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Resilience Gateway Ports

Why Climate Resilience Matters and What It Takes

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Introduction

Ports are among the most consequential pieces of infrastructure in the global economy. They carry the bulk of world trade and anchor the supply chains that deliver food, fuel, and critical minerals. Sitting where sea meets land, they are not only infrastructure to be protected from climate risk, but also gateways that can strengthen the resilience of the wider systems they connect.

That role is increasingly under strain. Ports are exposed to a growing range of climate hazards—and because a port sits within a wider network, disruption rarely stays contained, rippling outward into supply chains, industries, and communities far beyond the port gate. Resilience planning is advancing, but it remains uneven and still maturing and is not yet fully reflected in the broader decisions and investments that shape a port's future.

This paper examines how that gap can be closed, through five interconnected fields of action: 1) understanding system-level risk, 2) coordinating across the many actors involved, 3) leveraging sector trends such as digitalisation and decarbonisation, 4) financing resilience in new ways, and 5) designing solutions that deliver multiple benefits at once. Drawing on examples from ports around the world, it shows how resilience can be embedded across an asset's full life cycle, turning ports from infrastructure at risk into resilience gateways for the wider systems they anchor ([see Exhibit 1](#)).

EXHIBIT 1

Ports set foundation of socioeconomic resilience



1. Ports Are Resilience Gateways

Ports occupy a unique position at the intersection of the maritime and land-based economies. This bridging role, connecting seaborne flows with hinterland networks, is precisely what makes them so consequential: ports serve both as infrastructure to be protected from climate risk, and as gateways that ensure and strengthen the resilience of entire socioeconomic systems.

ENABLER OF GLOBAL TRADE AND MOBILITY

Approximately 80% of global trade by volume passes through the world's ports,¹ underscoring their foundational role in the global economy. Ports also serve as critical nodes for tourism and passenger transport, with more than 415 million passengers embarking and disembarking in EU ports alone in 2024.² Ports act as multipliers, with every dollar flowing through a port creating, on average, \$4.30 in value for the global economy.³ The operational continuity of ports is therefore central to maintaining reliable trade flows and the safe, continuous movement of people.

GATEWAY TO ESSENTIAL GOODS

Ports are anchor points of key global supply chains on which modern societies depend, from food and fuel to the critical minerals underpinning industrial production. More than 80% of global trade in grains and oilseeds, for example, is carried by maritime transport.⁴ This also means, however, that disruptions of port operations cascade across global supply chains and materialise in global and local economic and societal impacts, such as industrial production halts, price spikes, or reduced access to essential goods for communities and households (for example, food shortages). In 2018, for instance, Typhoon Yutu forced all ports in Guam and the Northern Mariana Islands to close for almost a week, disrupting trade flows and even preventing humanitarian supplies from reaching the islands.⁵ Such disruptions carry severe costs: cascading impacts can amplify port-level losses by a factor of three to five across global supply chains,⁶ potentially affecting economic activity and surrounding communities.

ENGINE OF REGIONAL ECONOMIES

Ports generate substantial economic value for the regions, cities, and communities that surround them, serving as major sources of economic activity, connectivity, and employment.⁷ The global port industry employs more than 30 million people⁸ whose wages circulate within local economies. Beyond direct employment, ports catalyse related economic activity in adjacent communities and provide market access to firms located well beyond the immediate port footprint, while also acting as hubs of the blue economy that support maritime industries and services.

2. Ports are increasingly exposed, but not yet prepared

However, ports are increasingly exposed to climate risks that can damage assets, disrupt operations, and reverberate through the socioeconomic systems they support (see Exhibit 2). Globally, 86% of ports are exposed to more than three types of climatic and geophysical hazards.⁹ The economic cost is already substantial: climate-related port disruptions are estimated to cost the global economy between \$7 billion and \$10 billion every year,^{10,11} a figure that, without adequate resilience and adaptation measures, is projected to rise to as much as \$30 billion by 2100.^{9,10}

CLIMATE-DRIVEN IMPACTS ON PORTS ARE INTENSIFYING

While ports have long been designed to withstand threats from the sea, those threats are now increasing in both frequency and severity. Coastal flooding is one example: driven by worsening tide and storm surge activity, flooding events with a 1-in-100-year return period could occur once every ten years by 2100.¹¹ Hurricanes and cyclones, which already shut ports down for a median of six days per event,¹² are becoming stronger and more frequent. Furthermore, ocean acidification is shortening the lifespan of maritime assets by 15% to 30%.⁹ Beyond seaside hazards, drought and extreme heat are increasingly disrupting port operations directly. At the Panama Canal, severe drought recently forced authorities to cut ship crossings by approximately one third, disrupting one of the world's most important trade routes.¹³ Extreme heat also affects the productivity and safety of the workforce that keeps port infrastructure running, creating a further channel through which climate stress translates into operational disruption.

1. UNCTAD, 2025. [2025 Review of maritime transport](#).

2. Eurostat, 2025. [Maritime passenger statistics](#).

3. Verschuur J. et al., 2022. [Ports' criticality in international trade and global supply-chains](#).

4. OECD, 2022. [MARITIME TRANSPORTATION COSTS IN THE GRAINS AND OILSEEDS SECTOR](#).

5. The Conversation, 2023. [Extreme storms and flood events cause damage worth billions to ports – and they are most disruptive to small island developing states](#).

6. ICSI, 2025. [PORT DECISION MAKERS' GUIDE TO CLIMATE RISK ASSESSMENT](#).

7. WEF, 2025. [Nature Positive: Role of the Port Sector](#).

8. Verschuur J. et al., 2023. [Multi-hazard risk to global port infrastructure and resulting trade and logistics losses](#).

9. EDF and RTI International, 2022. [Act Now or Pay Later: The Costs of Climate Inaction for Ports and Shipping](#).

10. UNCTAD, 2023. [Regional Cooperation Mechanism on Low Carbon Transport](#).

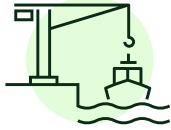
11. Kirezci et al., 2020. [Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st Century](#).

12. Verschuur, J. et al., 2020. [Port disruptions due to natural disasters: Insights into port and logistics resilience](#).

13. AP News, 2024. [Panama Canal traffic cut by more than a third because of drought](#).

EXHIBIT 2

The cost of climate impacts on ports is high, and rising



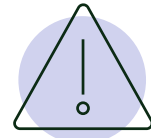
86%

of ports already exposed
to 3+ climatic and
geophysical hazards



\$7bn–\$10bn

annual cost of
climate-related port
disruptions today



~3x

projected increase in
that cost by 2100
without adaptation

IMPACTS ARE COMPOUNDED BY SYSTEM-LEVEL EFFECTS

Ports depend on the infrastructure around them, from the roads and railways that connect them inland to the power, utilities, and digital systems they run on. System-level disruptions to any of these can reverberate back into port operations. The roads and railways that provide access are a clear example. Extreme heat can cause road asphalt to melt and rails to buckle, as seen in the United States, where heat has caused an average of around 50 train derailments per year,¹⁴ degrading the connectivity on which ports depend. Flooding can threaten these links entirely, as in 2021, when floods and mudslides in British Columbia washed out the highways and rail lines serving Vancouver, halting all rail movement to and from Canada's largest port.¹⁵ Beyond transport links, critical supporting infrastructure such as power, utilities, and digital systems is similarly exposed, and its failure can trigger major disruptions to port activity if not actively managed.

