RESILIENCE4PORTS

PORT DECISION MAKERS' GUIDE TO CLIMATE RISK ASSESSMENT

International Coalition for Sustainable Infrastructure

AUTHOR

Dr Darshana Godaliyadde
Director, Resilience4Ports, International Coalition for Sustainable Infrastructure (ICSI) and Lloyd's Register

ABOUT RESILIENCE4PORTS

The Resilience4Ports (R4P) initiative, launched at COP27, is led by the International Coalition for Sustainable Infrastructure (ICSI) and supported by Arup, the UN Climate Change High-Level Champions and Lloyd's Register Foundation. The core focus of the R4P programme is to build a network of ports and communities that seeks to evaluate, co-create and test solutions across a variety of resilience issues. While the programme will focus initially on ports, given their pivotal role and acute climate risk exposures, it is intended to be scalable and encompass other elements of the maritime system.

Led by:

Supported by:

ABOUT THE INTERNATIONAL COALITION FOR SUSTAINABLE INFRASTRUCTURE (ICSI)

The International Coalition for Sustainable Infrastructure (ICSI) is the global movement for engineering action on infrastructure sustainability, resilience, and climate change. ICSI brings together a global coalition of change agents from across the engineering, investment, city, and philanthropic communities committed to bold action to solve the systemic problems that exist at the intersection of climate change, ecosystem degradation, ageing infrastructure, and underinvestment. Built upon a commitment to tangible and collaborative action, ICSI continues to broaden participation across stakeholder communities to accelerate the innovation, adoption and scaling of people-centred, sustainable, and resilient infrastructure solutions that support sustainable development for all.

ACKNOWLEDGEMENTS

We extend our sincere thanks to the following organisations for generously offering valuable contributions to this publication:
Global Center on Adaptation (GCA), African Group of Negotiators Expert Support (AGNES), Jupiter Intelligence, ARUP, Private Infrastructure Development Group (PIDG).

ABBREVIATIONS

AAAP	Africa Adaptation Acceleration Program
AGNES	African Group of Negotiators Expert Support
AI	Artificial Intelligence
BCR	Benefit-Cost Ratio
CAPEX	Capital Expenditures
CRA	Climate Risk Assessment
CBA	Cost Benefit Assessment
EAMT	East Africa Marine Transport
ERR	Economic Rate of Return
ESIA	Environmental and Social Impact Assessment
GCA	Global Center on Adaptation
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
IAPH	International Association of Ports and Harbours
IMO	International Maritime Organisation
ISO	International Organization for Standardization
KMFRI	Kenya Marine and Fisheries Research Institute
KMA	Kenya Maritime Authority
KPA	Kenya Ports Authority
MHWs	Marine Heat Waves
NAPs	National Adaptation Plans
NDCs	Nationally Determined Contributions
NbS	Nature based Solutions
NPV	Net Present Value

OPEX	Operational Expenditures
PCRAM	Physical Climate Risk Appraisal Methodology
PIDG	Private Infrastructure Development Group
PPPs	Public-Private Partnerships
ROI	Return on Investment
RfQ	Request for Qualification
SSP	Shared Socioeconomic Pathway
SuDS	Sustainable Drainage Systems
TCFD	Task Force on Task Force on Climate-related Financial Disclosures (
ToR	Terms of Reference
URC	Uganda Rail Corporation
VfM	Value for Money

Contents

	PAGE	SECTION DESCRIPTION
1. Introduction	**6**	Sets the stage for understanding the context of climate risks in port systems.
2. What is a CRA and Why is it Important?	**8**	Presents a clear understanding of the CRA concept, the different levels at which it can be applied, and the critical role of stakeholders in ensuring its relevance, inclusivity, and effectiveness
3. Scoping and Procuring CRAs	**18**	Establishes clear objectives, the scope, qualified technical partners, and transparent procurement processes to design a credible, efficient, and fit-for-purpose CRA that delivers actionable results for port systems.
4. Climate Risk Screening	**23**	**Undertaking the Climate Risk Assessment** Guides port systems through assessing and prioritising climate risks from initial screening to detailed analysis and identifying practical adaptation and resilience options to address the most significant risks to enhance resilience.
5. Detailed CRA	**32**	
6. Identification of Adaptation & Resilience Options	**39**	
7. Financing Adaptation and Resilience	**46**	Outlines climate finance options to secure the resources, innovation, and long-term investment needed to implement climate-resilient port systems and sustain adaptation efforts.
Annexes and References	**51**	

Foreword

Ports are a vital element of the trade ecosystem, facilitating the global supply of goods to millions of people around the world. Due to their proximity to both land and ocean, ports are under immense pressure from climate change. Higher temperatures, rising sea levels and more frequent and severe weather patterns will increasingly expose vulnerabilities in port infrastructure, particularly in small island developing states and emerging ocean economies, where the impact of these changes will be felt hardest. Overcoming these challenges will require significant investment, mobilising a vast amount of resources to adapt our ports and build resilience into our supply chains. The Resilience4Ports (R4P) initiative is playing a vital role in this transition, convening key actors across the port ecosystem to work together with a collaborative mindset, rather than a competitive one. The Port Decision Makers' Guide to Climate Risk Assessment (CRA), launched at COP30, is this vision in practice. It will help address capacity gaps for decision makers throughout the port value chain, providing a holistic and financeable approach to climate adaptation. Together, we can future-proof port systems and, in doing so, drive better working conditions, healthier ecosystems, and new access to capital for existing and emerging ports around the world.

THOMAS THUNE ANDERSEN
Chairman, Lloyd's Register Foundation

1. INTRODUCTION

Maritime shipping forms the backbone of the global economy, facilitating approximately 90% of international trade. At the heart of this system are ports, which serve as vital hubs connecting maritime routes with inland transportation networks such as road and rail. Their strategic position makes ports indispensable to the continuity and efficiency of global supply chains.

However, climate change is increasingly threatening the reliability of port systems. Ports are being exposed to a growing range of physical climate hazards, including more frequent and intense storms, higher wind speeds, and accelerating sea level rise (Christodoulou, Christidis and Demirel, 2019). These impacts not only disrupt port operations but also carry significant financial and logistical consequences, making ports some of the most vulnerable nodes in global trade networks.

The economic stakes are substantial. Recent analysis indicates that climate-related port disruptions cost the global economy an estimated $7-10 billion annually, with projections suggesting this could rise to $25-30 billion by 2100 without adequate adaptation measures (EDF and RTI International, 2022; UNCTAD, 2023). The cascading effects through global supply chains amplify these direct costs by a factor of 3-5, underscoring the critical need for proactive climate risk assessment and adaptation.

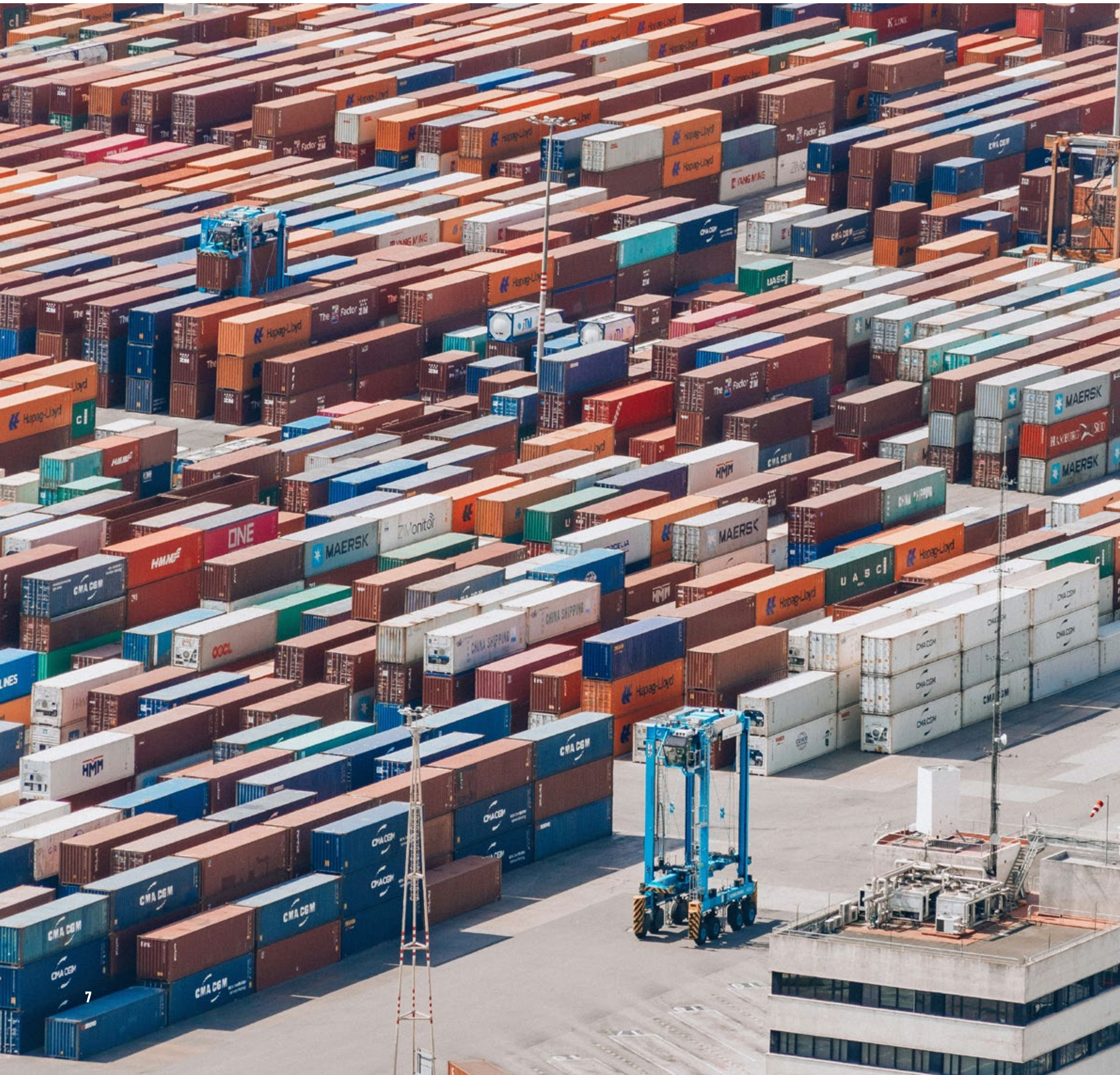
Given the critical function of ports in global trade and their exposure to multifaceted risks, they represent a logical starting point for the implementation of resilience and adaptation in maritime infrastructure. In the face of today's dynamic and uncertain economic conditions, strengthening resilience is essential, not only for maintaining port operations and the supply chains they underpin, but also for fostering economic growth and safeguarding environmental sustainability.

Port Decision Makers' Guide to Climate Risk Assessment (CRA) is an essential first step in helping ports understand, anticipate, and respond to the impacts of climate change. A structured CRA helps ports identify risks, prioritise adaptation measures, and ensure long-term resilience and sustainability.

There is growing recognition of the need for a structured and comprehensive CRA for ports, as emphasised by key sources including the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (IPCC, 2023). Recent submissions to the International Maritime Organisation (IMO) by the International Association of Ports and Harbours (IAPH) and Brazil highlight the critical role of ports in the energy transition, advocating for CRA-informed investment and policy decisions to support climate adaptation, mitigation, and a just transition in the maritime sector (IAPH, 2024; Brazil Government, 2024).

Port decision-makers are increasingly aware of the impacts of climate change - not only on infrastructure and operations, but also on the workforce, surrounding communities, and natural ecosystems that coexist with ports.

