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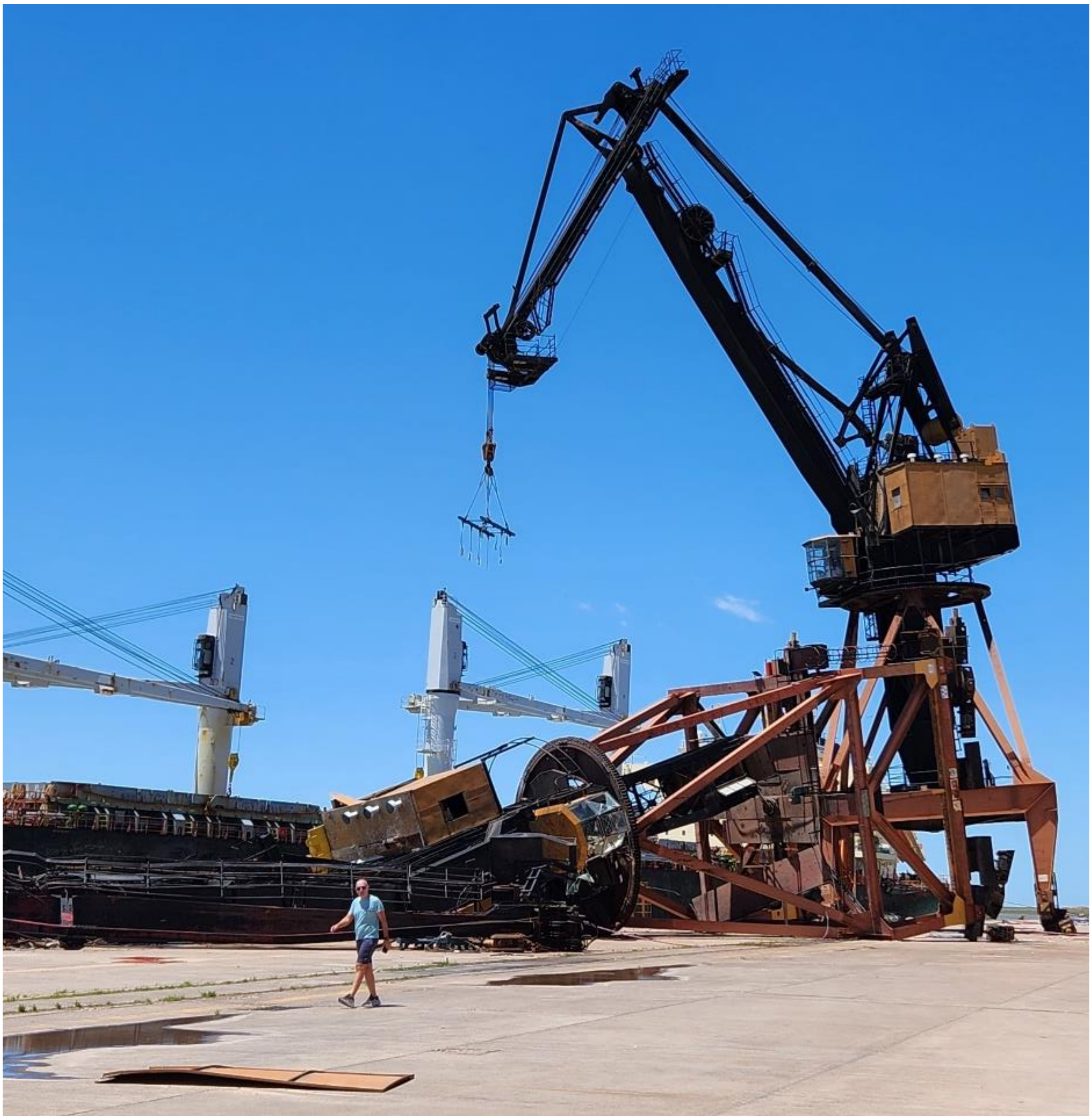
The World Association for Waterborne Transport Infrastructure

Climate Change Costs to Ports and Waterways:
Scoping the Business Case Assessment for Investment in Adaptation



Permanent Task Group for Climate Change

Technical Note No. 2 – 2024

TECHNICAL NOTE N° 2

PERMANENT TASK GROUP FOR CLIMATE CHANGE

Climate Change Costs to Ports and Waterways:
Scoping the Business Case Assessment for Investment in Adaptation

16 July 2024

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ABSTRACT

As the climate changes, port and waterway assets and operations are increasingly exposed to changes in temperature, precipitation, and sea level. They also face more frequent atypical or extreme hydrometeorological and oceanographic events. Climate change is a major business risk. Failing to act to address the risk can be costly. Yet recent industry surveys confirm that relatively few port and waterway operators have taken the urgent action needed to strengthen resilience and adapt.