RESILIENCE IS KEY, YET MOST PORTS ARE NOT YET ADEQUATELY PREPARED

Building resilience is therefore becoming an increasingly important operational and business priority, especially given the dual role ports play: strengthening their own resilience against the climate risks they face and extending resilience across the wider systems. It is not only an economic and social priority to reduce the cost of inaction and ensure social stability but also a strategic one. When climate shocks force ports to close, trade is diverted to others in the same region, and the ports that stay open absorb those flows and become strategic assets that draw national and foreign interest.¹⁶ At the same time, as climate change shifts where goods are produced, from crops to energy, it also shifts which ports matter most, so a port of limited importance today could become critical to a region's supply in the decades ahead. Resilience is therefore not a fixed priority for a fixed set of ports but a growing imperative across the network as a whole.¹⁷

Encouragingly, resilience planning is gaining ground. In Europe, with advanced regulations, a 2023 survey of port members found that 70% were already adapting existing infrastructure to increase resilience, and 76% were factoring climate change adaptation into the planning and delivery of new infrastructure projects.¹⁸ Globally, however, progress may be more uneven, and intent does not always translate into action. A global port industry survey found that while a majority of ports had begun to mainstream climate considerations into the planning, design, and construction of infrastructure, a significant share, around 40%, had not yet carried out any concrete work to identify or evaluate adaptation measures.¹⁹

Still, resilience is not always considered alongside the broader port development and investment decisions—and where action is taken, it tends to be incremental and ad hoc.²⁰ Resilience is often treated as a separate concern, an extra burden to take on rather than a lens that can be applied to the investments ports are already making, from major infrastructure upgrades and digitalisation to decarbonisation and environmental and community commitments. Viewed this way, the barrier can feel higher than it is, while in practice, resilience can be anchored by allowing a single effort to deliver several benefits at once.

14. Verma et al., 2025. [Extreme heat threatens railroads with connectivity and ridership loss in the United States.](#)

15. The Globe and Mail, 2021. [B.C. flooding shuts down highways and rail lines, damaging fragile supply chains.](#)

16. Xia, W. et al., 2024. [Seaport adaptation and capacity investments under inter-port competition and climate-change uncertainty.](#)

17. Cai, Y. et al., 2018. [Economic shifts in agricultural production and trade due to climate change.](#)

18. EPSO, 2023. [ESPO'S ENVIRONMENTAL REPORT 2023: CLIMATE CHANGE AGAIN TOP PRIORITY FOR EUROPE'S PORTS.](#)

19. UNCTAD, 2018. [Port Industry Survey on Climate Change Impacts and Adaptation.](#)

20. Jenkins K. et al., 2025. [Climate Change Adaptation in the Port Industry: Evaluating Evidence of Implemented Adaptation Using a National Adaptation Inventory.](#)

Deep Dive: The Resilience Maturity Gap Between Large and Small Ports

The capacity to build resilience is unevenly distributed across the sector, and the gap between large and small ports is especially wide. They often face climate risk on different terms, with differences showing up across three dimensions: funding, organisational capacity, and access to data and tools.

On funding, large operators can draw on strong balance sheets, credit ratings, and access to capital markets to fund adaptation, while smaller and resource-constrained ports frequently cannot raise capital on comparable terms or attract private investment.²¹ On capacity, larger ports tend to have dedicated risk and sustainability functions, often led by a chief risk or sustainability officer, whereas many smaller ports have no such role and little to devote to resilience at all.²² And on data, assessing climate risk calls for reliable information and modelling tools that larger operators can build or buy in-house, but that smaller ports often lack, along with the in-house climate expertise to use them, leaving them without the means to understand their exposure in the first place.²³

This gap matters because the smaller ports least able to act are often among the most exposed, or can be highly critical.²⁴ In many small island and developing states, they are the lifelines on which the entire economy depends, from food and energy imports to trade and tourism,²⁵ yet they sit on the front line of climate change with the fewest resources to respond.

The actions set out in section 3, 'Key Actions to Scale Port Resilience', address this gap directly. System-level risk assessment (Action 1) and coordination platforms (Action 2) can be designed to serve resource-constrained ports specifically, enabling smaller ports to pool resources and share expertise along a shared corridor, while blended and concessional finance (Action 4) is often the primary means by which smaller ports are able to act at all.

RESILIENCE ACTION IS IMPEDED BY STRUCTURAL CHALLENGES

This gap between intent and action is, in large part, a reflection of major structural challenges that impede resilience-building in ports. By their nature, ports are governed by many actors, from port authorities and city governments to terminal operators, leaving them prone to siloed thinking and fragmented decision-making. Responsibility for resilience is rarely held by any single party, so risks that cut across organisational boundaries can be left unaddressed, with no clear owner to act on them.²⁶

Their multi-modal interdependencies compound this, requiring system-level thinking that extends beyond the port to connected transport modes and supporting infrastructure.⁶ Encouraging steps are emerging, but coordination across ports and connected transport modes is only beginning to be institutionalised ([See Action 2](#)), and action on systemic risks still tends to rely on voluntary efforts rather than established standards or mechanisms.

In addition, ports are often run in public-private constellations, which makes mobilising private investment and engagement alongside public effort especially important for scaling resilience.²⁷ However, this involves a clear business case, while transport infrastructure faces a monetisation challenge, with users' willingness to pay typically falling short of investor return expectations. These gaps are not yet fully bridged by regulatory incentives or public finance, leaving private capital harder to mobilise.²⁸

Although these barriers remain significant, practical approaches to addressing them are already emerging across the sector. In section 3, we define five key action fields that turn the structural challenges into opportunities to build broader, system-level resilience.

21. UNCTAD, 2022. [Climate-resilience of seaports: Adequate finance is critical for developing countries but remains a major challenge](#).

22. UNCTAD, 2024. [Climate change adaptation, resilience-building and disaster risk reduction for ports \(Part 1\)](#).

23. Kontopyrakakis et al., 2025. [Ports and Climate Change: Exploring Stakeholder Insights, Governance and Policy Gaps in Greek Ports](#).

24. UNCTAD, 2024. [UNCTAD Strategy to support Small Island Developing States](#).

25. UNCTAD, 2014. [Small island developing States: Challenges in transport and trade logistics](#).

26. The Resilience Shift, 2021. [Resilience4Ports: Gateways to a resilient future](#).

27. Notteboom T. et al., 2026. [Port Economics, Management and Policy, Chapter 8. Port Governance](#).

28. The Resilience Shift, 2019. [Ports: An industry guide to enhancing resilience](#).

3. Key Actions to Scale Port Resilience

Port resilience can be strengthened through five key actions: 1) create system-level risk transparency, 2) build coordination platforms and governance structures, 3) anchor resilience in broader sector trends, 4) reframe and finance resilience investment, and 5) design multi-benefit resilience solutions [\(see Exhibit 3\)](#).