Based on published resources, this document aims to increase awareness of the scope, purpose and importance of a CRA. It provides practical, actionable insights to port decision-makers on how to effectively commission a CRA. Crucially, a well-executed CRA also serves as the essential evidence-based foundation required to access international climate finance. This approach turns a resilience necessity into a tangible investment opportunity. It also can empower ports that face challenges with lack of resources and capacity to take meaningful steps toward climate adaptation and secure finance, ultimately fostering a more equitable and robust global maritime network.



2. WHAT IS A CRA AND WHY IS IT IMPORTANT?

A CRA is a structured process used to identify, evaluate, and prioritise risks associated with climate change by analysing the interaction between climate hazards (e.g. extreme weather, sea level rise), the exposure of people, assets, or ecosystems to those hazards, and their vulnerability (the degree to which they are susceptible to harm and their capacity to adapt). The goal is to inform decision-making on adaptation and resilience planning by estimating potential impacts over time, including under future climate scenarios (IPCC, 2023; IDB Invest 2021).

Ports are exposed to a wide range of hazards (Figure 2.1) and they face a wide array of direct and indirect impacts, each posing significant risks to the physical infrastructure, port operations, workforce, and reputation (see Table 2.1). These issues extend indirectly to disruptions to services, supply chains, or economic activity (Global Center on Adaptation, 2025).

FIGURE 2.1.

Portion of ports (53 ports included in the study) reporting extreme weather events, such as those intensified by climate change (Adapted from: United Nations Environment Programme Finance Initiative, 2024)

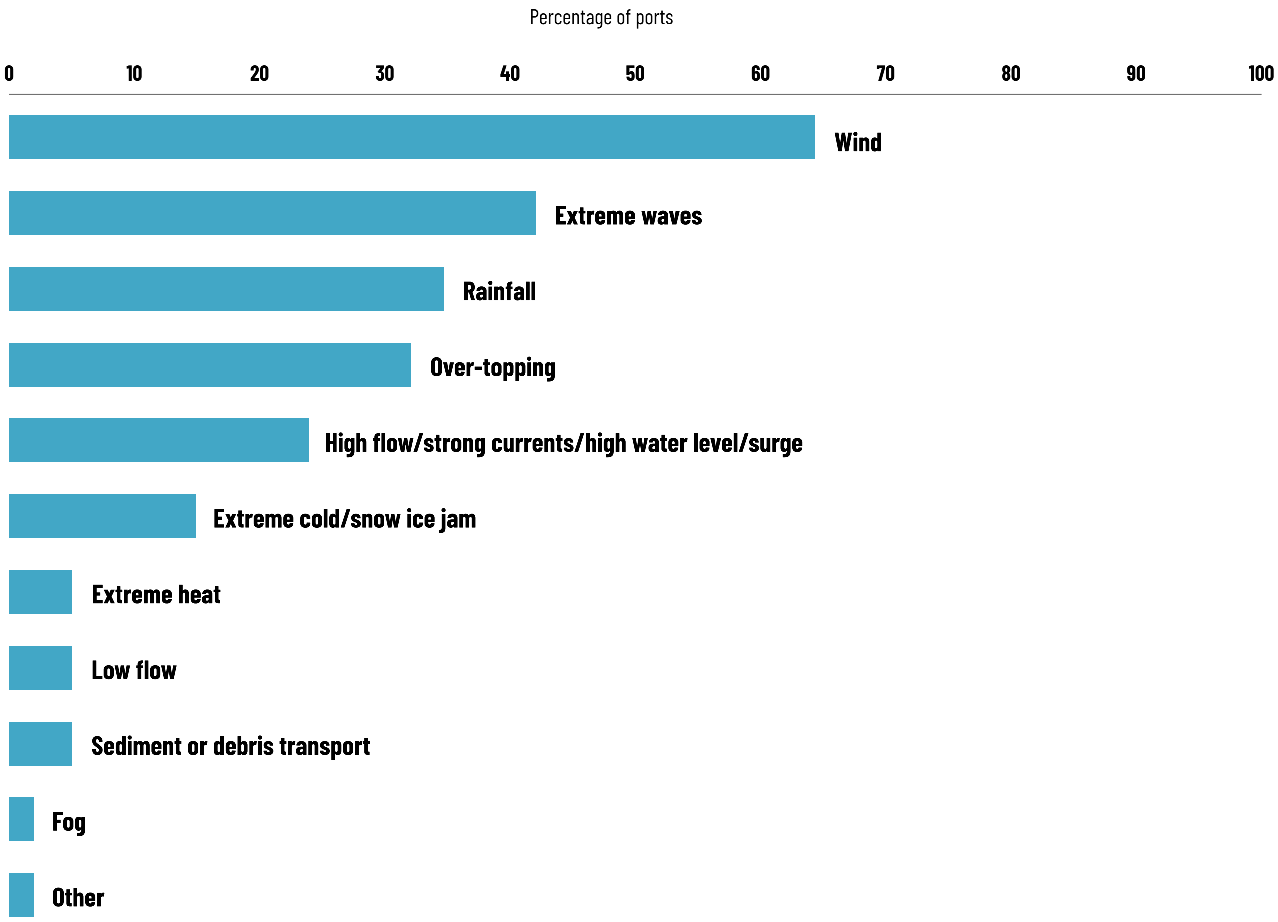


TABLE 2.1

Direct and indirect impacts of physical climate hazards on ports and maritime operations

Chronic hazard — *Persistent or recurring environmental stressor that builds over time and gradually undermines the stability or performance of natural and human systems.*

Acute hazard — *Sudden, short-term event (like a storm or tsunami).*

HAZARDS	DIRECT IMPACTS	INDIRECT IMPACTS
Sea level rise (chronic)	• Nuisance flooding • Damage to assets • Reduced bridge clearance	• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations • Port service delays • Damage to port reputation and brand • Higher insurance premiums from growing global losses and claims
Extreme precipitation (acute)	• Damage or destruction of assets • Equipment damage or destruction	• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations • Port service delays • Damage to port reputation and brand • Higher insurance premiums from growing global losses and claims
Flooding (acute)	• Damage or destruction of assets • Road closures • Silt accumulation in port channels, disrupting ship traffic	• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations • Port service delays • Damage to port reputation and brand • Higher insurance premiums from growing global losses and claims
Hurricanes/ Cyclones (acute)	• Damage or destruction of assets • Power outages	• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations • Port service delays • Damage to port reputation and brand • Higher insurance premiums from growing global losses and claims
Storm surge (acute)	• Damage or destruction of assets	• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations • Port service delays • Damage to port reputation and brand • Higher insurance premiums from growing global losses and claims

HAZARDS	DIRECT IMPACTS	INDIRECT IMPACTS
High speed wind	• Damage or destruction of assets including navigation and communication equipment. • Toppling of containers in yards	• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations • Port service delays • Damage to port reputation and brand • Higher insurance premiums from growing global losses and claims
Extreme heat	• Buckling and rutting of asphalt and rail lines • Work stoppages or more shift changes for worker safety	• Changes in agricultural production resulting in shifting trade flows
Compound Events	• Simultaneous failure of multiple systems • Overwhelmed drainage capacity • Cascading infrastructure failures	• Extended recovery periods • Regional economic disruption • Loss of market share to competitor ports
Coastal Erosion	• Loss of land area • Undermining of foundations • Reduced buffer zones	• Need for costly land reclamation • Regulatory compliance issues • Environmental litigation risks
Ocean Acidification	• Accelerated corrosion of marine infrastructure • Increased maintenance frequency	• Shortened asset lifespan by 15-30% • Higher lifecycle costs
Water stress	• Power outages for thermal power • plants, which require water for cooling	• Changes in agricultural production resulting in shifting trade flows

Source: The Resilience Shift, 2019

BOX 2.1

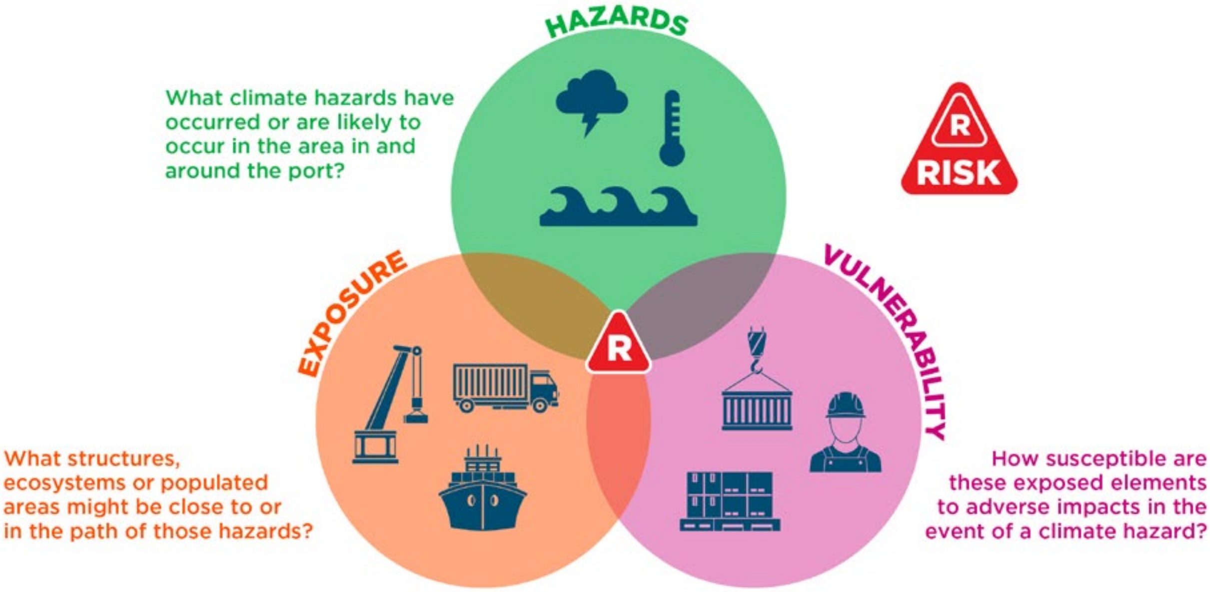
What is climate-related uncertainty and how does it affect decision-making?

Climate uncertainty refers to the range of unknowns in predicting future climate conditions, and it plays a critical role in how we plan for and respond to climate change. Recent research underscores the increasing frequency and severity of extreme weather events and ecosystem disruptions due to rising global temperatures, emphasising the need to limit warming to 1.5°C to avoid the worst impacts. Climate projections, such as those illustrated in the IPCC (2023), show a clear upward trend in global temperatures, indicating the range of uncertainty. This uncertainty arises from three main sources: natural variability (e.g. unpredictable climate system dynamics and feedback), limitations in climate models (which simplify complex systems and may lack regional precision), and human behavior (including unknown future emissions, economic trends, and policy choices). The IPCC accounts for these uncertainties through probabilistic language (e.g. "likely") and confidence levels based on evidence and expert consensus. Understanding and effectively communicating these uncertainties is essential for sound decision-making, particularly in sectors like ports, where long-term investments must be resilient under a wide range of future climate conditions.

The initial step in strengthening a port's resilience to climate change using the CRA approach involves assessing the level of risk by considering three key components: hazard, exposure, and vulnerability, as illustrated in Figure 2.2. This is typically a qualitative method that provides context and highlights the need for a more detailed, quantitative CRA. A comprehensive CRA allows decision-makers to determine whether adaptations or modifications to the port system are necessary to address potential climate impacts.

FIGURE 2.2

Components of Risk (IDB Invest, 2021)



BOX 2.2.

