ports to benefit from coordinated green transition, technological deployment and open market opportunities.

9.4. Conclusion

Overall, the assessment shows that the EU Ports Strategy provides a broad and relevant framework for addressing the evolving role of European ports, but that its effectiveness will depend on concrete implementation, stronger coordination and a more systematic evidence base.

The scenario analysis further shows that these priorities remain relevant under different future conditions, although their urgency increases significantly in more fragmented and competitive geopolitical environments.

The findings and recommendations of this study could also provide a basis for further structured discussion with EU institutions, Member States, port authorities and industry stakeholders.

Three issues appear particularly relevant for such further discussion. First, the diversity of the European port system raises questions about the appropriate scope and proportionality of EU port policy. Further work could examine port typologies and strategic functions, determine where common requirements may be necessary and where differentiated approaches are appropriate, and consider whether vulnerabilities in smaller or less strategically prominent ports could nevertheless create system-wide risks, for example in cybersecurity or organised crime. Second, several recommendations call for the EU to strengthen, support or facilitate action. Their operationalisation would benefit from greater specification of the instruments available, the appropriate level of intervention and the respective responsibilities of the EU, Member States, port authorities and industry.

Finally, implementation would benefit from a clearer understanding of the resources, institutional capacity and time required to deliver the proposed measures. This could include assessing investment needs and implementation timelines, identifying potential regulatory or institutional constraints, and considering where incentives among public and private actors may not be sufficiently aligned to deliver the desired outcomes. Such follow-up work could help translate the strategic direction provided by the EU Ports Strategy and the recommendations of this study into a realistic and prioritised implementation pathway for the European port system.

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ANNEX 1: METHODOLOGICAL APPROACH

This study is based on a mixed qualitative approach. It relies primarily on a review of the relevant academic, policy and sectoral literature, complemented by 32 interviews with stakeholders from the sector (see Annex 2) with more information about the stakeholder interview methodology).

In addition, two case studies of major ports outside the EU are used to identify relevant international practices from outside the EU. The analytical framework used in this study is further explained in the section below.

Box 8: Stakeholder interviews

Stakeholder interviews methodology

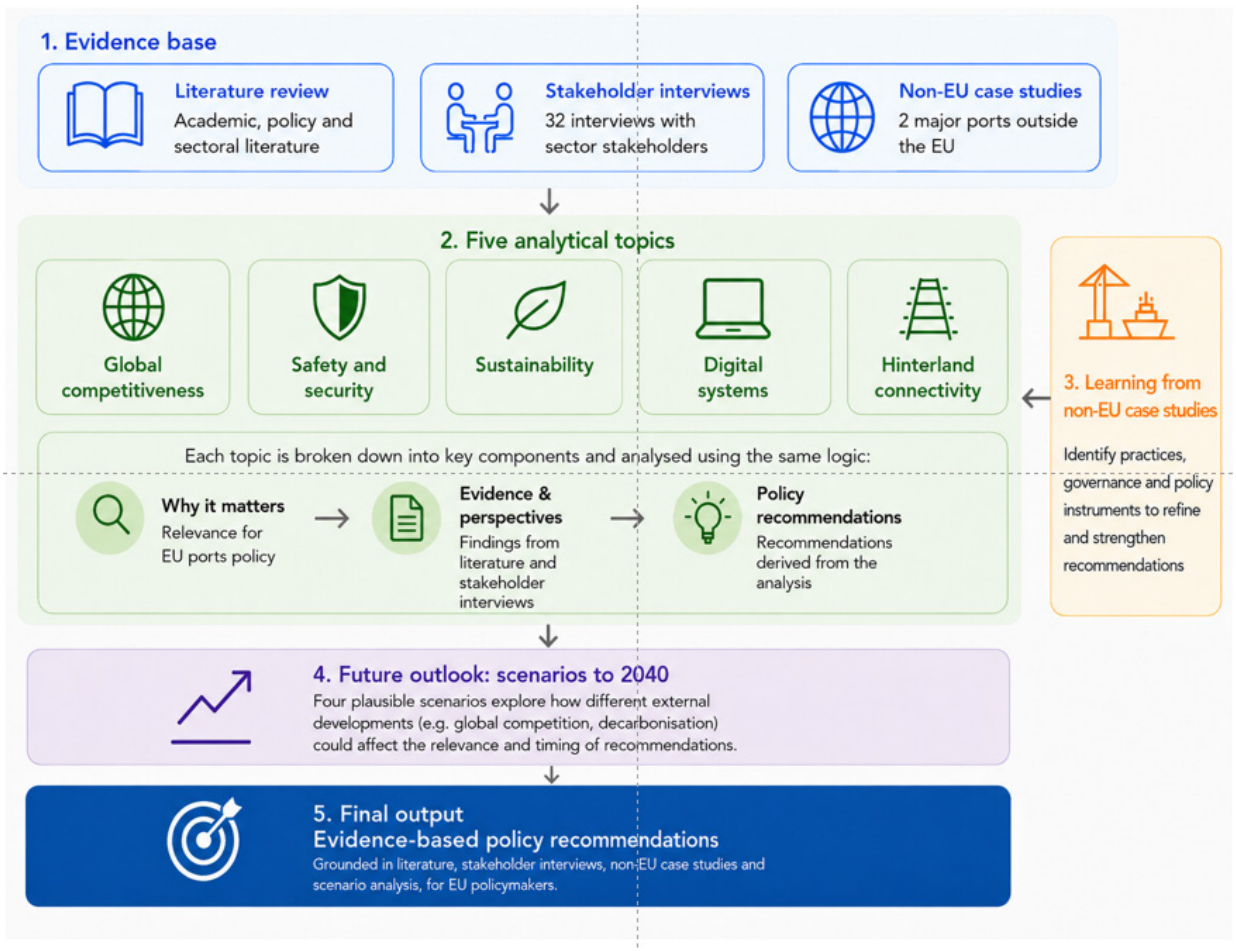
Stakeholder interviews were used to complement the desk research with qualitative evidence from across the European port sector. Interviewees were selected purposively, with particular emphasis on EU-level sector organisations and port administrations, while also ensuring coverage of Member State authorities, experts and academia. Geographical coverage was considered when selecting port-level stakeholders, with the aim of reflecting the main European port regions and the distribution of cargo activity.