Action 1: Create System-Level Risk Transparency

Ports are embedded in interconnected systems of road, rail, utilities, and digital infrastructure, where disruption at any one node can cascade across the wider transport and supply-chain network. With \$81 billion of global trade and at least \$122 billion of economic activity exposed annually to climate-induced port downtime,²⁹ resilience planning is effective when it identifies critical dependencies, quantifies cascading impacts, and supports coordinated action across the wider port and transport system.

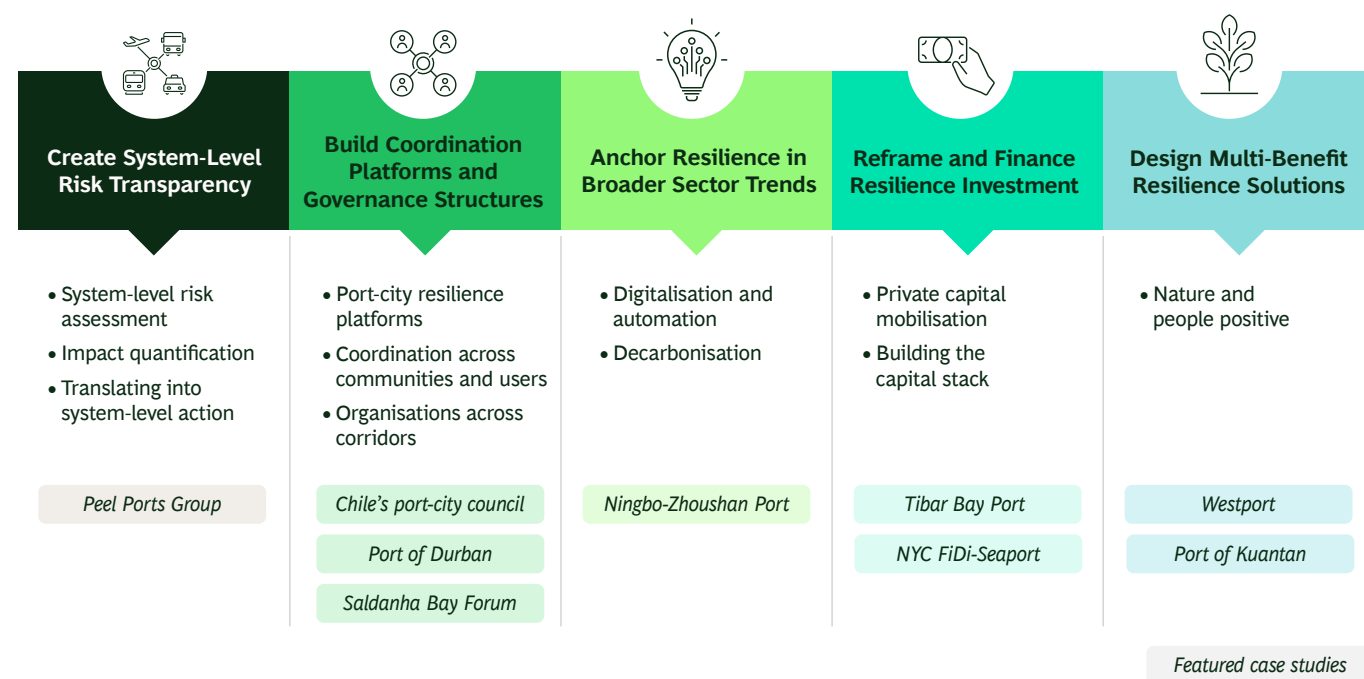
SYSTEM-LEVEL RISK ASSESSMENT

Systems thinking usually starts with extending risk assessment beyond the boundaries of the port itself. Climate events that cause no direct damage to port assets can still halt operations by severing the access roads, power supply, or digital systems on which terminals depend, and the resulting disruption can ripple outward across the wider supply chains the port serves. A meaningful assessment therefore looks at the broader system in which a port sits. A growing number of ports are beginning to take this broader view. The Port of Los Angeles, for example, based its resilience planning on a Sea Level Rise Adaptation Study that looked well beyond the waterfront. Rather than assessing cargo wharves alone, the study evaluated the port's critical facilities, transportation links such as rail and roads, community assets, and natural habitats together to identify where vulnerability was greatest.³⁰ Peel Ports offers another example, extending this system view to the risks that lie beyond a port's own control and acting on them with external partners³¹ [\(see Case Study 1\)](#).

A central part of the system-level risk assessment is criticality mapping: identifying which connections matter most so that resilience efforts can be focused where disruption would be most damaging. Criticality is shaped heavily by context. A port served by only limited road or rail capacity is acutely exposed to the loss of that access, since there is little redundancy to absorb a disruption. Likewise, a port that is the sole gateway for a small island faces outsized consequences if it goes down, because the entire territory's supply of food, fuel, and essential goods depends on it. Mapping these dependencies allows operators and planners to distinguish nationally or locally critical assets and connections, and to prioritise investment accordingly.

EXHIBIT 3

Key actions for port resilience



29. Verschuur J. et al., 2023. [Systemic risks from climate-related disruptions at ports](#).

30. IAPH, [World Ports Sustainability Program](#).

31. Peel Ports, 2024. [Climate Change Adaptation Report](#).

Case Study 1: Peel Ports Group System-Level Climate Risk Assessment

Peel Ports, one of the UK's largest port operators, offers an example of system-level risk assessment in practice, with a particular focus on the climate risks that lie outside a port's own control. Through a broad risk assessment, it identified functional, physical, spatial, economic, institutional, and social interdependencies through which port operations could be affected, directly or indirectly: across the utilities and services they rely on, such as power, water, and flood defence; the transport systems that connect them by road, rail, and water; and the wider supply chains they sit within.

The assessment also looked beyond the port's boundaries to medium- and long-term risks outside the influence of port operators. It considered, for example, how a changing climate could disrupt upstream stages such as agricultural commodity growth, in turn altering the flow of cargo through the port over time.

Peel Ports did not stop at assessment. Where adaptation decisions sit beyond its own control, it has moved to engage the organisations that hold them, for instance, working with the Environment Agency on flood protection and with the Highways Agency and local authorities on road access for the Port of Sheerness. In doing so, it turned a system-level risk assessment into coordinated action with the external partners its resilience depends on.³¹

IMPACT QUANTIFICATION

Based on the criticality mapping, system-level impacts can be quantified, which helps prioritise the right set of measures. It shows how much is at risk and can also strengthen the case for investment when resilience competes against other priorities. The interdependency map reveals which components combine high climate exposure with high criticality, where limited redundancy means disruption could cascade across the network.²⁹ Economic consequences then fall into two layers: direct losses (asset damage, lost revenue, recovery costs, and freight price effects) and the harder-to-estimate supply-chain spillovers, which can be screened roughly by scaling trade value against expected downtime or modelled in detail through trade-flow and input-output methods.^{8,29} The severity of these spillovers hinges on disruption duration and downstream inventory buffers.⁸ For just-in-time or perishable goods such as food, even a disruption of around a week can tip into shortages, whereas supply chains with larger inventory buffers absorb longer outages more easily. Small-island economies sit at the sharp end of this, since dependence on a single port and thin inventory buffers mean almost any disruption feeds quickly into local shortages.⁸ Some consequences, such as workforce safety and the social costs of lost access to essential goods, cannot easily be quantified but remain important alongside the numbers, not to be omitted. The effort is worthwhile because system-level losses often far exceed direct asset damage, and leaving them unquantified understates the true case for resilience investment.⁸