Digital Port Infrastructure Vulnerabilities

Modern ports are increasingly cyber-physical systems where digital technology controls and optimises operations. Climate hazards now threaten not only physical assets but also the digital systems that underpin port functionality. Port community systems, which coordinate documentation, vessel scheduling, and cargo tracking, can fail during power outages, extreme heat, or flooding. Automated terminal operations, including guided vehicles, stacking cranes, sensors, and Internet of Things (IoT) monitoring, are vulnerable to heavy rain, lightning, high winds, and temperature extremes (Argyriou and Tsoutsos, 2024). Navigation and communication systems, such as radar, satellite links, antennas, and weather stations, face disruption from storms, salt spray, and ice accumulation. Predictive maintenance systems rely on sensors and Artificial Intelligence (AI) models that may drift out of calibration or produce false readings during extreme events. Digital system failures can halt operations even when physical infrastructure remains intact, and recovery often requires complex troubleshooting and data restoration.

Real-world examples illustrate the vulnerabilities of digital port infrastructure. In 2025, a heatwave at the Port of Rotterdam caused significant disruption, affecting crane operations, rail freight transport, and logistics in the hinterland. Similarly, Hurricane Harvey in 2017 led to a two-week disruption at the Port of Houston, with ripple effects lasting up to five years due to infrastructure damage and failures in communication systems (UNCTAD, 2025). At the Port of Shanghai in 2021, extreme heat caused widespread sensor malfunctions in automated terminals, reducing handling efficiency by 30% during peak summer operations.

Adaptation measures for digital port infrastructure include implementing redundant systems with geographically separate backup data centers, using climate-controlled and waterproofed equipment, and conducting regular stress testing under extreme weather scenarios. Ports can also maintain hybrid operations with manual backup procedures to ensure continuity during digital system failures. Additionally, hardening infrastructure through elevated data centers, underground fiber optics, and weather-resistant enclosures further protects critical systems from climate-related hazards.

Protecting digital infrastructure is essential to maintain port functionality, safeguard billions in automation investments, and ensure resilience against cascading operational failures. As ports continue to digitise, climate adaptation strategies must explicitly address these cyber-physical vulnerabilities.

Conversely, resilient digital systems (e.g., advanced sensor networks, AI-driven predictive modeling) can significantly enhance a port's adaptive capacity because they provide real-time data for early warning and optimise operational responses during climate events.

CRA RESOURCES

Conducting detailed CRAs often requires the downscaling of global and regional climate models to capture local-scale impacts relevant to specific port systems. This process is technically complex and demands specialised climate modeling expertise, particularly interpreting and translating data into actionable insights for engineering and planning. As a result, downscaling introduces additional time and cost, which can be a barrier for developing regions or lower-capacity port authorities. According to PIANC (2020), tailoring climate information to site-specific conditions is essential for effective adaptation planning but requires both technical capacity and financial investment.

The following list shows widely accepted methodologies and resources for CRAs.

- IPCC AR6 Synthesis Report
- The Adaptation Support Tool (EU)
- PIANC - Climate Change Adaptation Planning for Ports and Inland Waterways
- The World Bank Climate Risk Assessment Toolkit
- PIEVC Protocol

2.1
Levels of analysis in CRAs

A CRA typically comprises two levels of analysis: a climate risk screening and a detailed CRA (see next page). A climate risk screening helps prioritise where detailed assessments should be applied, while detailed assessments provide the robust evidence base needed for engineering, policy, and financial planning. Together, they ensure that ports can identify, understand, and adapt to climate risks proactively. To enhance consistency, transparency, and credibility, it is essential that CRAs are aligned with internationally recognised standards such as International Organization for Standardization (ISO) 14090:2019 (Adaptation to climate change – Principles, requirements and guidelines) (ISO, 2019) and ISO 14091:2021 (Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment) (ISO, 2021). These standards offer a structured framework for integrating climate adaptation into decision-making processes.

BOX 2.3.

Aligning with international standards: ISO 14091:2021

ISO 14091:2021 provides a structured framework to help organizations to assess and manage the risks associated with climate change. It outlines practical guidelines for conducting robust risk assessments, addressing both present and future climate change risks.

With global trade and economies increasingly dependent on resilient transport infrastructure, CRAs for ports are not just a technical exercise, they are essential for safeguarding economic stability, protecting communities, and ensuring the continuity of global supply chains in the face of accelerating climate change. To be effective, CRAs must take a holistic, system-wide approach that considers risks across the entire port system, including infrastructure, operations, supply chains, the workforce, and the surrounding ocean and coastal environments. Addressing these broader connections ensures that adaptation strategies are robust, forward-looking, and capable of withstanding complex and cascading climate-related disruptions. It is recommended port authorities seek specialist guidance during this CRA process.

CRA ANALYSIS LEVELS

CLIMATE RISK SCREENING

Description

A high-level, initial assessment to quickly identify whether climate risks are relevant and potentially significant for a specific port. Involves reviewing available climate data, general hazard exposure (e.g., storm surges, temperature extremes), and sensitivity of key assets/functions. Often qualitative or semi-quantitative. Suitable for early planning or due diligence stages.

Key Questions to be addressed

- What climate hazards could affect the port system?
- What elements of the port system are exposed to these hazards?
- What could be the potential impacts of these hazards on the port system?
- Are the risks potentially significant? If the answer is YES, a detailed climate risk assessment is needed.

Data Required

- Historical climate and hazard data (precipitation, temperature, sea-level rise)
- Asset inventory
- GIS maps of port and surrounding areas
- Preliminary stakeholder input

Outputs

- Identification of key climate hazards
- Preliminary risk profile
- List of assets/functions potentially at risk
- Recommendations and ToRs for further detailed assessment

DETAILED CLIMATE RISK ASSESSMENT

Description

A comprehensive, quantitative analysis of climate hazards, vulnerabilities, and impacts across various timeframes and scenarios. May include asset-level modelling, future climate projections, adaptive capacity evaluations, and risk management planning. Examines specific infrastructure elements (e.g., quay walls, cranes, supply chains). Supports strategic decision-making and adaptation planning.

Key Questions to be addressed

- What additional data is required to understand climate risks in detail?
- How will the port system be exposed to hazards under different scenarios?
- How vulnerable is the port system to each hazard?
- What are the potential direct and indirect losses?
- What are the most significant threats in terms of severity, likelihood, and socio-economic consequences?
- What adaptation and resilience options should be considered?

Data Required

- Downscaled climate projections
- Engineering specifications of assets
- Flood/storm surge models
- Economic valuation of assets and services
- Local adaptive capacity indicators
- Stakeholder vulnerability and preparedness assessments

Outputs

- Quantified risk levels per asset or function
- Climate scenario modelling outputs
- Adaptive capacity assessment
- Actionable recommendations for adaptation and resilience (e.g., port infrastructure elevation, drainage redesign, emergency plans)

2.2
Role of stakeholders in supporting CRAs

Stakeholders play a pivotal role in supporting CRAs and resilience/adaptation options. Their engagement is critical for ensuring that the planning and decision-making processes are participatory, transparent, and informed by a diverse range of knowledge and practices, see Table 2.2.

TABLE 2.2.

Stakeholder contributions to the CRA process

STAKEHOLDER GROUP	CONTRIBUTION TO THE CRA
Port Authority	• Initiate CRAs • Act as the central convener and strategic leader of the CRA process • Implement and oversee adaptation measures • Develop and enforce policies or guidelines
Private Port Operators e.g. Terminals (where applicable)	• Firsthand knowledge of how climate hazards affect port operations, helping to identify port infrastructure and supply chain vulnerabilities. • Prioritisation of practical, business-aligned adaptation measures that ensure operational continuity and maintain efficient trade flows under changing climate conditions
Government Authorities (ministries) and Regulators	• Establish resilience standards for port infrastructure and establish enabling environments • Ensure integration of climate risks into public investment planning e.g. finance ministry • Encourage fiscal policies that promote resilience
Financial Institutions	• Promote the integration of long-term, climate-resilient strategies into port planning and operations, ensuring that adaptation measures are not only technically sound but also aligned with financial viability and return on investment expectations. • Provide guidance on financing mechanisms by outlining a range of funding options for identified adaptation measures, such as green and blue finance instruments, climate resilience bonds, concessional loans, grants, and Public-Private Partnerships (PPPs), helping ports navigate the financial landscape of adaptation. • Support risk-informed decision-making by encouraging the incorporation of climate-related financial risks into investment assessments and project appraisals, in line with frameworks such as the Task Force on Task Force on Climate-related Financial Disclosures (TCFD), thereby strengthening investor confidence and ensuring sustainable financial planning (TFCD, 2017).
Insurance Providers	• Use advanced climate models and data analytics to assess exposure to hazards, helping pinpoint high-risk areas across port infrastructure. • Inform insurance pricing, encouraging investment in adaptation measures by linking reduced risk to more favourable insurance terms.

STAKEHOLDER GROUP	CONTRIBUTION TO THE CRA
Academia and Research Institutions	• Contribute research and data on climate projections and differential impacts of climate risks on gender. • Offer tools and methodologies for conducting gender-sensitive CRAs.
Local Communities and Indigenous Groups	• Provide local knowledge on environmental and social conditions, past climate events, and impacts on livelihoods. • Share gendered perspectives on how climate impacts affect women, children, and vulnerable groups. • Offer insights into existing coping mechanisms and resilience strategies.
Civil Society Organizations e.g. NGOs	• Advocate for the inclusion of vulnerable groups in consultations and decision-making. • Conduct research on gendered and socio-economic impacts of climate change, informing the risk assessment. • Advocate for higher environmental standards, Nature based Solutions (NbS) and long-term thinking.

BOX 2.4.

Integrate considerations of gender, social inclusion, and the specific needs of marginalised and vulnerable groups

When conducting a CRA, it is essential to integrate considerations of gender, social inclusion, and the specific needs of marginalised and vulnerable groups. Women, children, persons with disabilities, and indigenous communities often face disproportionate risks from climate impacts due to social, economic, and cultural factors.

In port areas, where climate-induced or exacerbated events such as storm surges, flooding, and heatwaves can disrupt infrastructure and livelihoods, women may be particularly vulnerable due to caregiving responsibilities, limited mobility, and restricted decision-making power. These factors can delay evacuation, increase exposure to harm, and heighten risks such as gender-based violence or exploitation in temporary shelters. Vulnerable groups also face greater barriers to economic recovery, especially in port-related industries where employment is often gender-segregated or informal.

Moreover, climate adaptation or port expansion projects - such as land reclamation or renewable energy infrastructure - must respect the rights of indigenous peoples, particularly where ancestral lands or traditional coastal access are involved. A gender-responsive and socially inclusive CRA helps ensure that resilience planning addresses diverse needs, promotes equity in adaptation outcomes, and avoids reinforcing existing vulnerabilities (Deininger et al., 2023).

3. SCOPING AND PROCURING CRAs

Climate change presents growing physical and operational risks to port infrastructure, supply chains, navigational safety, hinterland connectivity, and business continuity. To address these challenges, port authorities must commission CRAs that are robust, context-specific, and actionable. While the full scoping process is comprehensive, port authorities can approach it progressively. They can start with a smaller-scale screening study, which will build momentum, secure stakeholder buy-in, and justify further investment in a detailed CRA.

3.1
Objectives of a CRA

A detailed CRA should support the following objectives:

* Identify and evaluate climate-related hazards (e.g. sea level rise, storm surge, wave overtopping, high winds, extreme heat, flooding, sedimentation) (IPCC, 2023).
* Assess vulnerability and adaptive capacity of physical infrastructure, port operations, and critical interdependencies (e.g. supply chains).
* Determine risk exposure across near, mid and long-term climate scenarios.
* Inform port master planning, design standards, investment strategies, emergency preparedness, insurance, and operational protocols (PIANC, 2020).
* Provide a foundation for adaptation planning, procurement of resilience works, and stakeholder engagement.