When PIANC's Working Group 178 guidance on climate change adaptation planning was published in 2020, two main barriers to adaptation action were identified: how to manage climate change uncertainties, and how to make the business case for adaptation investment. PIANC PTGCC Technical Note No.1 (2022) provided advice on the former. This Technical Note, No.2, tackles the latter.

Section 1 of Technical Note No.2 summarises how ports and waterways may be impacted by climate change. Section 2 discusses the main findings of several recent surveys reviewing the effects of atypical conditions or extreme events on port and navigation infrastructure and operations. Section 3 highlights some of the factors identified as potentially limiting adaptation action in the sector, along with the conditions needed to enable such interventions.

Section 4 of the Note explores existing and evolving drivers for action to strengthen resilience and adapt. These include understanding the impacts of projected increases in extreme events on port and waterway activities, and on economies and societies via supply chain issues.

Section 5 of the Technical Note brings all this information together to help the reader determine the scope of a business case assessment. It explains how potential costs and benefits can be identified and quantified to support the case for investment in adaptation action. It discusses the concept of climate change inaction; the 'triple dividend' benefits that can be realised by adapting and strengthening resilience; and the role of the losses-avoided principle in supporting the business case. It also highlights the potential relevance to some ports and waterways of the evolving position of the finance and insurance sectors; growing expectations in relation to climate-related financial risk disclosure; and the possible implications of failing to meet regulatory requirements or contractual obligations.

In addition, Section 5 summarises the growing evidence that early investment in adaptation makes good business sense. In low- and middle-income countries, the extra cost of building climate resilience into new infrastructure systems may be as low as 3% of overall investment. For existing infrastructure and operations, adaptation interventions are demonstrated to deliver benefit to cost ratios of between 4:1 and 10:1. Typical measures are capacity building; contingency planning including identifying alternative access or storage provision or planning for extreme heat; early warning systems (24 hours warning of a storm or heatwave can reduce losses by 30%); and flood preparedness including maintaining drainage capacity. These types of actions are relevant to most ports and waterways, and the costs of inaction are significantly greater than the cost of action.

Finally, Section 6 provides an overview of the costs and benefits of improved climate change preparedness and of the assessment scoping process, via a series of questions intended to provoke discussion. It recognises that the location of a particular port or waterway, its function in the local and national economic context, and its ownership and management or governance model will all influence the scope of the assessment. Technical Note No.2 therefore aims to provide an insight, enable the scoping process, and – ultimately – facilitate the preparation of a bespoke business case argument.

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1 INTRODUCTION

1.1 Background

1.1.1 How is the Climate Changing?

In addition to gradual changes in average temperature, sea level and seasonal precipitation, climate change is expected to increase the frequency and intensity of extreme events (IPCC, 2019; PIANC, 2023). Extreme hydro-meteorological or oceanographic conditions can damage maritime infrastructure, cause delays or disruption, or lead to port or waterway closures (PIANC, 2022; UNCTAD, 2020; UNECE, 2020) with potential consequences locally and throughout supply chains.

A record-breaking series of extreme weather events in 2022, affecting millions of people and costing billions of dollars globally, was likely elevated by the changing climate[1]. In 2023 when this Technical Note was in preparation, barely a week went by without the world's press drawing attention to another extreme event: cyclones, floods, heat, drought, and wildfires.

- The 2023 June-July-August season was the warmest on record by a large margin according to Europe's Copernicus climate change service, including a record number of days with extreme heat stress[2]. Globally, the mean temperature was nearly 0.7°C above average[3].
- The World Meteorological Organization (WMO)[4] highlighted the significant impacts, including loss of life, associated with extreme rainfall from:
  - Tropical cyclone Freddy in February and March 2023, one of the world's longest-lived tropical cyclones, affecting Madagascar, Mozambique and Malawi
  - Tropical cyclone Mocha, in May 2023, one of the most intense cyclones ever observed in the Bay of Bengal, and
  - Mediterranean cyclone Daniel in September 2023, impacting Greece, Bulgaria, Türkiye, and Libya.
- WMO also noted that the 2013-2022 rate of sea level rise was more than twice that recorded in the first decade of the satellite record (1993-2002) because of continued ocean warming and melting of glaciers and ice sheets.