In total, 38 organisations were approached and 32 interviews were conducted. Following each interview, a written interview report was prepared and shared with the stakeholder for validation. The validated reports were then coded against the study's analytical themes and reviewed to identify recurring issues, common views and areas of divergence across interviews.

A full overview of the organisations interviewed and the geographical and organisational distribution of the interviews is provided in **Annex 2**. The annex provides the interview codes assigned to each participating organisation; these codes are used throughout the study to attribute statements and findings to interviewees while they remain anonymous.

The analytical framework used in this study is shown in Figure 21.

Figure 21: Analytical framework for developing evidence-based policy recommendations



Source: Authors.

The research questions are organised into **five analytical topics**:

- global competitiveness;
- safety and security;
- energy efficiency and decarbonisation;
- digital systems; and
- hinterland connectivity.

In order to focus the analysis, the study identifies a number of components under each topic for more detailed assessment. These components are selected on the basis of three criteria: their relevance to the policy questions raised, their prominence in the literature and stakeholder interviews, and the extent to which EU-level policy action could realistically address them. The rationale for selecting these components is explained in the respective chapters. Table 24 shows the components discussed under each chapter.

Table 24: Components further analysed under each topic

Topic	Components
1. Global competitiveness	• Vulnerability of transhipment hubs • Port costs and efficiency • Technological leadership as a driver of port competitiveness
2. Safety and security	• Cybersecurity and digital security of EU ports • Protection of critical port infrastructure against organised crime, illegal activities, and border security threats • Dual-use Infrastructure and strategic resilience
3. Sustainability	• Alternative fuels and port readiness • Port electrification • Energy efficiency in port operations and industrial cluster
4. Digital systems	• Adoption of digital systems and solutions in ports • Data sharing and governance • Innovative digital solutions
5. Hinterland connectivity	• Multimodal port connectivity and hinterland integration • Dual-use requirements for port-hinterland infrastructure • Financial instruments and investments

Source: Authors.

Each component follows a **similar analytical logic**. First, the study explains why the issue is relevant for EU ports policy. It then discusses the main findings from the literature and compares these with the perspectives gathered through stakeholder interviews. Where appropriate, the analysis is complemented by benchmarking exercises and illustrative examples drawn from European ports. Rather than presenting recommendations within each component, the findings are progressively consolidated and synthesised into a dedicated policy chapter.

The **two non-EU case studies** are used to further refine these recommendations. They provide examples of how two major ports outside the EU, **Tanger Med and Singapore,** address comparable challenges, including competitiveness, infrastructure development, sustainability, digitalisation and security. The purpose of these case studies is to identify practices, governance arrangements or policy instruments that may offer useful lessons for EU policymakers.

The final part of the study develops **four plausible medium-term scenarios** to 2040. These scenarios are subsequently used to assess how different external developments—including geopolitical fragmentation, global trade dynamics and the pace of decarbonisation— may influence future policy actions.

Building on the findings from the five analytical topics and the case studies, the study consolidates the resulting **policy recommendations** into a dedicated chapter. This integrated approach facilitates comparison across thematic areas and provides policymakers with a single, coherent set of recommendations. The proposed recommendations are finally assessed against the medium-term scenarios to 2040; depending on the scenario, some recommendations may require greater prioritisation or earlier implementation.