3.2
Scoping considerations

When developing the scope of work, port authorities should ensure the assessment:

* Aligns with international standards (e.g. ISO 14091 on climate risk assessment; ISO 14090 on adaptation planning) (ISO, 2019; ISO 2021).
* Covers relevant geographic, communities and operational boundaries: terminals, berths, breakwaters, hinterland connections, storage zones, intermodal nodes.
* Addresses key timescales (e.g. 2030, 2050, 2100) and reflects emissions scenario uncertainty (e.g. Shared Socioeconomic Pathway (SSP) (SSP2-4.5 and SSP5-8.5)) (IPCC, 2023).
* Evaluates cascading risks (e.g. compound flooding, utility disruption) and systemic risks (e.g. trade rerouting).
* Incorporates nature-based and hybrid infrastructure options where appropriate.

SUGGESTED DELIVERABLES INCLUDE:

- Risk register with likelihood, vulnerability, and overall risk ratings/scores.
- Geographic Information System (GIS)-based hazard and vulnerability mapping.
- Climate adaptation options appraisal and prioritisation (ADB, 2021).
- Implementation roadmap and integration guidance for planning and operations.

3.3

Selecting technical partners

A high-quality CRA requires interdisciplinary expertise spanning climate science, coastal engineering, port operations, risk analysis, and stakeholder engagement.

Recommended selection criteria include:

* Demonstrated experience delivering ISO-aligned CRAs in port or maritime contexts.
* Proven use of climate projection data and ability to address extremes and uncertainty.
* Competence in hazard modelling (e.g. sea level rise, storm surge inundation), vulnerability analysis, and risk evaluation.
* Familiarity with port operations, logistics flows, asset management, and design integration.
* A multidisciplinary team, including climatologists, engineers, economists, GIS analysts, and other specialists.
* Capacity to support knowledge transfer and training of Port Authority staff.
* Ability to communicate climate uncertainty and potential impacts effectively.

3.4 Procurement and contracting considerations

To support effective procurement:

- Use ISO 20400 principles for sustainable procurement.
- Define technical outcomes and performance expectations clearly in the Terms of Reference (ToR).
- Include weighted evaluation criteria.
- Consider a phased approach (e.g. screening, detailed assessment, implementation support).
- Include optional contract clauses on data transparency, compliance with ISO standards, and adaptive management protocols.

A robust Request for Qualification (RfQ) process shall be followed to select a suitable technical partner to carry out a detailed CRA. A checklist has been compiled as a tool for port decision makers to easily implement the CRA process, see Annex A.

4. CLIMATE RISK SCREENING

The steps for undertaking a climate risk screening might vary slightly according to published guidelines and nomenclature. There is no one-size-fits-all methodology, with each assessment needing to be tailored to the specific context of both the port and its wider surroundings. As mentioned previously, it is however essential that CRAs are aligned with internationally recognised standards such as ISO 14090:2019 and ISO 14091:2021 to enhance consistency, transparency, and credibility. These typically comprise the following steps (Global Center on Adaptation, 2025).

4.1
Step 1: Identifying climate hazards that could affect the port system

This step involves identifying climate-related hazards that could impact the port, based on its geographic location. Hazards may be:

- Acute (e.g., storms, flooding)
- Chronic (e.g., sea-level rise, rising temperatures)

Key actions include:

- Collecting historical and projected climate data
- Reviewing geo-climatic hazard information
- Using climate models/data to estimate how hazard frequency and intensity may change over the port's lifespan
- Including non-climate natural hazards (e.g., earthquakes) to assess compound risks

The goal is to understand which hazards are relevant and how they may evolve over time.

To inform this step, organisations such as the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) provide free to access resources that can inform high level climate hazard assessments:

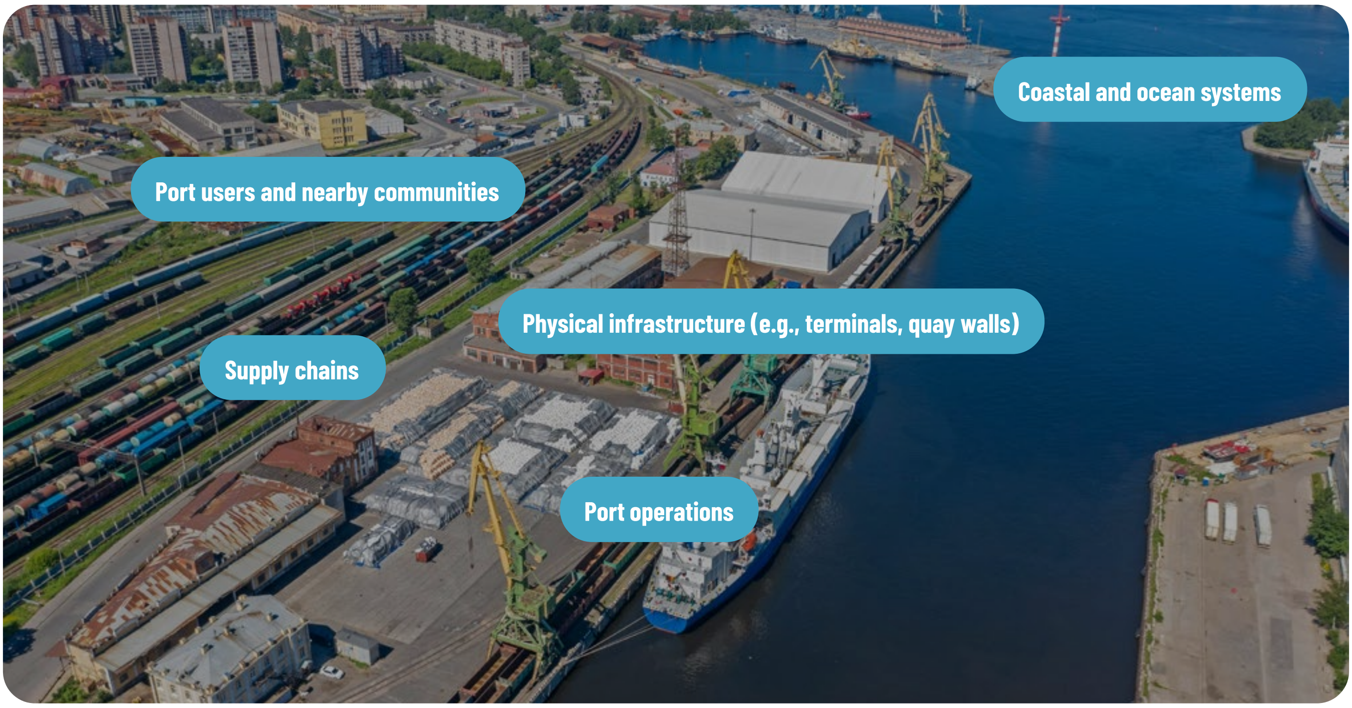
- GFDRR's ThinkHazard!
- The World Bank's Climate Change Knowledge Portal

4.2
Step 2: Assessing the exposure of the port system to the identified climate hazards at the port location

This step aims to understand how the port system is exposed to the climate hazards identified earlier.

Key actions include:

* Listing relevant hazards based on the port's location and environmental conditions and projections of future change
* Identifying exposed elements of the port system, such as:



The outcome is a clear picture of which components are at risk from each climate hazard.

4.3
Step 3: Estimating the impact of hazards on the port system/Estimate the vulnerability of exposed assets to the identified hazard

This step evaluates the potential impacts/vulnerability of climate and geophysical hazards on the port, both now and in the future.

Key points:

* Impact is assessed by combining:
  - The exposure level of port components
  - Vulnerability to hazards
* At this stage, vulnerability can be assessed either by subject matter experts (such as relevant asset managers) or by reviewing relevant design parameters
* Even with limited data, a high-level impact/vulnerability rating helps prioritise risks

This step complements exposure analysis and supports a more complete, risk-based screening, not just hazard identification. **The goal is to classify risks by likely severity of impact, aiding early decision-making.**

4.4
Step 4: Calculate initial risk scores

This step uses a simple risk calculation, outlined below to assign initial risk scores to each exposed asset-hazard pair in the present and for each future scenario.

Hazard*Exposure*Vulnerability=Risk

As discussed above, no universal methodology exists to calculate risk. A common approach, when using the above equation is to assign a value of 1 to 5 for hazard likelihood (rare to almost certain) and asset vulnerability (very low to very high), such as the one presented below, where exposure is binary, i.e. 1 (exposed) or 0 (not exposed).

The changes in risk over time, assuming future scenarios are assessed, can then help to prioritize risks in subsequent stages.

FIGURE 4.1.

Risk matrix to calculate risk scores

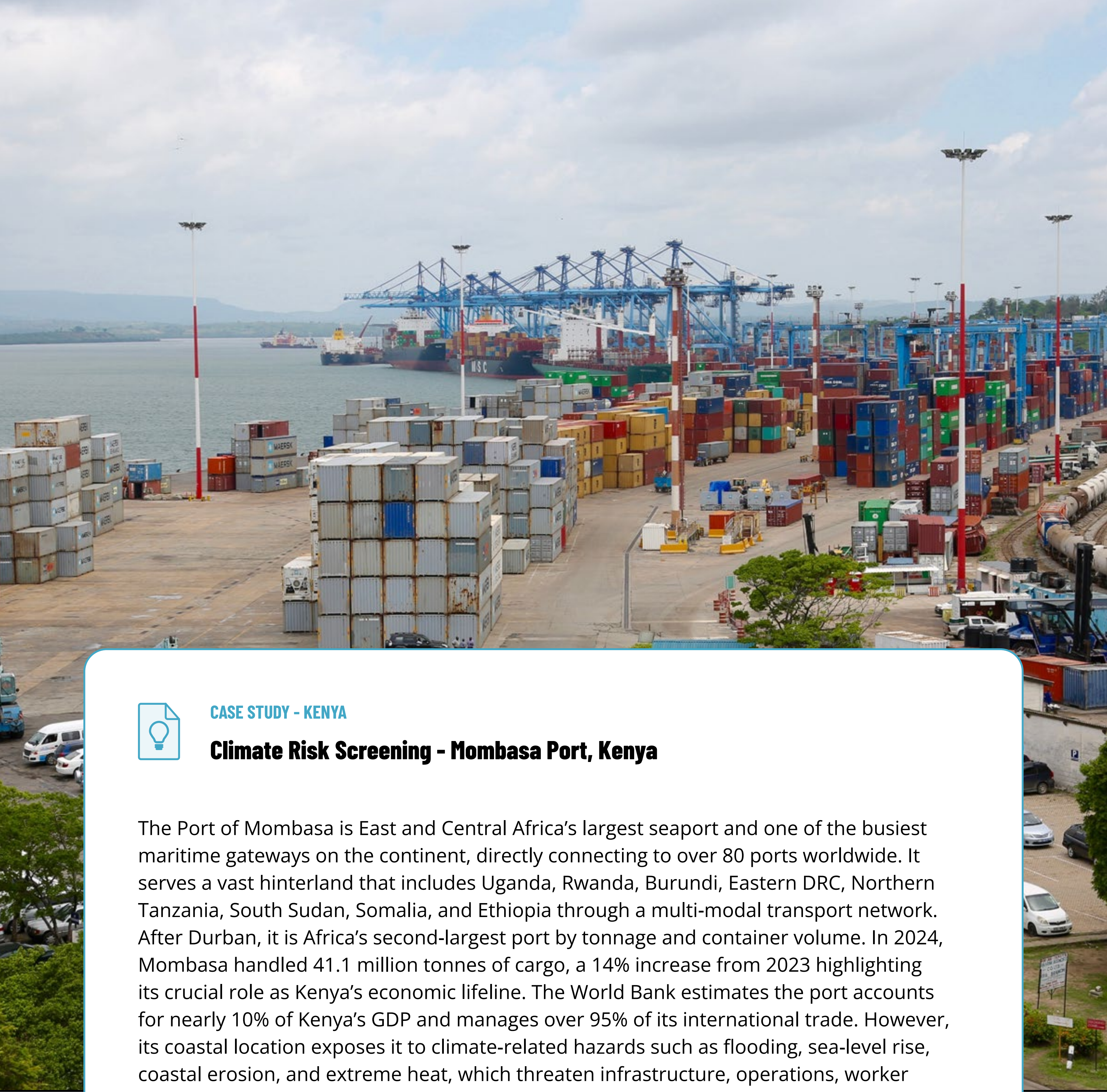
LIKELIHOOD \ VULNERABILITY	Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (5)
Rare (1)	Low – 1	Low – 2	Low – 3	Moderate – 4	Moderate - 5
Unlikely (2)	Low – 2	Moderate – 4	Moderate – 6	High – 8	High – 10
Moderate (3)	Low – 3	Moderate – 6	High – 9	High – 12	Critical – 15
Likely (4)	Moderate – 4	High – 8	High – 12	Critical – 16	Critical – 20
Almost certain (5)	Moderate – 5	High – 10	Critical – 15	Critical - 20	Critical – 25

BOX 4.1.