The Intergovernmental Panel on Climate Change (IPCC) confirmed that anthropogenic influences have already contributed to the intensification of extreme precipitation at the global scale (IPCC, 2022). They also conclude further increases in the frequency of heavy precipitation events; the length, frequency and/or intensity of heatwaves; and increases in mean maximum wind speeds associated with tropical cyclones are 'likely' or 'very likely' in most areas in the coming decades.

1.1.2 How will these changes affect ports and waterways?

The IPCC Working Group II contribution to the global Sixth Assessment Report entitled 'Climate Change Impacts, Adaptation and Vulnerability' (IPCC, 2022) paints a stark picture: "a dire warning about the consequences of inaction"[5]. Their report highlights ports' vulnerability to damage or operational disruption associated with sea level rise and flooding. It notes, for

[1] News Release **https://public.wmo.int/en/media/news/climate-and-weather-extremes-2022-show-need-more-action**

[2] UN News **https://news.un.org/en/story/2024/04/11487960**

[3] Press Release **https://climate.copernicus.eu/summer-2023-hottest-record**

[4] Press Release **https://wmo.int/news/media-centre/2023-shatters-climate-records-major-impacts**

[5] Press Release **https://www.ipcc.ch/report/ar6/wg2/resources/press**

example, that historically rare extreme sea levels are expected to occur annually by 2100 in many areas. It also points to ports' susceptibility to disruption and damage due to changes in wind characteristics, wave height/frequency, extreme heat, or fog. Box 1 illustrates the type of impacts extreme winds can have on port infrastructure, in this case in Argentina.

Damage at the Port of Bahia Blanca, Argentina, following the unprecedented winds associated with a storm on 16 December 2023. The storm, which brought wind gusts in some cases exceeding 140 km per hour and accumulations of rainfall exceeding 100 mm[6], also caused fatalities in the city.

(Photos: Gerardo Bessone, Port of Bahía Blanca)

Box 1: Storm Damage at the Port of Bahía Blanca, Argentina

Extreme heat can soften pavements or deform rail tracks in addition to impacting on worker health. Thermal expansion may cause structural or mechanical malfunctions, affecting lifting bridges, lock gates and similar. Figure 1 [PIANC, 2020a] highlights some of the many ways in which changes in climatic conditions can impact on port approaches and berthing areas, the port estate, and linked transport networks.

[6] https://reliefweb.int/report/argentina/argentina-storm-bahia-blanca-dref-operation-appeal-no-mdrar020