During the research, it also became clear that some policy issues and recommendations raised by stakeholders do not fit neatly within the five-topic structure. These **cross-cutting issues** are therefore

discussed separately and included in Annex 2. This ensures that relevant recommendations are not excluded simply because they fall outside the main analytical categories used in the study.

ANNEX 2: STAKEHOLDER CONSULTATION

Stakeholder selection

Stakeholder interviews formed an important source of evidence for the study and were used to complement the desk research with practical perspectives from across the European port sector. In selecting interviewees, preference was given to **EU-level sector organisations**, as these were expected to provide a cross-cutting perspective on developments and challenges across the EU as a whole. This was complemented by a substantial number of **port administrations**, which provided more detailed evidence on the challenges experienced at port level. Interviews were also conducted with Member State ministries and experts and academics.

Geographical coverage was considered when selecting port and other geographically specific stakeholders. The aim was not to achieve equal representation of each European sea basin, but rather to obtain a **broad geographical balance while reflecting the distribution of cargo activity across the European port system**. Consequently, comparatively greater representation was sought from regions accounting for substantial shares of EU port traffic, while ensuring that perspectives from the Mediterranean, Baltic and Black Sea regions were also included.

In total, **38 organisations were approached and 32 interviews were conducted**. Table 25 and Table 26 show the distribution of stakeholder interviews by organisation type and geography.

Table 25: Stakeholder interviews by organisation type

Organisation type	Number of interviews
EU sector organisation	10
Member State ministry	3
Port administration	13
Experts / academia	6
Total	**32**

Table 26: Stakeholder interviews by geographical coverage

Geographical coverage	Number of interviews
EU-level	14
North Sea	6
Mediterranean	8
Baltic Sea	2

Geographical coverage	Number of interviews
Black Sea	2
Total	**32**

Source: Authors.

A written interview report was prepared following each interview and shared with the respective stakeholder, providing them with an opportunity to **validate the record and, where necessary, provide corrections or clarifications**. The interview reports were subsequently analysed systematically by the study team. Relevant passages were coded according to the analytical themes of the study, such as competitiveness, security, sustainability, digitalisation and hinterland connectivity. The coded material was then reviewed across interviews to identify **recurring themes, areas of convergence and divergence between stakeholders, and statements or concerns raised consistently across different interviews**. These findings were used throughout the thematic analysis alongside evidence from the literature.

Interview codes are assigned to each participating organisation. These codes are used throughout the study to attribute statements and findings to interviewees while they remain anonymous.

#	ID	Date	Format
1	EU Sector organisation 1	28/05/2026	Online interview
2	EU Sector organisation 2	10-06-2026	Online interview
3	EU Sector organisation 3	10-06-2026	Online interview
4	EU Sector organisation 4	25/06/2026	Online interview
5	EU Sector organisation 5	27/05/2026	Written input
6	EU Sector organisation 6	27/05/2026	Online interview
7	EU Sector organisation 7	12/06/2026	Online interview
8	EU Sector organisation 8	25/06/2026	Online interview
9	EU Sector organisation 9	12/06/2026	Online interview
10	EU Sector organisation 10	30/06/2026	Online interview
11	Expert 1	09-06-2026	Online interview

#	ID	Date	Format
12	Expert 2	15/06/2026	Online interview
13	Expert 3	02/07/2026	Written input
14	Expert 4	26/06/2026	Online interview
15	Expert 5	18/06/2026	Online interview
16	Expert 6	13/06/2026	Online interview
17	Expert 7	17/06/2026	Written input
18	Expert 8	18/06/2026	Written input
19	Member State Ministry 1	26/06/2026	Online interview
20	Member State Ministry 3	08/07/2026	Online interview
21	Port administration 1	15/06/2026	Online interview
22	Port administration 2	27/05/2026	Online interview
23	Port administration 3	09/06/2026	Online interview
24	Port administration 4	30/06/2026	Written input
25	Port administration 5	30/06/2026	Online interview
26	Port administration 6	30/06/2026	Written input
27	Port administration 8	20/07/2026	Written input
28	Port administration 9	19/05/2026	Written input
29	Port administration 11	25/05/2026	Written input
30	Port administration 12	10/06/2026	Written input
31	Port administration 13	19/06/2026	Written input
32	Port administration 14	10/06/2026	Written input

Stakeholder consultation results

In addition to the findings under the main analytical topics, the interviews yielded **several cross-cutting insights that do not fit neatly within a single policy area**. These insights concern issues such as the broader strategic role of ports, the implementation and follow-up of the EU Ports Strategy, the need for EU funding for public-interest functions, and the relevance of port governance for investment capacity and strategic performance.