Recap: Actions for port decision makers at climate screening stage

- Collect and review location-specific climate and hazard data (historical + projected)
- Engage internal departments (engineering, operations, logistics) to identify exposed assets and functions
- Initiate discussions with local stakeholders, including communities and supply chain partners, to understand broader exposure
- Begin developing a list of high risks to support prioritisation of further detailed CRA

Further detailed guidance for port decision makers with climate risk screening is shown in the Annex B.



CASE STUDY - KENYA

Climate Risk Screening - Mombasa Port, Kenya

The Port of Mombasa is East and Central Africa's largest seaport and one of the busiest maritime gateways on the continent, directly connecting to over 80 ports worldwide. It serves a vast hinterland that includes Uganda, Rwanda, Burundi, Eastern DRC, Northern Tanzania, South Sudan, Somalia, and Ethiopia through a multi-modal transport network. After Durban, it is Africa's second-largest port by tonnage and container volume. In 2024, Mombasa handled 41.1 million tonnes of cargo, a 14% increase from 2023 highlighting its crucial role as Kenya's economic lifeline. The World Bank estimates the port accounts for nearly 10% of Kenya's GDP and manages over 95% of its international trade. However, its coastal location exposes it to climate-related hazards such as flooding, sea-level rise, coastal erosion, and extreme heat, which threaten infrastructure, operations, worker safety, and economic stability.

The risk screening conducted by African Group of Negotiators Expert Support (AGNES) followed a structured, multi-step approach integrating climate modelling, stakeholder engagement, and field validation. High-resolution, localised climate data and projections were obtained from Jupiter Intelligence, a leading provider of physical climate risk analytics. The data modelled changes in temperature, sea level, rainfall patterns, and the frequency of extreme weather events up to 2050. AGNES then analysed these projections to identify relevant climate hazards, namely coastal flooding, storm surges, sea-level rise, coastal erosion, ocean acidification, marine heatwaves, and extreme heat.

Photo: Port of Mombasa (Credit: DFID - UK Department for International Development)

To validate modelled findings and ground them in local realities, AGNES conducted fieldwork in October 2025, engaging stakeholders from the KPA, Kenya Maritime Authority (KMA), Kenya Marine and Fisheries Research Institute (KMFRI), and port workers' representatives. These consultations provided qualitative insights on how climate hazards affect port operations and workers. Using the guidance given in this section, each hazard was assessed by its likelihood, exposure, and asset vulnerability, producing a comparative risk profile for the port.

The screening revealed that Mombasa Port faces both acute (short-term) and chronic (long-term) climate hazards, which interact with compound risks.

- **Flooding** emerged as the most disruptive acute hazard. Between 2020 and 2023, heavy rainfall repeatedly inundated container yards, internal roads, and storage areas, causing major operational delays. Projections show rainfall will intensify under high-emission scenarios, amplifying future flood risks.
- **Strong winds and storm surges** generate violent waves that occasionally halt operations, damaging equipment and reducing productivity.
- **Sea-level rise**—currently around 0.3 mm per year—is expected to continue and accelerate, heightening the risk of coastal inundation and infrastructure destabilisation.
- **Coastal erosion** is gradually degrading shorelines and threatening quay walls and storage areas.
- **Extreme heat** peaks during February–March, exposing outdoor workers to health risks and reducing operational efficiency.
- **Marine Heat Waves (MHWs) and ocean acidification** are emerging concerns, contributing to corrosion of port structures and threatening marine ecosystems critical to port sustainability.

Regional trends compound these risks. Increasing rainfall variability and upstream runoff intensify erosion and sedimentation. Research shows MHWs in the western Indian Ocean have increased by 1.2–1.5 events in recent decades, further stressing marine systems (JGR Ocean, 2022).

Climate hazards affect both physical and socio-economic systems. Flooding, strong winds, and storm surges frequently delay vessel handling, cargo clearance, and terminal operations raising turnaround times and maintenance costs. Inundation and erosion damage quays, storage yards, and internal access roads, undermining port efficiency.

Worker safety is another concern. Heat stress and polluted air during stagnant weather conditions cause respiratory problems, while casual workers such as vendors suffer livelihood disruptions when port activity slows. These effects disproportionately impact vulnerable groups who depend on the port economy.

Chronic hazards, particularly sea-level rise and heat, will gradually worsen infrastructure degradation. Corrosion from higher marine temperatures and acidification will shorten the lifespan of quay walls, pipelines, and vessels. These long-term pressures demand sustained investment in climate-resilient and corrosion-resistant infrastructure.

These findings emphasise the need for targeted adaptation measures to address the most critical risks, as outlined in Table 4.1, which details the varying levels of threat posed by each hazard based on its likelihood and vulnerability.

TABLE 4.1.

Risk scores for key climate hazards at Mombasa Port

CLIMATE HAZARD	LIKELIHOOD	ASSET VULNERABILITY	RISK SCORE
Ocean acidification	Moderate (3)	Medium (3)	High – 9
Marine heatwaves	Moderate (3)	Medium (3)	High – 9
Strong winds / storm surges	Almost Certain (5)	Medium (3)	Critical – 15
Extreme heat	Almost Certain (5)	Medium (3)	Critical – 15
Coastal erosion	Almost Certain (5)	High (4)	Critical – 20
Flooding (heavy rainfall)	Almost Certain (5)	Very High (5)	Critical – 25
Sea level rise	Almost Certain (5)	Very High (5)	Critical – 25

Flooding and sea-level rise represent the most immediate and severe threats, followed by erosion. Strong winds, storm surges, and extreme heat cause operational disruptions, while marine heatwaves and acidification are emerging long-term risks.

The Climate Risk Screening confirms that the Port of Mombasa faces escalating climate threats that jeopardise infrastructure, operations, and livelihoods. Flooding, erosion, sea-level rise, and extreme heat are the most urgent concerns. While KPA's Green Port Policy which has already been implemented marks a progressive shift toward sustainability and resilience, the findings highlight the need for a detailed CRA to prioritise investments, strengthen adaptive capacity, and safeguard Kenya's maritime economy. Collaborative planning between KPA, government agencies, and local communities will be critical to ensure that the port's resilience strategy is both inclusive and future-ready. Full case study can be accessed here.

5. DETAILED CRA

The detailed CRA builds on the findings of the high-level climate risk screening. This step will help the Port Authority obtain a comprehensive understanding of a port system's climate risks and how they might change in the future. Several methodologies for undertaking climate risk assessments currently exist, and while many share common elements, there is often limited consistency across approaches. In this context, alignment with international standards is essential to ensure comparability and credibility.

Key steps typically included in a detailed CRA are presented below.

1 Collate data required for the CRA

This step focuses on gathering all additional data needed for a detailed CRA, beyond what's already been collected during the initial screening.

Key steps include:

* Identify and compile relevant documents, including port system maps, project proposals, preliminary and current design documents, as well as baseline technical, economic, and financial assessments.
* Review existing studies, including geological and hydrogeological surveys, zoning and land-use plans as well as protocols or guidance from similar ports or locations exposed to comparable hazards.
* Coordinate with national meteorological agencies and climate experts for downscaled future climate projections.
* Organise all information into a data register, ensuring it's catalogued and accessible for the CRA team.

2 Depending on data availability, decide on the most appropriate method of risk assessment to undertake:

A. A qualitative CRA would be most suitable where specific hazard or asset data (such as detailed flood maps or asset design parameters) is not available

B. A semi-quantitative CRA would be most suitable where data is incomplete or uncertain such as a lack of specific design thresholds

C. Where good spatial data for both climate hazard and assets is available (and asset criticality is well understood) a quantitative CRA can be undertaken

The more data is available, the more confidence can be placed in the result of the assessment. Therefore, it is crucial to identify as many relevant data sources as possible before beginning with a detailed CRA.

BOX 5.1.

What is criticality?

According to PIANC (2020), Criticality is defined as “a measure of the relative importance that enables the identification of assets, systems or operations where disruption or destruction would have a significant adverse impact on the continued functioning of the port or waterway or those that are indispensable in some other way”. Determining the relative criticality of assets is suggested to provide focus to the collection of climate change data and the scope of the risk assessment.

3

Analyse the hazards to which the port system is exposed, for a range of scenarios

At this stage, a more detailed analysis of climate and geophysical hazards is conducted, building on the high-level findings from climate risk screening.

Key steps include:

- Reassess the frequency and intensity of each hazard using detailed, site-specific data
- Consider multiple climate scenarios (e.g., different time horizons and emissions pathways)
- Incorporate stakeholder input to refine assumptions and validate findings
- Update or confirm the risk from each hazard, reflecting the new data and insights

4

Assess exposure in greater detail for current and future scenarios

Depending on the context, a more nuanced assessment of exposure may be appropriate at this stage. In ISO14091:2021, for example, exposure is defined as the “presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social or cultural assets in places and settings that could be affected”.

5

Assess the vulnerability of the port system for each scenario

This step evaluates how vulnerable the port system is to the identified hazards under different climate scenarios.

Key steps include:

* Assess direct and indirect losses for each scenario
  - Identify key physical impacts, such as:
  - Structural damage
  - Operational disruptions
* Analyse the root causes of impacts, i.e., which features of the hazard (e.g., intensity, duration) lead to specific damages
* Evaluate the port system's capacity to resist, absorb, and recover from both direct and indirect impacts. The port system's capacity to resist, absorb, and recover from both direct and indirect impacts should be taken into account here. ISO14091 (2021)'s Annex G and Annex H provide useful information on the components of adaptive capacity and how to assess this.

6

Recalculate the risk score for each scenario

Depending on the chosen method, this could be a repeat of the risk calculation outlined above.

Where good spatial data for both climate hazard and asset is available, more advanced approaches, such as ones to calculating asset vulnerability (such as vulnerability functions) can be incorporated into the final risk calculation.

7

Recalculate the risk score for each scenario

This step examines how multiple hazards interact and amplify impacts across the port and connected systems.

Key steps include:

- Model concurrent hazard scenarios (e.g., high tide + storm surge + heavy rainfall)
- Map interdependencies between port systems and external infrastructure
- Assess cascade failure pathways using system dynamics or network modeling
- Evaluate regional supply chain vulnerabilities and indirect economic impacts
- Quantify economic consequences using input-output or agent-based models
- Identify which hazard combinations and system interactions drive the most severe outcomes
- Assess the port system’s capacity to resist, absorb, and recover from compound and cascading impacts

BOX 5.2.

Recap: Actions for port decision makers (with specialist support) at detailed CRA stage:

- Appoint a CRA coordination team with cross-department representation
- Ensure timely access to internal and external data sources
- Facilitate communication between technical staff, external consultants, and stakeholders
- Align CRA outcomes with infrastructure planning, budgeting, and regulatory compliance
- Use findings to prioritise adaptation investments and risk mitigation actions.