TRANSLATING INTO SYSTEM-LEVEL ACTION

Resilience solutions, in turn, can be designed at the same system level. Hardening a single asset works best when the connections it depends on are protected alongside it. A port terminal in a flood-prone location may be elevated to guard against future flooding, but if the access road or rail line serving it is not upgraded in parallel, the terminal would simply function as an island in a flood event: physically resilient, yet operationally isolated. Tanzania's Intermodal and Rail Development Project reflects this systemic logic. Rather than upgrading the Port of Dar es Salaam alone, the project also climate-proofed the flood-prone rail corridor connecting the port to its hinterland and to its landlocked neighbours.³²

32. Ecofin Agency, 2025. [Tanzania Launches Phase 2 of Rail and Intermodal Transport Upgrade Project](#).

Action 2: Build Coordination Platforms and Governance Structures

Much of the implementation gap is, at its core, a governance problem. Port systems sit at the intersection of port authorities, terminal operators, road and rail agencies, local governments, national regulators, investors, workers, and surrounding communities, each holding a different piece of the resilience puzzle, with no single actor accountable for the whole.³³ At the industry level, sector associations are beginning to convene their domains around shared resilience standards, from PIANC (Permanent International Association of Navigation Congresses) for waterborne infrastructure to PIARC (Permanent International Association of Road Congresses) for road, and UIC (International Union of Railways) for rail.³⁴ Initiatives such as R4P (Resilience4Ports), the ICSI (International Coalition for Sustainable Infrastructure)-hosted cross-sector coalition of port authorities, financiers, engineers, and multilateral partners, are also working to turn the standards these associations set into practical guidance and funded pilots on the ground.³⁵ These are encouraging signs, but coordination remains at an early stage, with much still to be done on the ground. Some instructive progress is taking shape closer to the ground in how ports coordinate with their host cities and the communities and users around them.

PORT-CITY RESILIENCE PLATFORMS

Among the many coordination relationships in the port ecosystem, the one between a port and its host city stands out as important.³⁶ Ports and cities share the same coastline, infrastructure, and exposure to climate hazards, and their economies and communities are deeply intertwined, yet their assets, mandates, and defences are often planned separately.³⁷ Where responsibility is split this way, the risks that sit at the interface between the two can fall through the gaps, leaving critical areas, and the communities and economic activity that depend on them, exposed.

A growing number of ports and cities are closing this gap by coordinating through durable structures. In Chile, port-city coordination has been written into national law,^{38,39} while in Canada's Lower Mainland, it takes place within a wider regional partnership, where the Port of Vancouver, the City of Vancouver, and more than 40 other partners align their planning against shared flood risk^{40,41} (see Case Studies 2 and 3).

Case Study 2: Chile's Port-City Coordination Councils

Chile offers an example of how port-city coordination can be institutionalised, by writing it into national law. Many Chilean ports operate within or alongside dense urban areas, requiring constant alignment with cities and communities on land use, traffic, environmental impact, and access routes.

To manage this, Chile established Port-City Coordination Councils (Consejos de Coordinación Ciudad-Puerto) under its State Port Modernization Law, requiring every city with a state port company to convene a council that brings together regional and municipal authorities, transport and public-works ministries, and the port company, extended as needed with permanent guests such as railway operators, workers, and civil-society representatives. Each council can spin up issue-specific working groups, on matters from territorial planning and transport to environment and community engagement, that provide technical analysis back to the full council.

The model has supported concrete port-city outcomes, from converting former port land into public waterfront space in Valparaíso to coordinating Chile's largest port expansion at San Antonio around environmental review, urban traffic, and worker protection. By giving the port and the city a standing forum, the model creates the venue needed to plan jointly for shared risks, from flooding and storm exposure along the waterfront to the access routes both depend on, rather than addressing them in isolation.^{38,39}

33. Monios, Wilmsmeier et al., 2024. [A new conception of port governance under climate change](#).

34. UIC, 2025. [We rely on each other: building transport resilience through partnership](#).

35. ICSI, [Resilience4Ports](#).

36. AESOP, 2024. [The Role of Governance in the Sustainability of the Port-City Relationship: Comparative Experiences](#).

37. Sabino, M.R. et al., 2025. [Building resilience in port-cities: the role of open innovation and innovation ecosystems](#).

38. Puerto Valparaíso, 2023. [Consejo de Coordinación Ciudad Puerto de Valparaíso cierra el 2023 con balance positivo](#).

39. Puerto San Antonio, [CONSEJO DE COORDINACIÓN CIUDAD PUERTO](#).

40. Fraser Basin Council, 2016. [LOWER MAINLAND FLOOD MANAGEMENT STRATEGY Phase 1 Summary Report](#).

41. Fraser Basin Council, 2023. [Phase 2 — Lower Mainland Flood Management Strategy - Inform Strategy Work](#).

Case Study 3: Lower Mainland Flood Management Strategy (Canada)

In British Columbia's (BC's) Lower Mainland, the risk of major Fraser River and coastal flooding is projected to worsen as sea-level rise and higher peak river flows increase both the frequency and magnitude of floods.

Through the Lower Mainland Flood Management Strategy initiative, the Fraser Basin Council coordinated a region-wide information development, engagement and planning process, convening more than 40 partners across the federal government, the Province of BC, First Nations, local governments and transport bodies including the Port of Vancouver and the Vancouver International Airport.⁴⁰ Together, they built a shared understanding of flood risk and jurisdiction's perspective and collective flood management priorities in the region. The Port of Vancouver took part as one of these many partners, aligning its own resilience planning with the wider system it depends on.

Phase 2 closed with final reports and recommendation for action in 2023.⁴¹ The initiative shows how a port can contribute as a participant in regional, inter-jurisdictional climate adaptation.

In both cases, the strength of the collaboration comes from the anchor in durable structures. Embedding port-city coordination in law, formal agreements, or standing forums sets out clear roles and responsibilities, so risks at the interface are less likely to fall through the gaps. It creates a predictable venue where issues can be raised and resolved before they escalate. And it allows cooperation to persist over time, which matters for resilience in particular, where risks build slowly and responses, from sediment management to corridor planning, play out over decades rather than years.

COORDINATION ACROSS COMMUNITIES AND USERS

Beyond aligning ports and cities, resilience also depends on engaging two distinct groups: the users who depend on the port day to day, and the communities that live alongside it. Both see risks and consequences that planners may miss, from the operational pain points users feel first to the local environmental and social impacts communities absorb.

Communities also depend on the coastal ecosystems and the wider blue economy around the port, from fisheries to tourism, which resilience investment can help protect and strengthen. At the same time, resilience measures are not always benign: a breakwater, seawall or flood defence can disrupt the very ecosystems and livelihoods that local people rely on.⁴² Because resilience measures often affect these groups directly, involving them early builds the shared understanding and legitimacy that decisions need to hold over time. Engaging users brings those who depend on the port day to day into defining which risks matter most.