These cross-cutting findings also lead to policy recommendations for the European Parliament. They are discussed in this section alongside the stakeholder views from which they emerged.

i. Recognition of ports in EU policy

Across the interviews, stakeholders generally welcomed the fact that the European Commission has developed a dedicated EU Ports Strategy. Several stakeholders considered the strategy valuable because **it gives ports greater visibility in EU policy** and recognises their broader strategic role. In this sense, the strategy also functions as an agenda-setting instrument that helps to "put ports on the map" across different policy areas and government departments (EU sector organisation 1, 2, Port administration 1, 3, 5).

ii. Coordination across EU policy areas

This recognition is important because ports do not fall neatly within a single policy domain. They are relevant for not only transport and logistics but also other domains such as industry, energy, climate policy, security, defence, digitalisation, regional development and strategic autonomy. Several stakeholders therefore stressed that **port policy should not be treated only as a matter of transport policy or port-specific legislation**. Instead, the role of ports should be reflected more consistently in horizontal EU policy files and across different Commission Directorates-General (EU sector organisation 1, Port Administration 1, 2, 3, 9, Expert 1).

iii. Ports as strategic hubs serving public-interest objectives

Stakeholders also pointed to the EU Ports Strategy framing of ports as places that contribute to public-interest objectives such as resilience, energy security, decarbonisation, cyber resilience, critical infrastructure protection and military mobility. Many of these objectives require substantial investment, but do not always generate a direct or immediate commercial return. Stakeholders therefore stressed that the strategy should be supported by sufficient EU funding and by policy instruments that enable ports to deliver these wider public functions without undermining their commercial competitiveness (EU sector organisation 1, 3, Port Administration 1, 2, 3).

iv. Implementation, prioritisation and follow-up

Stakeholders generally welcomed the EU Ports Strategy as an important agenda-setting document, but several stressed that its value will depend on concrete follow-up. One stakeholder noted that the strategy addresses many relevant challenges, but that its impact depends on "what comes next" (EU Sector organisation 2). Another stakeholder similarly argued that some actions in the strategy are not very committal and that the EU should focus on a limited number of credible actions that really work (Port Administration 2). Another stressed that the strategy will only have practical value if ports are structurally reflected in future EU legislation, funding instruments and policy programmes (Port Administration 1).

v. Port governance, a political sensitive topic

Port governance emerged as an important cross-cutting theme in the interviews. Governance models differ considerably between European ports, including in the degree of public ownership, corporatisation, private-sector involvement, landlord functions, concession arrangements and strategic autonomy.

Academic literature confirms that port governance models influence port performance and the roles that port authorities can play (Adler et al., 2025; de Oliveira et al., 2021; Langen & Saragiotis, 2018). Several stakeholders stressed that direct EU intervention in port governance would be politically sensitive and could be disruptive, given the diversity of national port systems and the importance of local flexibility. They argued that detailed EU involvement could reduce the ability of ports to respond quickly to local market conditions. At the same time, governance remains relevant because some port authorities may be better positioned than others to integrate public-interest objectives into their strategy, investment decisions and operational role.

One stakeholder therefore argued that the EU Ports Strategy **should have recognised governance and investment capacity more explicitly**, even if direct EU intervention in national port governance remains politically difficult (Expert 2). This suggests that the strategy does not necessarily need to prescribe a particular governance model, but it could more clearly acknowledge that governance affects ports' ability to deliver the strategic functions now expected of them.

vi. Completeness and scope of the EU Ports Strategy

Stakeholders generally did not identify one major policy area that is entirely absent from the EU Ports Strategy. However, several interviews **pointed to areas where the strategy could be more complete or more precise**.

First, some stakeholders argued that the strategy could be **more growth-oriented**. A stakeholder considered that the strategy could have been more ambitious in setting objectives and providing the means for European ports to regain a stronger global position (EU sector organisation 3). Another stakeholder argued that the strategy places considerable emphasis on small and medium-sized ports, while giving less attention to the competitiveness of ports of major European strategic importance (EU sector organisation 3, Expert 2).

Second, some stakeholders considered that **specific port functions or impacts receive insufficient attention**. One argued that the strategy applies a relatively narrow understanding of sustainability and should address biodiversity, water quality, underwater noise, habitat protection and the environmental consequences of port expansion more explicitly (EU sector organisation 3). A port noted that passenger traffic and tourism are underrepresented, despite their relevance for certain ports (Port administration 5). Another argued that the strategy should give more attention to port congestion, hinterland connectivity and the market power of major shipping lines, including their vertical integration into terminals and inland logistics (EU sector organisation 4).