Further detailed guidance for port decision makers with CRA is shown in the Annex B.

CASE STUDY - GAMBIA

Integrating CRA into Port Infrastructure Planning - The Port of Banjul

Under the Africa Adaptation Acceleration Program (AAAP), the Global Center on Adaptation (GCA) provided technical assistance to mainstream climate resilience into the Port of Banjul 4th Expansion Project. This support includes advanced climate analytics, stakeholder engagement, and investment planning, all aimed at ensuring the port's long-term viability in the face of escalating climate risks. At the heart of this assistance is a CRA, designed not as a standalone diagnostic but as a strategic tool embedded within the project's feasibility and design process.

The CRA followed a structured two-step process, providing a robust foundation for stakeholder engagement, informing the selection of targeted adaptation measures, and ensuring climate risks were integrated into the project's design and investment planning. First, a rapid screening identified key climate hazards such as sea level rise, extreme temperatures, and drought using global and local data sources to establish baseline risks. This was followed by a detailed vulnerability stress test, which quantified the economic and operational impacts of these hazards on port infrastructure, services, and surrounding ecosystems.

The CRA's scope extended well beyond the port's physical footprint. It included the surrounding urban infrastructure, the Bund Road corridor, and critically, the adjacent Tanbi Wetlands Complex—a Ramsar-listed ecosystem that connects the Atlantic coast with the River Gambia estuary. The wetlands play a vital role in flood mitigation for the city and

Photo: Port of Banjul (Credit: Salvador-Aznar) its infrastructure systems, carbon sequestration, and support for fisheries and tourism. Recognising this, the CRA assessed not only the vulnerability of port assets but also the resilience of the surrounding mangrove system and its essential ecosystem services, underscoring the need for its continued protection to sustain regional socio-economic stability.

Stakeholder engagement was central to the CRA's credibility and impact. A Multi-Stakeholder Climate Risk Dialogue convened over 30 participants from national agencies, development banks, civil society, and private sector actors. The dialogue validated the CRA's findings, aligned them with local experience, and surfaced operational priorities. The use of local climate data was praised for improving model accuracy. The Gambia Port Authority acknowledged the projected $27 million in cumulative damages over 30 years—23% of the planned $114 million investment—and up to 3% annual revenue loss. These metrics provided a compelling rationale for adaptation.

Following the CRA, a comprehensive evaluation of adaptation and resilience options was undertaken (see Section 6 for more information). Measures were categorised into physical, social, and institutional interventions and prioritised through a high-level Cost Benefit Assessment (CBA). The total capital investment for these measures was estimated at €5 million, with operational costs of €250,000 annually. Collectively, they are projected to reduce climate risk by 40–50%, while acknowledging residual risks inherent to port operations. The CRA also informed site selection for the new ferry terminal and supported the proposal for a community-based mangrove rehabilitation program, including monitoring, education, and land-use regulation.

By embedding the CRA into the investment cycle and expanding its scope to include natural systems and stakeholder perspectives, the Port of Banjul project demonstrates how climate analytics can shape resilient infrastructure, protect ecosystems, and align development with national adaptation priorities.

6. ADAPTATION AND RESILIENCE OPTIONS

Once the CRA is completed, appropriate adaptation measures are identified and appraised with the aim to strengthen the port system's climate resilience and adaptation. Importantly, adaptation strategies must also consider the broader social and ecological dimensions of port development. Historically, port planning has emphasised economic performance and efficiency, often overlooking the social and environmental costs. It is increasingly clear that effective adaptation requires more than minimising harm, it must actively generate positive outcomes for surrounding communities and ecosystems.

Resilience measures can be divided broadly into two categories[1]:

STRUCTURAL ('HARD') MEASURES:

Any physical construction that reduces or avoids possible impacts of hazards, reduces exposure or sensitivity, or the application of engineering techniques, such as green/blue/gray infrastructure or technology to achieve hazard resistance and resilience in structures or systems. See Box 6.2 for more details.

NON-STRUCTURAL ('SOFT') MEASURES:

Non-physical measures to reduce climate risks and impacts, such as policies, strategies, plans and governance to enhance the enabling environment; knowledge, practice, capacity building, and education for public awareness raising.

RESILIENT PORT SYSTEM

To achieve a resilient port system, a combination of both structural and non-structural measures is required. This combination of actions may be different for each port system as they will be context-dependent.

Some key characteristics of resilience and adaptation measures include:

- Resilient options must be able to adaptively transform port systems to overcome unexpected and unforeseen events.
- Resilient options must be environmentally integrated so that they do not cause any other damage.
- Infrastructure must be protected by design from the hazards that could impact an asset once delivered.
- Resilience must be a shared responsibility, with focus on collaborative data and knowledge sharing regarding an asset.
- Resilient options require continuous learning to optimize the ability of port systems to cope with what's ahead.

1. (Global Center on Adaptation, 2025; IDB Invest, 2021; and PIANC 2020)

6.1
Resilience options appraisal process

1

Establish objectives for climate resilience

During this stage, the main climate resilience objectives for the project are identified. Integrating climate resilience and adaptation measures will improve the resilience of port systems, as well as deliver a range of socio-economic and environmental co-benefits.

In addition, it can also contribute to national and local climate goals. The Port Authority should align resilience objectives for the port system with national and local climate strategies and plans, such as Nationally Determined Contribution National Adaptation Plans (see Box 6.1). This would provide Port Authorities (governments) with a stronger case for directing and influencing investments by the private sector and others to support the implementation of prioritised adaptation actions.

INTEGRATING GENDER CONSIDERATIONS

In addition to assessing climate risks, the Environmental and Social Impact Assessment (ESIA) should include a gender impact analysis to understand the socio-economic effects on local stakeholders. This should also mandate standardised gender mainstreaming, measured through gender-responsive indicators like access to services and employment opportunities (Global Center on Adaptation, 2025).

BOX 6.1.

Nationally Determined Contributions and National Adaptation Plans

Nationally Determined Contributions (NDCs): The NDCs lie at the heart of the Paris Agreement. They are each party's action plans that aim to reduce national greenhouse gas emissions and adapt to the impacts of climate change. In 2023 and then every five years, each party will undertake a stock take, assessing their performance against their NDCs, which will inform the preparation of the subsequent NDCs to align with the achievement of the Paris Agreement.

National Adaptation Plans (NAPs): The NAPs encourage adaptation efforts, with technical and financial support made available to developing countries. The two main objectives of the NAPs are to reduce vulnerability to the impacts of climate change by building adaptive capacity and resilience and to integrate adaptation into new and existing policies and programs, especially development strategies.

2 Identify applicable resilience options and associated co-benefits

This stage will consider what options can be implemented to enhance the resilience of the port system and they will be assessed against the hazards identified in the CRA. Identification of resilience options will consider gray, blue, green or hybrid solutions (see Box 6.2), sector-specific resilience policies and strategies (e.g. NAPs, design codes and guidelines etc.) and other relevant information. Adaptation co-benefits that the resilience options for the port system are likely to generate will then be identified. These are additional to the port system's own co-benefits. Table 6.1 provides some high-level examples of resilience options for a port system, as well as their direct benefits and co-benefits.

BOX 6.2.

Gray, blue, green or hybrid infrastructure solutions

Gray infrastructure: refers to built-up, engineered and physical structures, often made of concrete or other long-lasting materials e.g. sea walls, centers and breakwaters for riverine and coastal flood protection, piped drainage systems for stormwater management (such as storm sewers or concrete detention basins), and air conditioning or cooling centers to cope with extreme heat.

Blue infrastructure: can also be characterized by well-functioning biophysical systems but primarily related to water e.g. ponds and wetlands.

Hybrid infrastructure: a blend of natural and engineered structures that allows for some ecosystem functions mediated by technological solutions. NbS often fall into this category. Examples include bioswales; porous pavement; green roofs; rain gardens; constructed wetlands; Sustainable Drainage Systems (SuDS).

TABLE 6.1.

Examples of resilience options, direct benefits and co-benefits for a port system (World Bank, 2025; Global Center on Adaptation, 2025)

CLIMATE HAZARD	RESILIENCE OPTION	DIRECT BENEFITS	CO-BENEFITS
Flooding	Restoring wetlands near port to act as natural flood buffers Mangrove and salt marshes restoration	• Reduces flood impacts on port system • Protects against severe disruptions	• Support integrity of ecosystems • Maintain or enhance biodiversity, soil quality and water quality of the site area and its surroundings • Reduced cost of repair
Extreme heat	Use of heat-resistant materials to accommodate thermal stress	• Ensures service continuity	• Increases asset lifespan, reducing the need for replacement
	Vegetation buffers in port areas provide shade and reduce heat stress	• Lowers maintenance and repair costs	• Enhances biodiversity in the port system • Sequesters carbon • Improves air quality and visual aesthetics

3

Conduct an economic analysis of applicable resilience options

A comprehensive economic analysis is essential for evaluating the viability of implementing climate resilience measures in port systems. This step aims to determine the net economic benefits of integrating resilience options, comparing them to a baseline scenario with no adaptation. The analysis should be conducted over a relevant time horizon, typically the full expected service life of the asset and apply a discount rate in line with national guidelines or international best practices (e.g., World Bank, 2010; OECD, 2018).

STEPS TO CARRY OUT ECONOMIC ANALYSIS

1. **Establish the baseline (no-adaptation scenario):**
   Assess the Net Present Value (NPV) of the port system without any resilience measures, based on the CRA.
2. **Value costs and benefits of resilience options:**
   For each option, quantify:
   - Costs: Capital Expenditures (CAPEX), Operational Expenditures (OPEX), and other related costs (e.g. soft measures).
   - Benefits: Direct benefits from reduced climate risks, and co-benefits such as increased asset lifespan, reduced maintenance, and socio-economic gains.
3. **Apply discounting:**
   Convert future costs and benefits into present values using a suitable discount rate (e.g., 3%–7%).
4. **Estimate net benefits:**
   Calculate the incremental net benefits by comparing each option's NPV against the no-adaptation scenario.
5. **Conduct sensitivity analysis:**
   Test how results vary under different assumptions and uncertainties (e.g., cost estimates, discount rate, climate impact severity).
6. **Rank and compare options:**
   Rank resilience options based on NPV and without resilience options. These findings may complement with additional metrics such as:
   - Internal Rate of Return (IRR)
   - Economic Rate of Return (ERR)
   - Return on Investment (ROI)

4

Conduct an economic analysis of applicable resilience options

A comprehensive economic analysis is essential for evaluating the viability of implementing climate resilience measures in port systems. This step aims to determine the net economic benefits of integrating resilience options, comparing them to a baseline scenario with no adaptation. The analysis should be conducted over a relevant time horizon, typically the full expected service life of the asset and apply a discount rate in line with national guidelines or international best practices (e.g., World Bank, 2010; OECD, 2018).

CASE STUDY - MOZAMBIQUE

Undertaking a Cost Benefit Assessment (CBA) for NbS - Port of Beira

The Beira Coastal Development Protection Strategy is a long-term initiative aimed at enhancing local resilience against climate risks such as flooding, erosion, and cyclones through the implementation of NbS (Global Center on Adaptation, 2025). Co-financed by the World Bank and Invest International with a commitment of $60 million, this project is part of the Cyclone Idai Kenneth Emergency Recovery and Resilience Project. It responds to the devastating impacts of Cyclones Idai and Kenneth in 2019, which caused extensive damage to infrastructure, the economy, and the environment, affecting over 1.7 million people and leading to estimated recovery costs of $3.4 billion.