In developing its climate adaptation strategy, the Port of Rotterdam consulted its users, mainly transport and logistics firms, developers, and real-estate owners, to understand the level of risk they considered acceptable across the different sub-areas of the port, then merged these judgements with a parallel evaluation by public authorities representing the wider public interest, producing a shared, co-designed view of acceptable risk levels across the port.⁴³ Such engagement can also endure as a standing institution, as at Saldanha Bay in South Africa⁴⁴ (see Case Study 4).

ORGANISATIONS ACROSS CORRIDORS

Coordination also can widen beyond the individual port to the corridors and regions in which it sits, because many climate risks do not respect a port's boundaries. Sediment movement, flooding, and water quality often play out across an entire stretch of coastline or river system such that what one port does affects its neighbours, and no single port can manage the risk alone. As noted earlier, this kind of corridor-level cooperation is especially valuable for smaller ports, which can pool resources and build a joint operational model, shared financing mechanisms, and a common resilience strategy along a common corridor in ways that would be out of reach individually. This turns resilience into a differentiator for the corridor as a whole rather than a burden each port carries alone. This type of action has begun to emerge along corridors such as a waterway freight route in France and a developing Italy-Croatia corridor.⁴⁵

42. Charoenlerkthawin, W. et al., 2025. [Unintended coastal transformation from small-scale infrastructure and land use change](#).

43. Climate-ADAPT, [Rotterdam port adaptation strategy for climate resilient transport and business activities](#).

44. Saldanha Bay Water Quality Trust, [Saldanha Bay Water Quality Trust](#).

45. North Adriatic Sea Port Authority (Interreg Italy-Croatia Programme), [PRESPOST](#).

Case Study 4: Saldanha Bay Water Quality Forum Trust

Saldanha Bay in South Africa offers an example of coordination that has taken hold voluntarily, without a formal mandate. Where port and industrial development reshaped a sensitive bay-and-lagoon ecosystem, a voluntary body, the Saldanha Bay Water Quality Forum Trust, was set up in 1996 to bring industry, government, and community together around the health of the bay.

Funded voluntarily by local industry, it runs a continuous environmental monitoring programme and convenes the parties at regular meetings where new industrial or port developments are discussed collectively, concerns are raised, and the parties reach mutual agreement on how to limit and remediate impacts. This gives the port and its neighbours a shared, evidence-based basis for managing the bay together.

Notably, it has sustained this for nearly three decades on a voluntary footing, showing that coordination can take hold and endure through shared purpose and local ownership, not just through formal mandates.⁴⁴

Action 3: Anchor Resilience in Broader Sector Trends

Ports are being reshaped by broader market and sector trends, most notably automation, digitalisation, and decarbonisation. These shifts are usually pursued for their own reasons, from efficiency and competitiveness to emissions targets, but they intersect with resilience in important ways. Approached deliberately, they can become levers that strengthen a port's ability to withstand and recover from climate shocks. Approached in isolation, they can introduce new vulnerabilities of their own.

DIGITALISATION AND AUTOMATION

Digitalisation and automation are reshaping how ports operate, largely for reasons unrelated to climate. Ports are deploying networks of sensors, connected equipment, and data platforms to track cargo, optimise traffic, and run operations more efficiently, while building digital twins, which are virtual real-time models of the port, to plan and manage activity. Automation is advancing in parallel, with automated cranes, remote-controlled equipment, and driverless vehicles taking over tasks once performed by hand, primarily to raise productivity, safety, and competitiveness.⁴⁶ These technologies are already widespread: in its 2025 World Ports Tracker, the International Association of Ports and Harbors found that more than half of the ports surveyed had adopted automation and robotics solutions, from fully automated container terminals to robotic process automation for administrative tasks, while connected sensors and Internet-of-Things devices were in use at over 40% for real-time monitoring of assets and vehicles.⁴⁷ These shifts are driven mainly by commercial and operational goals, but the same capabilities turn out to be powerful tools for resilience.

On the digital side, the gains come from visibility and foresight. Networks of sensors, weather stations, and connected equipment can feed analytics that flag emerging hazards before they escalate, trigger automated safety alerts when conditions such as wind speed exceed safe thresholds, support predictive maintenance that keeps critical assets in service, and, through shared platforms, enable real-time resilience coordination across connected transport actors.

These tools can also help ports prepare for hazards before they strike. The Port of Corpus Christi in the United States, the largest crude-export terminal in the country, has built a digital twin known as OPTICS (Overall Port Tactical Information Computer System) that combines live vessel tracking, geospatial data, weather feeds, and emergency-dispatch information into a single real-time 3D view of the port. Beyond day-to-day monitoring, the system generates hypothetical incidents for emergency-response training, and the port is extending it to support scenario simulation, helping operators prepare for difficult conditions such as fog before they disrupt operations.⁴⁸ Other ports are putting the same tools to work in real time, as at Ningbo-Zhoushan, where a weather-data platform helps operators adjust to fast-changing conditions as they unfold ([see Case Study 5](#)).

46. UNCTAD, 2024. [Review of Maritime Transport 2024](#).

47. PierNext (Port de Barcelona), 2025. [The digital and sustainable transformation of ports: a snapshot of an industry in full revolution](#), reporting on the IAPH World Ports Tracker 2025.

48. Business Insider, 2025. [A massive seaport in Texas is using an AI-powered digital replica to track ships and prepare for emergencies](#).

Case Study 5: Ningbo-Zhoushan's Early Warnings for All

Ningbo-Zhoushan, the world's busiest port by cargo throughput, shows what real-time digital tools can be worth in practice. The port sits in a location frequently exposed to gales and sea fog, where weather-related disruption causes up to 1,000 hours of operational downtime a year.

The port participated in the China Meteorological Administration's MAZU (Multi-hazard, Alert, Zero-gap and Universal) initiative under "Early Warnings for All", with the Zhejiang Provincial Meteorological Service providing early-warning products across 4 severe-weather categories and 13 disaster signals. It rolled out the "Maritime Meteorological Report" mobile app, providing real-time, minute-scale alerts and maritime/port weather data to support operational planning by dispatchers and operators, and built an intelligent service platform covering the typhoon life cycle, combining marine meteorology expertise with disaster-prevention experience.

In 2024, the early-warning system added an estimated 98 hours of workable time and generated RMB 370 million (around \$51 million) in direct economic benefits. During Typhoon Co-May in July 2025, real-time wind forecast updates enabled port managers to adjust work schedules and recover ten hours of operating time.^{49,50}

Automation strengthens resilience from a different angle: by reducing the human exposure that climate hazards create. The clearest illustration is APM Terminals' Maasvlakte II in Rotterdam, one of the world's most advanced fully automated terminals. There, battery-powered automated guided vehicles move containers between the quayside and the storage yard without human drivers, while remote-controlled ship-to-shore cranes and automated stacking cranes handle vessels under software control, with around 80% of crane movements automated and the rest performed remotely.⁵¹ Because workers are largely removed from the quayside, operations can keep running through extreme heat and other hazardous conditions that would otherwise force a shutdown. Removing the human bottleneck also lets automated systems respond more quickly to fast-changing climate conditions, adjusting operations as hazards develop rather than waiting on manual intervention.