Third, some stakeholders noted that **key terms could be defined more clearly**. For example, the strategy's references to small and medium-sized ports are not always clearly linked to the TEN-T distinction between core and comprehensive ports (Expert 2). Similarly, the term critical infrastructure may require a clearer operational definition to avoid either under-protection of genuinely strategic assets or over-regulation of activities that do not present the same risk profile (Expert 2, Port Administration 2).

vii. Social cohesion, skills and quality jobs

Social cohesion, skills and quality jobs were not a central focus of this study, but they were raised by several stakeholders. Stakeholders noted that new technologies and policy requirements will change the skills needed in ports. Alternative fuels, shore-side electricity, electrification, AI, automation, cybersecurity, digital integration and resilience management all require new technical capabilities. This means that skills, training, upskilling and reskilling are enabling conditions for the implementation of the EU Ports Strategy (EU sector organisation 3, Expert 5, 7, 8).

The interviews do not provide a sufficient basis for detailed policy recommendations on this theme. Nevertheless, the interviews do not suggest that the Commission's decision to include this theme in the EU Ports Strategy is misplaced. On the contrary, the stakeholder input indicates that workforce development will be necessary for the successful implementation of several other objectives, including competitiveness, digitalisation, security, safety and the energy transition.

ANNEX 3: SCENARIO ASSESSMENT

The four scenarios outlined in Chapter 8 describe **different external environments in which European ports may operate towards 2040**. This annex analyses the robustness of the proposed recommendations from chapter 9. It does so by assessing **how urgent and relevant** the policy recommendations are under each scenario. The recommendations are assessed against each scenario to determine whether the need for EU-level attention, prioritisation or implementation increases.

Global competitiveness

Table 27: Urgency policy recommendations related to global competitiveness across the four scenarios

	S1 Fragmented Fossil Security	S2 Green competition	S3 Open trade, weak global action	S4 Green cooperation
P1-1: Ensure credible monitoring of leakage risks under EU maritime climate legislation	+++	++	+++	+
P1-2: Strengthen the evidence base on EU port competitiveness and in ongoing EU policy processes	+++	+++	++	+
P1-3: Translate the EU Ports Strategy's technological leadership objective into a concrete port innovation deployment agenda	+	+++	+	++

Source: Authors' own elaboration.
Note: + =lower urgency ++ = medium urgency, +++ = higher urgency.

Recommendation P1-1: Further investigate the vulnerability of cargo diversion of transhipment ports

The recommendation to investigate cargo diversion risks at transhipment ports is most urgent in S1 and S3, where geopolitical uncertainty, cost pressures and weaker global climate action increase the risk that cargo flows shift to neighbouring non-EU ports.

In S2, the recommendation remains relevant due to divergent decarbonisation standards, but it is less urgent because decarbonisation is accelerating across major economies. In S4, the urgency is low, as coordinated global climate action and regulatory convergence reduce the likelihood of significant regulatory-driven cargo diversion.

Recommendation P1-2: Strengthen the evidence base on EU port competitiveness and ensure port competitiveness considerations are reflected in ongoing EU policy processes

This recommendation is most urgent in S1 and S2, where geopolitical fragmentation increases uncertainty and EU ports may face stronger competitive pressure from non-EU ports operating under different conditions.

In S3, the recommendation remains relevant because open trade preserves competitive pressure between EU and non-EU ports, while weak global climate action may leave EU ports exposed to higher regulatory and decarbonisation costs than competitors. In S4, the urgency is lower, as coordinated

climate action and regulatory convergence reduce some competitiveness risks. However, even in this scenario, a stronger evidence base remains useful to monitor whether EU ports benefit from open trade and decarbonisation opportunities, and whether ongoing EU policy processes sufficiently support port investment, grid capacity, permitting and funding needs.

Recommendation P1-3: Translate the EU Ports Strategy's technological leadership objective into a concrete port innovation deployment agenda

The recommendation to take leadership in green and digital technologies is most urgent in S2, where accelerated but fragmented decarbonisation creates strong competition over standards, fuel pathways and certification systems. In this context, the EU need to strengthen their technological position to remain competitive and avoid dependency on non-EU solutions.

The recommendation is also relevant in S4, where green technologies are highly relevant and open market increases changes of EU technologies being adopted worldwide. Through technological leadership, EU ports and industry can benefit from the first-mover advantage. In S1 and S3, the urgency is lower, as weaker climate ambition reduces the immediate demand for green technologies, although digitalisation remains relevant for security, resilience and efficiency.

Safety and security

Table 28: Urgency policy recommendations related to safety and security across the four scenarios

Policy recommendation area	S1: Fragmented Fossil Security	S2: Green Competition	S3: Cost-Led Global Trade	S4: Green Cooperation
P2-1: Strengthening cybersecurity and digital resilience through consistent and operational implementation of existing EU requirements	+++	+++	++	++
P2-2: Strengthening resilience of critical port infrastructure through common risk assessment and preparedness and resilience-by-design approaches	+++	+++	++	++
P2-3: Strengthen the fight against organised crime through whole-logistics-chain cooperation, risk-based controls and secure information sharing	+++	++	+++	+
P2-4: Strengthen governance, implementation capacity and access to EU support for security and resilience	+++	+++	++	++

Source: Authors' own elaboration.
Note: + =lower urgency ++ = medium urgency, +++ = higher urgency.