The project focuses on developing a coastal resilience strategy for the Port of Beira, Mozambique, by integrating a combination of gray and green infrastructure solutions. These measures aim to bolster the resilience of upwards of 200,000 individuals and their livelihoods against the frequent threats posed by cyclones and flooding. A CBA was conducted to evaluate the feasibility of various coastal resilience options, highlighting the economic viability of combining ecological restoration with traditional engineering approaches. Outputs from the CBA were used to prioritise investments in four stretches of Beira's coastline that are mostly impacted by climate hazards (See Figure 6.1).

The CBA was based on the development of full preliminary designs, which included construction material costs, estimates of the capital investments needed, the direct benefits (i.e., avoided damages), and indirect benefits (i.e., improvement of ecosystem services, health benefits, and avoided indirect flood damages) provided. The preliminary design of coastal protection measures during the feasibility studies considered not only the climate risks that the four coastal stretches were exposed to but also the physical conditions and landscape characteristics to propose adequate investment alternatives.

These measures adopt a nature-based approach, where gray and green solutions are combined to achieve the greatest risk reduction and indirect risk benefits. Furthermore, they also consider the use of local materials (e.g. sand) for the implementation of measures. For each of the four coastal stretches considered, three investment scenarios were considered.

Table 6.2 shows alternatives for Coastal Stretch 4, where Alternative 1 proposes dune conservation with a sand suppletion buffer, which is required to be replenished every 10 years, Alternative 2 proposes a levee with sand suppletion buffer (also creating a beach); and Alternative 3 proposes an inland levee with a road on top.

FIGURE 6.1.

Proposed NbS along Beira's coastline

TABLE 6.2.

Results of the CBA

ECONOMIC INDICATOR	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 2
Total costs	$50.7 mil	$203.9 mil	$43.2 mil
Direct Benefits	$5.1 mil	$5.1 mil	$2.6 mil
Indirect Benefits	$126.7 mil	$133.2 mil	$0.1 mil
BCR	2.60	0.68	0.06
ENPV	$92.5 mil	($65.6 mil)	($38.1 mil)
EIRR	17.0%	3.5%	-6.7%

Assuming a discount rate of 6%, investment Alternative 1, which proposed dune conservation measures with a sand suppletion buffer, was the most economically viable measure, with a Benefit-Cost Ratio (BCR) of 2.6, an Estimated Net Present Value (ENPV) of $92.5 million, and an Economic Internal Rate of Return (EIRR) of 17%.

7. FINANCING ADAPTATION AND RESILIENCE

A CRA provides a critical evidence base for informed decision-making and investment planning. By identifying climate-related risks to the port system, the assessment enables port leadership and other decision makers, e.g. finance ministry, to prioritise adaptation measures that reduce disruption, enhance resilience, and safeguard long-term asset performance. The results can be used to justify budget allocations, de-risk capital investments, strengthen regulatory compliance, and support applications for climate finance or insurance. By linking risk findings to operational, financial, and strategic outcomes, the assessment helps build a robust business case for timely and cost-effective adaptation actions.

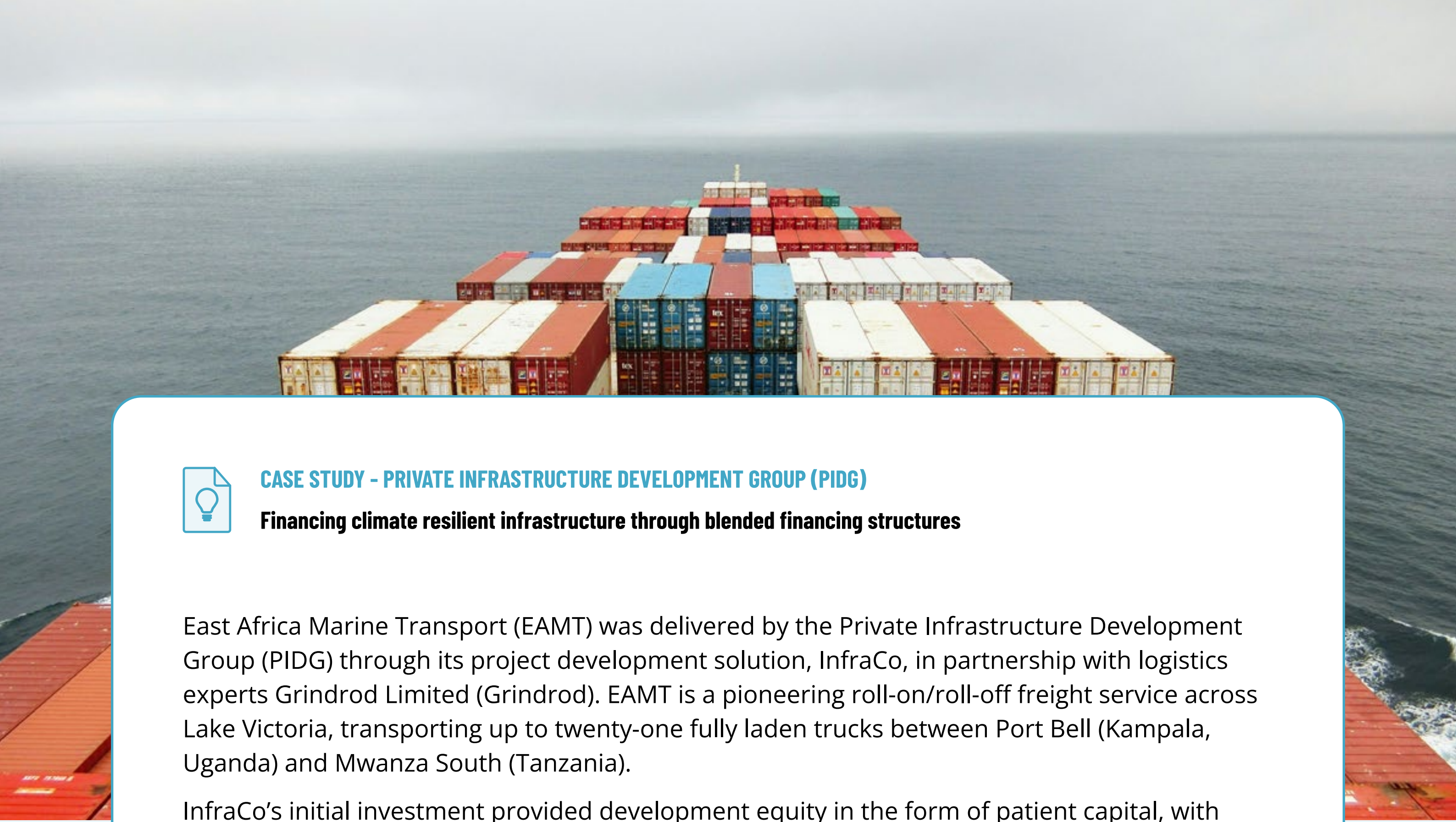
7.1
Mobilising climate finance

Climate finance instruments can play a pivotal role by helping assess, fund, and structure projects designed to address climate impacts. At this stage, climate financing tools can provide additional finance to support projects that align with climate resilience, adaptation, and mitigation goals. These instruments can be particularly helpful in making projects with higher upfront costs due to climate-resilient features financially viable, making such projects more attractive to investors and ultimately more feasible to implement, instruments, see Table 7.1.

TABLE 7.1.

Climate finance instruments

INSTRUMENT	DESCRIPTION
Grants	Non-repayable financial support, often provided in early project stages to help identify climate risks, engage stakeholders, or develop adaptation frameworks, especially useful in capital-constrained regions.
Concessional loans	Loans with below-market interest rates or extended repayment terms to ease the financial burden of climate projects and enable more funding to be allocated to planning and implementation (OECD, 2020).
Green bonds	Debt instruments used to raise capital for environmentally beneficial projects. Typically issued by governments, banks, or corporations to fund climate-aligned planning, design, and infrastructure.
Blue bonds	A sub-type of green bonds, focused on funding marine- and ocean-related sustainability projects such as coastal resilience, marine biodiversity, and green port infrastructure.
Resilience bonds	Financial instruments that integrate insurance and resilience financing by linking premium savings to risk reduction. Monetized avoided losses can be reinvested into further resilience measures.
Carbon market instruments	Market-based tools (e.g. carbon credits) that allow projects to earn revenue for emissions reductions compared to a baseline. Must align with carbon standards like CDM, Verra, or Gold Standard.
Blended finance	Combines public, philanthropic, and private funds to de-risk and attract private investment into climate adaptation projects, such as port resilience or infrastructure PPPs (OECD, 2021).



CASE STUDY - PRIVATE INFRASTRUCTURE DEVELOPMENT GROUP (PIDG)

Financing climate resilient infrastructure through blended financing structures

East Africa Marine Transport (EAMT) was delivered by the Private Infrastructure Development Group (PIDG) through its project development solution, InfraCo, in partnership with logistics experts Grindrod Limited (Grindrod). EAMT is a pioneering roll-on/roll-off freight service across Lake Victoria, transporting up to twenty-one fully laden trucks between Port Bell (Kampala, Uganda) and Mwanza South (Tanzania).

InfraCo's initial investment provided development equity in the form of patient capital, with the aim of crowding in additional private sector investment as the business and fleet expand, or through demonstration effects that validate the market opportunity and operating model. A key part of this effort is to demonstrate the climate resilience and sustainability of the asset. A CRA was conducted using the Physical Climate Risk Appraisal Methodology (PCRAM) (see more information here).

Chronic changes to lake levels were identified as the key climate-related risk. While most projections suggest minimal disruption, climate models for East Africa diverge significantly on key variables such as precipitation, leading to contrasting forecasts. Further uncertainty stems from the long-term implementation of hydropower management regimes, which may deviate from agreed approaches and the global trajectory of greenhouse gas emissions.

To manage these uncertainties, an adaptive pathways approach was developed, providing a flexible framework for decision-making. Projections indicate that lake levels are more likely to vary gradually over multiple years rather than through abrupt shocks – allowing investment decisions to be guided by observed trends.

EAMT offers significant time, reliability, and efficiency gains compared to overland routes, saving 1-2 days of travel between Mwanza and Kampala. The service supports one of East Africa's main logistics corridors – Dar es Salaam to Kampala – contributing to regional economic growth.

Investment in adaptation and resilience measures was primarily assessed against avoided losses from potential service disruptions. Different resilience options were evaluated based on their cost–benefit performance and impact on IRR compared to scenarios with no adaptation investment.

As part of the study, the resilience investment case also considered additional beneficiaries of a more resilient ferry service. A benefit-mapping exercise highlighted that the port infrastructure is operated under a long-term lease by Uganda Rail Corporation (URC) and any resilience investments would likely benefit other port users as well.

Other indirect economic benefits of a climate-resilient ferry service include lower crossing fees, fuel, time, and wage costs, as well as reduced maintenance and inventory expenses. Resilience measures, where needed, help safeguard these benefits, protecting value for both users and the broader economy.

The study provided confidence that – even under more extreme future scenarios – investment in resilience would not undermine investor returns, while also highlighting the importance of understanding how such investments generate value across supply chains and the wider economy. Mapping beneficiaries can help identify risk-reward dynamics and support collaboration between public and private stakeholders, informing effective cost- and benefit-sharing mechanisms.

BOX 7.1.

Disclosing climate risks for Ports

Port authorities are increasingly expected to disclose climate-related risks and opportunities in line with the **Task Force on Climate-related Financial Disclosures (TCFD)**[2] framework (TFCD, 2017). Alignment ensures transparency, supports investor confidence, and guides strategic resilience planning.

Governance: Port boards and executive management should clearly oversee climate risk management. Responsibilities include setting risk appetite, monitoring adaptation progress, and integrating climate considerations into decision-making.

Strategy: Ports should assess how climate hazards may affect business models, operational continuity, and long-term growth. Scenario planning, including extreme weather and sea-level rise, informs investment prioritisation, operational adjustments, and long-term resilience strategies.