Automation, however, does come with a trade-off. The same shift that takes workers out of harm's way also reduces the sector's substantial workforce, and where that happens, the communities around a port can lose an important source of livelihood just as the port itself becomes more resilient to climate shocks, which can undermine the wider case for resilience investment. Supporting workers through upskilling and reskilling, helping them move into the new roles that automated operations create, from remote monitoring and control to digital operations and maintenance, is proving to be one way to make resilience socially as well as operationally durable.⁵² Singapore's PSA offers one example: at Tuas port, it has worked closely with the Singapore Port Workers Union and the Port Officers' Union to retrain its workforce, so that staff are equipped to take on new and higher-value roles created by this shift.⁵³ Approaches such as this suggest that resilience and workforce continuity can be pursued together. Alongside this, automation introduces a technological dependency. Greater reliance on digital and automated systems can also create new dependencies, where a communications outage, a control-room disruption, or damage to a data network risks disrupting operations. This makes the climate resilience of the digital infrastructure itself an important consideration, so that the systems meant to strengthen resilience do not become a new point of vulnerability.

DECARBONISATION

Driven by their own reasons, from emissions targets and regulation to competitiveness, ports are investing in renewable energy sourcing, onsite generation and storage, and the electrification of cargo-handling equipment. This decarbonisation reshapes both the infrastructure ports depend on and the role they play in the wider energy and transport system. Some ports are transforming entirely, such as Esbjerg in Denmark, which has turned from a fishing harbour into the world's largest base port for offshore wind.⁵⁴ This transformation is not only limited to individual ports, but also redrawing the energy geography itself. With renewables being built out and energy-export terminals increasingly under stress, a more fragmented set of ports is responsible for carrying energy flows where energy is produced, brought in from offshore, and passed on to the wider grid and transport network, giving them a growing part in how energy reaches people.⁵⁵

49. Meteorological Technology International, 2025. [Zhejiang's early warning system boosts port resilience and village safety](#).

50. China Daily, 2026. [Chinese solution provides 'early warnings for all'](#).

51. APM Terminal. [Our Terminal - APM Terminals](#).

52. WEF, 2024. [How ports can lead a just transition for workers in an automated future](#).

53. PSA Singapore, 2022. [PSA Singapore Opens Tuas Port, a Focal Point of the Wider Tuas Ecosystem](#).

54. State of Green, 2025. [From fishing hub to the world's largest offshore wind port](#).

55. Notteboom T. et al., 2026, [Port Economics Management and Policy, Ch.3.4 Ports and Energy Transition](#).

While more than half of the world's ports are now working towards carbon-neutrality targets,⁵⁶ investment is not yet flowing at the scale required, and many projects stall before reaching delivery.⁵⁷ Where these investments are made, the same infrastructure can also strengthen resilience, much as with digitalisation, changing how ports power their operations, the equipment they run, and the role they play in the wider transport system around them—and opening new opportunities to build resilience.

How ports source power is changing most visibly. A port that draws its electricity from the external grid and its fuel from outside suppliers is exposed every time those systems fail—and climate shocks are a common cause of such failures, with storms and flooding regularly knocking out regional grids for days. Generating power onsite through renewables, storage, and microgrids reduces that exposure, allowing a port to keep critical operations running even when the surrounding grid goes down. The Port of Valencia, for instance, is targeting energy self-sufficiency by 2035 through a mix of solar, wind, and wave technologies, which would leave it far less dependent on an external grid that climate events can disrupt.⁵⁸ Some ports go further, supplying surplus renewable power or clean fuels back to the grid and the transport that depends on them.⁵⁹ As they take on this role, the storms, floods, and rising seas that threaten a port can disrupt the wider energy supply too, so resilience built at the port helps keep the whole system running.

Electrifying cargo-handling equipment brings a different benefit by loosening the port's exposure to fuel-supply chains. Replacing diesel cranes, tractors, and handlers with electric ones, as at the Port of Long Beach, which reached 21% zero-emission cargo-handling equipment in 2024, removes the risk that disruptions to diesel supply, themselves often climate-driven, bring operations to a halt.⁶⁰

The same infrastructure also strengthens the resilience of the transport system around the port, not just its emissions. Because ships and hinterland trucks, trains, and barges all converge on the port, it is uniquely placed to provide the charging and refuelling infrastructure that low-carbon transport depends on, anchoring the energy transition of the wider freight network rather than its own operations alone. When that infrastructure is paired with onsite generation and storage, it does double duty: a port that can generate, store, and dispense its own power is far less exposed when the surrounding grid goes down. Shore power and clean-fuel bunkering keep vessels supplied, while fast-charging for electric trucks, such as that installed at Antwerp-Bruges, allows zero-emission hinterland transport to run reliably.⁶¹ Where these charging hubs are paired with onsite generation and storage, they can keep maritime and hinterland freight moving even when the surrounding grid is disrupted, turning the port into a hub through which the decarbonisation, and the resilience, of both maritime and inland transport can be strengthened.

These gains, however, also come with a shared condition. Each can replace an established dependency with a new one, and the resilience benefits are likely to be strongest where the low-carbon infrastructure is itself built to withstand the conditions it will face. Renewable generation is climate sensitive, so leaning on solar and wind introduces vulnerabilities that can be managed through storage and backup. As terminals electrify, reliable power becomes more important. And if charging and refuelling assets are not climate resilient, a single shock can cascade outward into vessel delays, truck queues, and rail disruption.

Action 4: Reframe and Finance Resilience Investment

Finance is the condition that determines whether resilience moves from plan to practice at scale. The economics are increasingly favourable: adding resilience to a project raises upfront costs by only around 3%–10%, yet can deliver benefit-cost ratios of up to 4:1 from avoided losses alone.⁶² The challenge is that these benefits are not yet fully recognised or captured in the way ports build their business case. Resilience delivers value across the many roles a port plays, not only as a transport hub but also increasingly as an energy hub and an economic hub for the region around it. Yet much of this value remains hard to monetise, and typically materialises over the long term, creating a mismatch with investor return expectations and fund life cycles.²⁶ In addition, these benefits and costs are distributed unevenly across actors of the ecosystem, which can lead to misaligned incentives.²⁸ The economics compound this are that transport tariffs, for example, often fall short of recovering costs.

The opportunity is to connect resilience to the investments ports are already making across those roles, from capacity and modernisation to digitalisation and decarbonisation. Building resilience into those investments, rather than funding it separately, lets a single outlay serve several ends at once and brings its wider benefits into a stronger, broader business case.⁶³ Reframed this way, the financing question becomes less about paying for resilience on its own and more about mobilising capital and sharing risk for the investments ports are making anyway.

56. AJOT, 2026. [IAPH World Ports Tracker 2026 reveals state of global port sustainability](#).

57. ADB, 2025. [Advancing Green Ports: Funding and Financing for Maritime Decarbonization](#).

58. Valenciaport, [Valenciaport sets 2035 as its target for energy self-sufficiency and emissions neutrality](#).

59. DNV, 2024. [Energy Outlook: The role of ports in a decarbonized energy system](#).

60. AJOT, 2025. [Port of Long Beach continues to meet long-term air emissions goals](#).

61. Milence, 2025. [Milence deploys its first Megawatt Charging System solution at the Port of Antwerp Bruges](#).

62. GCA, 2019. [ADAPT NOW: A GLOBAL CALL FOR LEADERSHIP ON CLIMATE RESILIENCE](#).

63. Systemiq et al., 2025. [Returns on Resilience: Investing in Adaptation to Drive Prosperity, Growth and Competitiveness](#).