The analysis indicates that the EU already has a substantial regulatory and policy foundation for port safety, security and resilience. The main policy challenge is therefore effective and consistent

implementation across a highly diverse European port system, rather than the creation of a separate regulatory framework. The recommendations below complement the EU Ports Strategy by translating its strategic objectives into concrete implementation mechanisms, with particular attention to interoperability, operational preparedness, cross-border cooperation, capacity building and access to EU support.

Recommendation P2-1: Strengthening cybersecurity and digital resilience through consistent and operational implementation of existing EU requirements

The EU should support the practical implementation of NIS2 and related requirements in port environments, taking account of the specific interdependencies between information technology, operational technology and physical operations. This should include maritime-specific guidance under NIS2, where appropriate, and common or interoperable approaches to cyber-risk assessment, incident response and preparedness testing. Secure information sharing between port authorities, terminal operators, customs, logistics operators and relevant digital service providers should be strengthened, alongside regular cyber-resilience exercises covering potential cascading effects between digital systems and physical port operations. Targeted technical assistance and skills development should be provided to smaller, peripheral and island ports facing constraints in specialised expertise and resources.

Recommendation P2-2: Strengthening resilience of critical port infrastructure through common risk assessment and preparedness and resilience-by-design approaches

The EU should support more consistent approaches to identifying vulnerabilities and preparing for disruptions affecting interconnected transport, energy, digital and logistics infrastructure, while respecting Member States' responsibilities for national security and critical infrastructure protection. This should include common principles and interoperable methodologies for risk assessment, resilience benchmarking and continuity planning, complemented by regular multi-agency exercises covering cyber incidents, organised crime, critical infrastructure disruption and complex multi-hazard scenarios. Cross-border crisis communication and continuity arrangements should also be strengthened, particularly where disruptions affect wider transport and logistics networks. Port investments should increasingly incorporate resilience by design, including redundancy and the coordinated planning of transport, energy and digital infrastructure.

Recommendation P2-3: Strengthen the fight against organised crime through whole-logistics-chain cooperation, risk-based controls and secure information sharing

The EU should strengthen operational cooperation against drug trafficking, cargo-related fraud, insider threats and the exploitation of digital and logistical vulnerabilities across the wider logistics chain. This should include structured intelligence sharing between customs, law-enforcement authorities, port authorities and relevant private operators on high-risk cargo, emerging criminal patterns and vulnerabilities, and extending risk-based security monitoring beyond the port perimeter to inland terminals, logistics centres and strategically important hinterland corridors. Interoperable digital tools for cargo traceability, monitoring and risk analysis should be promoted to support intelligence-led inspections and enforcement. Particular attention should also be given to insider-risk management, including appropriate personnel awareness and corruption-prevention measures, and to stronger coordination between physical security, customs, law-enforcement and cybersecurity functions. Enhanced security controls should remain risk-based and proportionate, avoiding unnecessary administrative burdens and delays for legitimate trade.

Recommendation P2-4: Strengthen governance, implementation capacity and access to EU support for security and resilience

The EU should strengthen the capacity of Member States, port authorities and relevant private operators to implement safety, security and resilience measures consistently, while recognising differences in port size, governance and strategic role. This should include technical assistance, peer learning, capacity building and specialised workforce development, particularly for smaller, peripheral and island ports, together with stronger coordination between public authorities, port authorities, infrastructure managers, terminal operators and other relevant private actors. Systematic post-incident learning and structured sharing of lessons from significant disruptions and security incidents should also be promoted. Access to relevant EU funding instruments, including CEF, Horizon Europe and the Internal Security Fund, should be improved for eligible investment in cybersecurity, critical infrastructure protection, preparedness and resilience. Where relevant, the security and resilience dimensions of dual-use infrastructure and military mobility should be considered in investment appraisal and prioritisation and proportionately integrated into TEN-T, resilience and corridor planning, rather than through a separate regulatory regime.

Sustainability and energy transition

Table 29: Urgency policy recommendations related to sustainability and energy transition across the four scenarios

	S1 Fragmented Fossil Security	S2 Green competition	S3 Open trade, weak global action	S4 Green cooperation
P3-1: Target alternative-fuel policy at demand, supply and investment conditions	++	+++	++	+
P3-2: Translate long-term EU decarbonisation targets into predictable investment conditions for ports	++	+++	++	+
P3-3: Support international alignment through IMO	++	+++	+++	++

Source: Authors' own elaboration.
Note: + =lower urgency ++ = medium urgency, +++ = higher urgency.