Risk Management: Climate risks should be embedded within enterprise risk management processes. This includes identifying, assessing, and mitigating physical, operational, financial, and reputational risks.

Metrics & Targets: Quantitative indicators help track performance and guide investments. Key metrics may include:

- Percentage of assets assessed for climate risk
- Estimated annual climate-related losses
- Adaptation investment as a proportion of CAPEX
- Insurance coverage adequacy ratio

By aligning port operations with TCFD recommendations, authorities can systematically integrate climate risk into governance, planning, and financial decision-making, while enhancing accountability and resilience in a changing climate.

[2] In 2023, responsibility for monitoring and further developing this framework transferred to the International Sustainability Standards Board (ISSB) under the IFRS Foundation.

7.2

Public Private Partnerships (PPPs) for climate resilient port infrastructure

Public Private Partnerships (PPPs) can be defined as a long-term contract between a private party and a government entity (Port Authority), for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance.

PPPs aim to achieve Value for Money (VfM) by leveraging private sector efficiency, innovation, and risk management through performance-based contracts. By transferring appropriate risks to the private sector and adopting a whole-life costing approach, PPPs can optimise the design, construction, operation, and maintenance of port infrastructure projects. Well-structured PPPs help deliver projects on time and within budget while offering risk-adjusted returns to investors and cost-effective services to the public.

However, climate change poses significant challenges to the effectiveness of PPPs by increasing the frequency and severity of extreme weather events, which can disrupt port services, raise maintenance costs, and reduce asset lifespan. These impacts threaten both public benefits and private returns. Integrating climate resilience and adaptation into PPPs enhances long-term port performance and safeguards VfM by reducing climate-related risks, ensuring service continuity, and creating additional value with minimal extra cost.

PPPs offer a powerful framework to embed climate resilience throughout the infrastructure lifecycle. Their long-term contract structures naturally align with managing climate risks over decades, enabling risk-sharing mechanisms and resilience-focused project design that enhance asset durability and reduce disruptions. Performance-based incentives tied to climate-adaptive metrics further encourage the private sector to deliver resilient infrastructure. PPPs also promote innovation such as NbS through flexible, output-driven contracts.
By integrating resilience across design, construction, operation, and maintenance, PPPs optimise lifecycle costs and service continuity. Additionally, they enhance post-disaster recovery and offer scalable, globally applicable models for climate-resilient infrastructure delivery.

To realise these benefits, PPP contracts must be carefully structured to provide clear resilience incentives, supported by robust climate risk data and thoughtful risk-sharing frameworks. Properly designed PPPs are uniquely positioned to enhance climate resilience and adaptation in infrastructure projects while maintaining VfM and fostering sustainable development. Further information on PPP procurement and contract management please refer to Global Center on Adaptation (2025). For further general information on funding and financing of infrastructure please refer to Infrastructure Pathways (2024).

ANNEXES AND REFERENCES

Annex A

CHECKLIST FOR SCOPING CRAS

- ☐ Boundaries defined (assets, geography, interdependencies, timescales)
- ☐ Data quality and completeness assessed
- ☐ Standards (ISO 14091/14090/31000) referenced
- ☐ Hazard scenarios selected (incl. extremes, multiple pathways)
- ☐ Uncertainty treatment documented
- ☐ Vulnerability analysis included (exposure, sensitivity, adaptive capacity)
- ☐ Adaptation options across grey, green, hybrid measures
- ☐ Outputs integrated into planning/design/operations
- ☐ Deliverables specified (methods statement, risk register, GIS, roadmap)
- ☐ Stakeholder validation of findings

PHYSICAL INFRASTRUCTURE

- ☐ Identify most vulnerable assets to hazards
- ☐ Failure thresholds for each critical system

OPERATIONAL CONTINUITY

- ☐ Acceptable downtime limits for port functions
- ☐ Impact on vessel scheduling and berth availability
- ☐ Workforce safety thresholds for different weather conditions

FINANCIAL IMPLICATIONS

- ☐ Estimated annual average losses under different scenarios
- ☐ Impact on insurance premiums with/without adaptation
- ☐ Cost-Benefit ratio of proposed adaptations

SUPPLY CHAIN INTEGRATION

- ☐ Climate risks affecting hinterland connectivity
- ☐ Dependencies on external utilities and services
- ☐ Potential trade pattern shifts due to regional climate impacts

CHECKLIST FOR PROCURING TECHNICAL PARTNERS

- ☐ Evidence of standards application
- ☐ Case studies from similar sectors/assets
- ☐ Recognised CRA methods/tools used
- ☐ Multidisciplinary team capability
- ☐ Integration of NbS and equity
- ☐ Transparent approach to data and uncertainty
- ☐ QA and governance plan
- ☐ Knowledge transfer and capacity building commitment

CHECKLIST FOR EVALUATION & AWARD

- ☐ Technical approach aligns with standards and context
- ☐ Team capability adequate across disciplines
- ☐ Methodological robustness demonstrated
- ☐ Deliverability (timeline, budget, risk management)
- ☐ Sustainability and social value addressed

Annex B

Interactions of Port Decision Makers with Climate Risk Screening

Decision makers are actively involved at each stage to ensure the screening reflects operational realities, strategic priorities, and local knowledge:

1. IDENTIFYING CLIMATE HAZARDS

- Decision makers provide input on historical hazard events, operational disruptions, and vulnerabilities specific to the port's geographic location.
- They review and approve data sources, such as meteorological records, hazard maps, and climate model outputs.
- They ensure that both climate-related and relevant non-climate hazards (e.g., earthquakes) are considered to capture potential compound risks.

2. ASSESSING EXPOSURE

- Decision makers identify which port assets, operations, users, and surrounding communities are exposed to each hazard.
- They validate exposure assumptions against operational knowledge, such as the location of critical infrastructure and high-value cargo areas.
- Their input ensures that the screening accurately reflects both physical and operational exposures.

3. ESTIMATING IMPACTS

- Decision makers review preliminary impact ratings to assess potential consequences of hazards on infrastructure, operations, and supply chains.
- They provide insight on sensitivity and adaptive capacity, helping the screening team calibrate risk ratings appropriately.
- They confirm that early prioritisation aligns with strategic objectives and operational realities.

Use of Screening Results for Decision-Making

- **Prioritisation:** Identify assets or systems that require a detailed CRA or targeted assessments (IDB Invest, 2021).
- **Resource allocation:** Focus technical and financial resources on high-risk areas.
- **Early adaptation planning:** Implement low-cost, rapid measures where feasible.
- **Monitoring:** Integrate lower-risk assets into routine monitoring or long-term adaptation planning.
- **Escalation:** Flag compound or cascading hazards that may require more in-depth analysis, even if individual hazards are rated lower.

Interactions of Port Decision Makers with the Detailed CRA

At each stage of the CRA, decision makers play a critical role in guiding, validating, and applying the assessment results to inform actionable decisions:

1. DATA COLLATION

- Decision makers provide access to port system maps, design documents, project proposals, and baseline economic and technical assessments.
- They guide the CRA team toward relevant internal studies, regulatory documents, and operational protocols.
- By ensuring all data is comprehensive and organised in a central register, decision makers enable the CRA team to work efficiently and accurately.

2. HAZARD ANALYSIS

- Decision makers contribute insights on past hazards, operational disruptions, and maintenance issues.
- They validate assumptions regarding frequency, intensity, and scenario selection, ensuring that site-specific knowledge and strategic priorities are incorporated.
- Their engagement ensures that the CRA reflects realistic operational and climatic conditions.

3. VULNERABILITY ASSESSMENT

- Decision makers review the identification of direct and indirect impacts, including structural damage, operational disruptions, and cascading effects on logistics, energy, water, and communications.
- They help interpret the root causes of vulnerabilities and assess existing capacities to resist, absorb, and recover.
- These insights allow decision makers to prioritise areas for resilience investments and operational improvements.

4. COMPOUND AND CASCADING RISK ANALYSIS

- Decision makers guide scenario modeling by identifying critical interdependencies and key supply chain connections.
- They review findings on cascade failure pathways, regional impacts, and economic consequences.
- This information informs strategic decisions, such as which assets to protect first, where to invest in redundancy, and how to design contingency plans.

Use of CRA Results for Decision-Making

- **Strategic planning:** Prioritise adaptation measures, infrastructure upgrades, and new investments.
- **Financial allocation:** Justify funding requests for resilience projects or climate finance applications.
- **Operational preparedness:** Update emergency response plans, staffing protocols, and maintenance schedules.
- **Policy and regulation:** Inform updates to port codes, standards, and procurement requirements to embed resilience.
- **Monitoring and review:** Establish performance indicators and track adaptation effectiveness overtime.

References

Argyriou, I. and Tsoutsos, T., 2024. Assessing Critical Entities: Risk Management for IoT Devices in Ports. Journal of Marine Science and Engineering, 12(9), 1593.

Asian Development Bank (ADB), 2024. Support for Action on Climate Change 2021-2023.

Brazil Government, 2024. Impacts and Risks of Climate Change to Brazilian Coastal Public Ports: IMO MEPC 82/INF.41.

Christodoulou, A., Christidis, P. and Demirel, H., 2019. Sea-level rise in ports: a wider focus on impacts. Maritime Economics & Logistics, 21, pp.482–496.

Deininger, F., Woodhouse, A., Kuriakose, A.T., Gren, A. and Liaqat, S., 2023. Placing gender equality at the center of climate action.

EDF and RTI International, 2022. Act now or pay later: The costs of climate inaction for ports and shipping.

Global Center on Adaptation, 2025. Climate-Resilient Infrastructure Handbook.

IDB Invest, 2021. Climate Risk and Ports: A Practical Guide on Strengthening Resilience.

Infrastructure Pathways, 2024. Climate-resilient infrastructure guidance across the lifecycle. Available at: https://infrastructure-pathways.org/

International Association of Ports and Harbours (IAPH), 2024. Study on Port Climate Adaptation and Decarbonization Investment Requirements of Developing Nations: IMO ISWG-GHG.

IPCC, 2023. Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

ISO, 2019. ISO 14090:2019 – Adaptation to climate change – Principles, requirements and guidelines. Geneva: International Organization for Standardization.

ISO, 2021. ISO 14091:2021 – Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment. Geneva: International Organization for Standardization.

JGR Ocean, 2022. Genesis and Trends in Marine Heatwaves Over the Tropical Indian Ocean and Their Interaction with the Indian Summer Monsoon.

OECD, 2018. Cost-Benefit Analysis and the Environment: Further Developments and Policy Use.

OECD, 2020. Climate Finance Provided and Mobilised by Developed Countries in 2013-18.

OECD, 2021. The OECD DAC Blended Finance Guidance.

PIANC, 2020. Climate Change Adaptation Planning for Ports and Inland Waterways: EnviCom WG Report No. 178. Brussels: The World Association for Waterborne Transport Infrastructure. ISBN 978-2-87223-001-3.

TFCD, 2017. Recommendations of the Task Force on Climate-related Financial Disclosures.

The Resilience Shift, 2019. An Industry Guide to Enhancing Resilience.

UNCTAD, 2023. Regional Cooperation Mechanism on Low Carbon Transport. UN Economic and Social Commission for Asia and the Pacific.

UNCTAD, 2025. Building Capacity to Manage Risks and Enhance Resilience. PART II – Port disruption and resilience.

United Nations Environment Programme Finance Initiative, 2024. Climate Risks in the Transportation Sector.

World Bank, 2010. Cost-Benefit Analysis in World Bank Projects.

World Bank, 2025. Nature-Based Solutions for Ports: An Overview of NBS Implementation in Practice – Opportunities and Challenges.

International Coalition for Sustainable Infrastructure

www.sustainability-coalition.org