PRIVATE CAPITAL MOBILISATION

Closing the resilience gap depends on drawing in private capital. The same reframing applies to how private actors weigh these investments. Rather than assessing a resilience measure in isolation, where its returns look long term and hard to monetise, investors can consider the fuller business case: the value of keeping a port, and the wider regional economy it anchors, running through disruption. Viewed at a portfolio level, resilience can also be weighed alongside the digitalisation and decarbonisation investments already underway in ports, where it strengthens the durability of those investments rather than competing with them for capital.

Mobilising commercial capital at scale often also calls for public and concessional support, used not to fund projects outright but to absorb early risk and make them attractive enough for private capital to come in. Public-private partnerships (PPPs) can provide the structure: they share the cost, risk, and reward of a project across public and private partners, allocating risks to whoever is best placed to manage them and giving the private partner a defined way to recover its investment. Tibar Bay Port in Timor-Leste is one example of PPP financing in practice⁶⁴ (see Case Study 6).

PPPs, such as the one at Tibar Bay, provide a structure into which different sources of capital can be layered. Within such arrangements, concessional and blended finance can change the economics. By using limited public or concessional funds to absorb early risk, they make a project bankable enough to crowd in private capital that would otherwise stay on the sidelines, as the public viability-gap funding did at Tibar Bay. The Port of Banjul in the Gambia is one example. Exposed to coastal flooding and sea-level rise, a partnership between the African Development Bank and the Global Center on Adaptation channelled more than \$20 million in concessional grants, together with funding for feasibility studies and climate risk assessment, to de-risk an expansion project and move it from planning towards implementation, with the resilience measures identified expected to cut climate risks by 40%–50%.⁶⁵

The guiding principle here is to use as little concessional support as necessary while mobilising as much private capital as possible. That means blending public funds only where there is a demonstrated financing gap to close, avoiding over-subsidy of projects the market could fund on its own, and keeping the structure transparent and aligned with what private investors are mandated to do.

Case Study 6: Tibar Bay Port Public-Private Partnership

Timor-Leste's existing Dili port faced capacity constraints and congestion, increasing logistics costs. The Tibar Bay site was selected to replace it for expanded, efficient, and climate-resilient port infrastructure.

Timor-Leste's Tibar Bay Port was delivered as a 30-year PPP with a total cost of around \$280 million that embedded climate resilience into the project from the outset. The deal was structured through a special-purpose vehicle that combined \$45 million in private equity from the port operator and \$105 million in debt with \$130 million of public viability-gap funding from the government.

The operator recovers its investment through user charges set in the concession agreement and bears the traffic and performance risk while the government earns royalties based on the cargo volumes passing through the port. The project includes development of nature-based solutions, restoring mangroves, coral reef, and seagrass that buffer the port against coastal flooding, erosion, and storm surges.⁶⁴

64. World Bank, 2025. [Financing Climate Adaptation and Nature-Based Infrastructure](#).

65. ADB, 2022. [The Gambia: African Development Bank commits grants of \\$20.56 million to further upgrade Banjul port](#).

BUILDING THE CAPITAL STACK

Beyond combining public and concessional funds with commercial debt and equity, financing resilience projects often means assembling a capital stack from several sources at once: new revenue streams that let a port charge for the protection it provides, instruments such as bonds and carbon credits that widen the pool of capital, and insurance that transfers the risks left over. The task is to layer these so that each covers the part of the project it is best suited to. New York City's plan to protect Lower Manhattan shows how these pieces can fit together⁶⁶ (see Case Study 7).

Insurance transfers the risks that remain once a project is built. It can also work as a forcing function: by linking premiums or coverage to the resilience measures a port puts in place, as New York's plan envisages, it rewards genuine risk reduction rather than simply passing the risk on. Holding coverage can also improve a port's creditworthiness, making resilience financing easier to raise. Newer instruments are also emerging, such as parametric insurance, which pays out quickly when a pre-agreed trigger such as a given wind speed or flood level is met. Because payouts are tied to the threshold trigger rather than to actual damage, where the threshold is set is what determines whether cover reflects the losses a port is likely to face.

Other instruments can widen the pool of capital a port draws on. Where a port restores mangroves, seagrass, or other coastal habitats, those ecosystems sequester carbon that can be certified and sold as blue carbon credits, turning a protective measure into a source of revenue. This is already working at community scale: In Kenya, the Mikoko Pamoja project, the world's first community-led mangrove carbon scheme, sells verified credits and channels the proceeds back into mangrove restoration and local services, showing how habitats that buffer the coast can also help fund their own upkeep.⁶⁷ Blue bonds, through which governments, development banks, and a growing number of private issuers raise capital earmarked for the marine economy and coastal resilience, can offer a further channel still largely untapped by ports themselves.

Case Study 7: New York City's FiDi-Seaport Climate Resilience Plan

New York City's approach to protecting Lower Manhattan shows how different financing pieces can fit together. The Financial District (FiDi) and Seaport waterfront is the last unprotected gap in Lower Manhattan's coastal defences, exposed to tidal flooding, storm surge, and sea-level rise, with the cost of inaction estimated at up to \$20.3 billion by 2100 against a defence costing \$5.5 billion in 2025 to build.

To fund protection at this scale, the city's Resilience Finance Task Force recommended a four-part strategy. Shoreline Protection Districts would levy a fee on the property owners the infrastructure protects, funding operations and maintenance so that those who benefit contribute in proportion to their exposure. Construction would draw on multiple long-term revenue sources, such as tax surcharges, rather than any single one, with a dedicated Resilience Finance Authority issuing bonds backed by those revenues to fund the build. Alongside this, the city would work with insurers to translate resilience investment into financial benefits for protected residents, from preserved coverage to lower premiums, while federal co-financing through the US Army Corps of Engineers could cover up to 65% of design and construction costs.

No single one of these would fund the project, but together, they make it financeable. The approach establishes a financing framework that could support a broader citywide portfolio of coastal resilience projects beyond FiDi-Seaport.⁶⁸

66. New York City Economic Development Corporation, 2025. [Moving FiDi-Seaport Forward](#).

67. Panorama, 2023. [Blue carbon credits financing community-based mangrove management](#).

Action 5: Design Multi-Benefit Resilience Solutions

Resilience projects can be designed with further environmental and social benefits, which contribute to economic development and support local livelihoods, thus advancing broader sustainability objectives. This also strengthens the resilience business case in the process, with further potential revenue streams applying.

NATURE- AND PEOPLE-POSITIVE SOLUTIONS

Nature-positive approaches are already gaining momentum across the sector. Industry frameworks such as PIANC's Working with Nature⁶⁸ and Integrated Port Management,⁶⁹ alongside broader green port initiatives, have encouraged a growing number of ports to adopt nature-based solutions. These have largely been pursued for environmental or sustainability goals, but the same measures, from restored wetlands and seagrass to ecological breakwaters and natural sediment management, also deliver resilience benefits, buffering coasts, absorbing storm surge, and reducing erosion. Recognising that overlap means a port can approach nature-based solutions not only as an environmental obligation but also as part of how it builds resilience.