Recommendation P3-1: Target alternative-fuel policy at conditions that determine demand, supply and investment

This recommendation is most urgent in S2, where accelerated but fragmented decarbonisation creates strong uncertainty over fuel pathways, standards, certification systems and investment priorities. In this scenario, EU policy needs to support the conditions under which demand, supply and investment in alternative fuels can develop, rather than placing the main responsibility on ports alone.

The recommendation is also highly relevant in S1 and S3. In S1, geopolitical fragmentation and energy-security concerns may slow or distort investment in alternative fuels, making targeted support for viable fuel pathways more important. In S3, weak global climate action may reduce international demand for alternative fuels, while EU actors still face decarbonisation requirements. In S4, the urgency

is lower because coordinated global climate action provides a more favourable market environment, although EU policy still has a role in supporting deployment.

Recommendation P3-2: Translate long-term EU decarbonisation targets into predictable investment conditions for ports

This recommendation is most urgent in S2, where rapid but fragmented decarbonisation increases the risk of uncertainty for investors, ports, shipping companies and fuel suppliers. Clear and reliable long-term targets are needed to reduce the risk of stranded investments and to provide direction for infrastructure planning, fuel production and port readiness.

In S1 and S3, the recommendation remains highly relevant. In S1, energy-security pressures may create uncertainty about the pace and direction of the transition. In S3, weak global action may make EU targets more exposed to competitiveness concerns, which increases the need for clear policy direction and predictable implementation. In S4, the urgency is lower because international alignment reduces uncertainty, but stable targets remain important for long-term investment planning.

Recommendation P3-3: Support international alignment through IMO

This recommendation is most urgent in S2 and S3. In S2, fragmented green competition increases the importance of international standard setting, fuel certification and regulatory alignment. A strong EU role in IMO negotiations can help avoid competing global standards and support the international uptake of sustainable maritime fuels and technologies.

In S3, the recommendation is also critical because weak global climate action could leave EU ports and shipping actors exposed to higher decarbonisation requirements than international competitors. Strengthening the EU's role at IMO level would help reduce this asymmetry by promoting more ambitious and coherent global rules. In S1, the recommendation remains highly relevant, although geopolitical fragmentation may make international agreement more difficult. In S4, the urgency is somewhat lower because global cooperation is already stronger, but continued EU engagement remains important to maintain ambition and ensure effective implementation.

Digital systems

Table 30: Urgency policy recommendations related to digital systems across the four scenarios

	S1 Fragmented Fossil Security	S2 Green competition	S3 Open trade, weak global action	S4 Green cooperation
P4-1: Establish mechanisms for scaling up and replicating proven digital solutions across European ports	+++	++	+	+
P4-2: Strengthen the EU policy and governance framework for interoperable port, hinterland, and supply-chain data exchange	+++	+++	++	+
P4-3: Build investment and implementation capacity for port digitalisation	+++	+++	++	+

Source: Authors' own elaboration.
Note: + =lower urgency ++ = medium urgency, +++ = higher urgency.

Recommendation P4-1 Establish mechanisms for scaling up and replicating proven digital solutions across European ports

This recommendation is most urgent under S1, where geopolitical fragmentation, supply chain disruptions and higher security concerns increase the need for efficient, resilient and digitally enabled port operations, as well as for the rapid replication of proven solutions. In S2, the recommendation remains highly relevant as European ports must improve efficiency and operational flexibility to remain competitive while accommodating multiple fuel pathways. Under S3, the relatively favourable economic environment and open trade give less pressure for additional EU intervention. In S4, the urgency is lower, as international cooperation, regulatory convergence and coordinated digitalisation provide more favourable conditions for the diffusion and replication of mature digital solutions across the port sector.

Recommendation P4-2 Strengthen the EU policy and governance framework for interoperable port, hinterland, and supply-chain data exchange

Strengthening interoperability and data exchange is most urgent under S1 and S2, where geopolitical fragmentation, divergent regulatory approaches and increasing competition require stronger EU coordination to ensure secure, trusted and seamless information exchange across logistics chains. Greater interoperability between existing port, hinterland and supply-chain digital systems can reduce fragmentation, improve operational resilience and support coordinated management of logistics flows, including in response to disruptions. Under S3, the recommendation remains important to support efficient freight movements and reduce administrative burdens in a growing global trading system. In S4, the urgency is lower because greater international cooperation and convergence of digital standards naturally facilitate interoperability and reduce the need for additional EU intervention.

Recommendation P4-3 Build investment and implementation capacity for port digitalisation

This recommendation becomes most urgent under S1 and S2, where geopolitical uncertainty, industrial transformation and increasing international competition increase the need for sustained investment in port digitalisation. Adequate investment capacity, organisational capabilities and digital skills are

particularly important to enable ports to implement and maintain digital solutions and adapt to changing operational requirements. Under S3, the recommendation remains relevant to ensure continued investment in infrastructure and digitalisation while supporting the competitiveness of EU ports. In S4, the urgency decreases, as coordinated global climate action, stronger international cooperation and greater policy convergence provide a more favourable environment for investment and reduce the need for additional governance interventions.

Hinterland connectivity

Table 31: Urgency policy recommendations related to hinterland connectivity across future scenarios

Policy recommendation	S1 Fragmented Fossil Security	S2 Green competition	S3 Cost-Led Global Trade	S4 Green cooperation
Develop a European port-hinterland connectivity and resilience observatory	+++	+++	++	+
Use EU funding instruments strategically for integrated port-access packages	++	+++	++	+++
Mainstream dual-use and resilience appraisal in strategic port-hinterland corridors	+++	++	+	++

Source: Authors' own elaboration.
Note: + =lower urgency ++ = medium urgency, +++ = higher urgency.

Recommendation P5-1: Develop a European port-hinterland connectivity and resilience observatory

The recommendation becomes critically important in S1 and S2, where uncertainty, geopolitical tensions and supply-chain disruptions increase the need for timely information on corridor performance and network resilience. In S1, disruptions at strategic maritime chokepoints and growing security concerns require continuous monitoring of alternative hinterland routes, multimodal capacity and network vulnerabilities to support rapid operational responses. In S2, the combination of accelerated but fragmented decarbonisation, reshoring and growing intra-European trade places increasing pressure on rail, inland waterway and terminal capacity, making a common European monitoring framework essential for coordinated investment decisions. Under S3, the observatory remains highly relevant because increasing trade volumes require efficient monitoring of corridor performance, although the absence of major geopolitical fragmentation reduces its urgency. In S4, strong international cooperation and coordinated infrastructure planning lower the immediate need for resilience monitoring, but the observatory continues to provide valuable evidence for maintaining efficient multimodal networks and supporting long-term strategic planning.

Recommendation P5-2: Use EU funding instruments strategically for integrated port-access packages

This recommendation is most urgent under S2 and S4, where substantial infrastructure investment is required to support changing freight patterns and the energy transition. In S2, fragmented decarbonisation pathways, reshoring and intensified competition between regions require coordinated investment in multimodal infrastructure, terminal capacity and energy networks to preserve the competitiveness of EU ports. In S4, coordinated global decarbonisation drives large-scale deployment

of alternative fuels, electrification and new logistics infrastructure, making integrated investment packages critical for delivering efficient and resilient hinterland connections. In S1, investment remains important for strengthening resilience, but constrained public budgets and lower economic growth reduce the pace of implementation, lowering the urgency compared with S2 and S4. Under S3, growing global trade supports continued investment needs, although weaker international climate action reduces pressure for rapid infrastructure transformation.

Recommendation P5-3: Mainstream dual-use and resilience appraisal in strategic port-hinterland corridors

The urgency of integrating dual-use and resilience considerations into strategic transport corridors is highest in S1, where geopolitical tensions, supply-chain disruptions and increased security risks make transport infrastructure a strategic asset. Under this scenario, ensuring that port-hinterland corridors are capable of supporting both commercial freight and emergency or defence-related logistics significantly strengthens European resilience. In S2, dual-use considerations remain important because geopolitical rivalry persists and competition over strategic resources intensifies, although the main investment priority shifts towards supporting the energy transition and industrial competitiveness. Under S3, open global trade and lower geopolitical tensions reduce the immediate need for dual-use infrastructure, making this recommendation comparatively less urgent despite the continued importance of resilience against climate-related disruptions. In S4, enhanced international cooperation lowers security concerns but does not eliminate the need for resilient transport networks. Dual-use planning therefore remains relevant as part of a broader strategy to improve infrastructure robustness and supply-chain continuity, although it is no longer a critical priority.

ANNEX 4: ADDITIONAL PORT-SPECIFIC REFERENCES AND SOURCES

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Note: Unlike other ports, Vienna has very little peer-reviewed literature specifically devoted to the digitalisation domain. This is not because Vienna is not digitalised, but because research on inland ports tends to focus on systems (intermodal logistics, inland navigation, digital freight corridors) rather than on individual ports.

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This study assesses the challenges facing European ports across five key areas: competitiveness, safety and security, energy transition and decarbonisation, digital systems, and hinterland connectivity. Drawing on two non-EU port case studies, it develops a strategic framework for strengthening EU port competitiveness, assesses the EU Ports Strategy adopted by the European Commission and offers targeted policy recommendations to advance the strategy's goals. This document was provided at the request of the TRAN Committee.

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