In addition to considering nature, many cases show that involving the communities that live and work around a port from the outset, not only as consultees but also as co-designers, strengthens the resilience measures put in place. In practice, this means treating local coastal livelihoods, from fisheries to the trade that grows up around a port, as assets to protect and strengthen, and building in mechanisms, such as community monitoring roles or a share of the revenue from restored ecosystems, that give local communities a stake in the resilience measures built around them. Approached this way, the same investment can strengthen a port's resilience, restore the ecosystems around it, and support the communities that depend on both. Westport in Australia⁷⁰ and the Port of Kuantan in Malaysia⁷⁴ both show this in practice, using nature-based solutions to strengthen resilience to coastal hazards while restoring ecosystems and supporting surrounding communities (see Case Studies [8](#) and [9](#)).

Case Study 8: Westport's Nature- and People-Positive Design, Western Australia

Westport, the new container port planned for Kwinana in Western Australia, offers an example of designing resilience to work with both nature and the surrounding community. The project mapped the seagrass meadows of Cockburn Sound and used that picture to shift the port's footprint a kilometre south, reducing direct impacts to just 2% of existing meadows.⁷¹

Beyond protection, Westport is leading restoration efforts, including an Australian-first trial of robotic seed-planting technology, and a single effort here works on several fronts at once. The restored meadows buffer the shoreline, improve water quality, and store carbon, making the coast itself more robust while reviving a habitat that had suffered decades of decline and underpins the Sound's wider biodiversity.⁷² They also sustain local fisheries, such as snapper and blue swimmer crab.⁷² And the work is carried out with the community, not just for it, backed through one of Australia's largest volunteer seagrass programmes that mobilises local divers and citizen scientists to collect and plant seeds.⁷³

Westport treats the environment and surrounding communities not as limits on what a port can build, but as dimensions through which a single investment can create value on several fronts at once.

68. PIANC, 2018. [Guide for Applying Working with Nature to Navigation Infrastructure Projects](#).

69. UNEP, 2023. [Towards Sustainable Port Development in the Western Indian Ocean - Toolkit for Sustainable Port Development in a Blue Economy](#).

70. Lloyd's Register Foundation, 2026. [Foresight review of nature-positive engineering](#).

71. Westport, 2025. [Science in the Sound: How research is shaping the future of container trade in WA](#).

72. Westport. [Westport's seagrass planning and management](#).

73. Westport, 2024. [Seagrass restoration gets major funding boost](#).

74. GEF, 2025. [Transforming Malaysia's Port Infrastructure Development through a Nature-Centric Approach for Biodiversity Conservation and Land Degradation Control](#).

Case Study 9: Nature-based Solutions (NbS) for Coastal Resilience and Multi-Benefit Sustainability at Port of Kuantan

The Port of Kuantan offers an example of how NbS can strengthen infrastructure resilience, support climate mitigation, and extend asset durability at once. The port's coastal location exposes it to severe, fluctuating monsoon conditions that trigger coastal erosion and threaten physical operations, a challenge compounded by accelerating sea-level rise.

To address these threats within its enterprise ESG framework, Kuantan Port is adopting the R4P Port Decision Makers' Guide to Climate Risk Assessment framework, developed by ICSI and Lloyd's Register Foundation. Guided by this structured approach to evaluating hazard, exposure, and vulnerability, the port authority has designated the adjacent 34-hectare Tanjung Gelang Hill as a permanent, zero-development protected area dedicated entirely to NbS and ecosystem-based adaptation. This natural buffer mitigates slope degradation to safeguard the port's main access entrance, prevents coastal runoff contamination, and protects high-value strategic infrastructure such as the port's primary water tank, lighthouse, and national security facilities from extreme weather.

Beyond physical defence, the hill serves as a vital carbon sink. Utilizing local sampling and laboratory analysis aligned with the IPCC 2006 Guidelines for National Greenhouse Gas Inventories (Volume 4), the port has verified that this protected ecosystem generates a significant amount of oxygen each year and sequesters enough carbon to absorb port's emissions.

Building on these baselines, a \$27-million Global Environment Facility (GEF-8) project, developed in partnership with the Maritime Institute of Malaysia (MIMA), is deploying advanced marine engineering solutions. By pairing terrestrial preservation with marine innovations such as floating mangroves and artificial reef balls, Kuantan Port shows how structured climate risk data can translate into scalable, nature-positive, and community-inclusive infrastructure.⁷⁴

4. Call to Action

Climate risk is not confined to a single moment in a port's life. It builds across the entire life cycle of the infrastructure, from the planning stage through its design, financing, and construction to decades of operation and eventual retirement. Resilience therefore can be embedded at every stage rather than addressed in an isolated manner. These stages are not strictly sequential, and decisions taken at one point shape the options available at others. Practical guidance is beginning to support this approach: the Transport Pathways | Resilience Gateways Ports guidance,⁷⁵ developed by ICSI and Boston Consulting Group, offers one example of how resilience can be embedded throughout, and informs the approach set out in this paper.

Each life cycle step offers a distinct entry point. The planning and preparation phase is a chance to coordinate across ports, transport modes, cities, and communities so that resilience is built into the system from the start. The design phase can build in resilience from the outset, sizing and configuring assets for the climate conditions they will face over their lifetime, and drawing on nature-based solutions that protect the port while restoring ecosystems and supporting communities. The financing phase can build the business case and combine public, private, and concessional capital to fund resilient projects. Operations and maintenance can leverage digitalisation and technology, such as real-time monitoring, to anticipate climate hazards and keep services running as risks evolve. And the end-of-life phase can turn retirement and repurposing into an opportunity to recover value and deliver wider social and environmental benefits.

The examples in this paper illustrate the growing case for action. Ports sit at the heart of the systems that economies and communities depend on, and the risks they face are mounting. Encouragingly, practical approaches are already emerging across the sector, from system-level risk assessment and stronger coordination to new ways of financing resilience and designing for multiple benefits. Building on them at scale will take the combined effort of everyone with a stake in the port: port authorities and terminal operators, connected transport operators and utility providers, city and national governments, investors and insurers, transport and logistics users, and the communities that live alongside them. The risks are shared, and so is the opportunity. By acting together, and starting now, these actors can secure the trade, mobility, and prosperity that ports make possible.

75. To be updated; This paper and the accompanying Transport Pathways | Resilience Gateways for Ports guidance draw on the practical experience and perspectives of ICSI's Resilience4Ports coalition.

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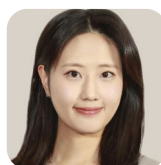
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About ICSI

The International Coalition for Sustainable Infrastructure (ICSI) is the global movement for engineering action on infrastructure sustainability, resilience, and climate change. ICSI works to accelerate the innovation, adoption, and scaling of people-centred, nature-positive infrastructure solutions that support sustainable development. By placing engineers at the forefront of climate action, ICSI connects practical expertise with urgent global needs, developing and scaling solutions that deliver real-world impact where it matters most.

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