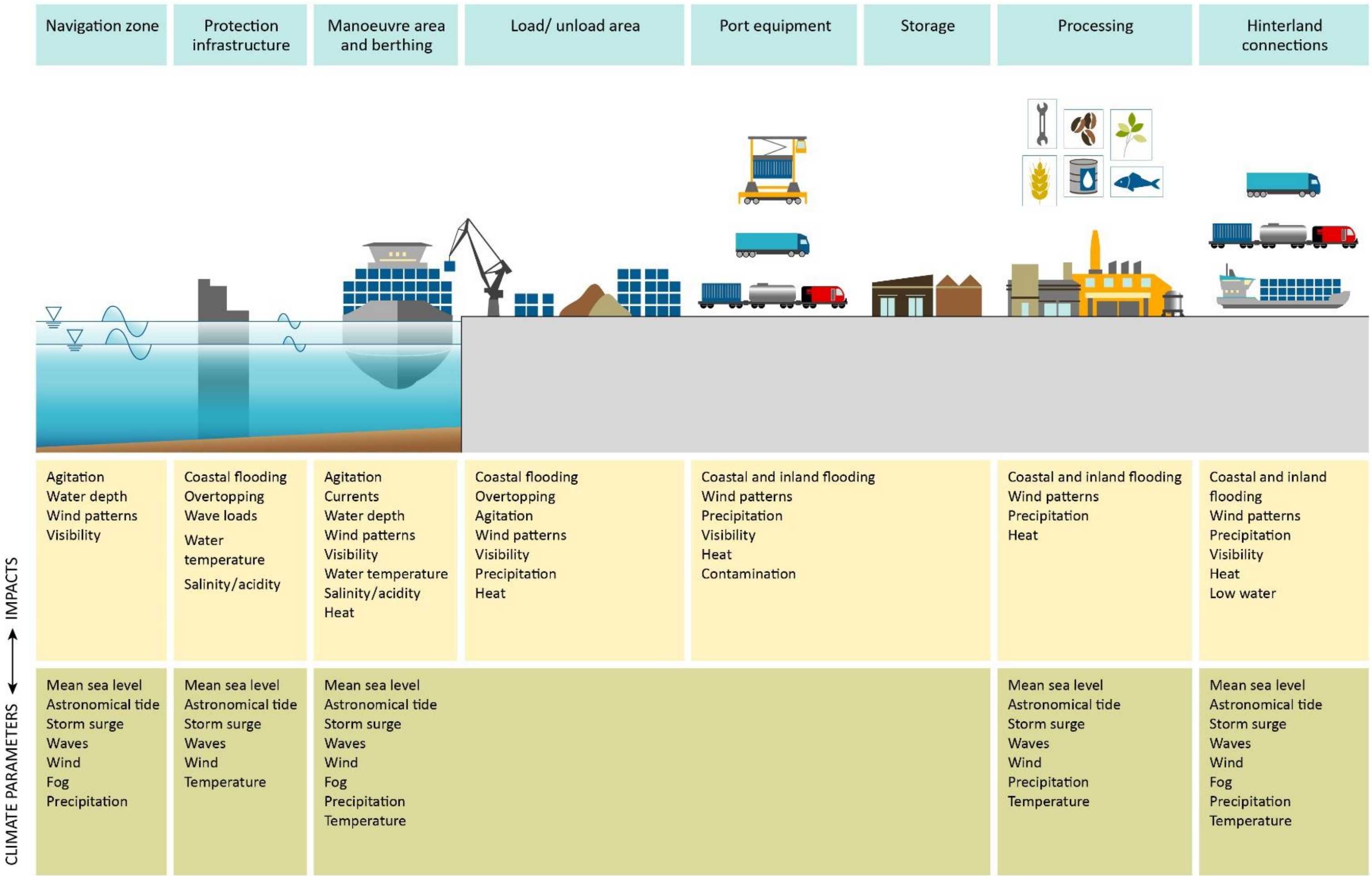

Figure 1: Potential climate change impacts on ports and navigation

Like seaports, inland waterways and inland ports will be affected by the changing climate. Increasingly frequent droughts or floods may result in extreme low or high flows – reducing navigability and causing disruption or even waterway closures. Changes in other precipitation characteristics, including seasonal totals and rainfall intensity, may similarly impact on flow levels and thus navigability.

Figure 1 highlights that ports and waterways will also face other less obvious but nonetheless important impacts. Maintenance dredging regimes may need to be modified as sediment dynamics are impacted by changes in flow regimes or due to storm conditions. Changes in wind direction or more frequent exceedance of key operational wind speed thresholds can disrupt pilotage, berthing, or loading/unloading operations. Changes in acidity may increase microbiological corrosion of steel marine structures. For inland waterways, increases in water temperature may have operational implications. As illustrated in Box 2, changes in vegetation growth rates or invasions of economically or environmentally damaging non-indigenous (alien) species can increase management costs or result in operational difficulties.

Furthermore, for some ports and waterways, anecdotal evidence suggests that 'atypical' conditions or more frequent operational threshold exceedances leading to damage, delays or disruption may become important climate change-related challenges – even if, individually, such events are not considered 'extreme'.

Climate change will have a wide range of biological and chemical implications for the management of some navigable waterways. Warmer water temperatures may increase native vegetation growth rates or make conditions more conducive to the establishment of invasive alien species. Excessive vegetation growth reduces flow rates, impacts flood risk, impedes navigation, and increases the costs associated with cutting or clearance regimes. Periods of drought may result in desiccation and the loss of bankside vegetation, threatening riverbank stability. More frequent intense storms can increase nutrient run-off and algal blooms, negatively impacting on both biodiversity and amenity value. Such impacts are not exclusive to inland waterways; marine, coastal, and estuarine waters will experience similar issues.

(Photos: Martin Manigold, VNF)

Box 2: The biological effects of climate change may impact on port and waterway management

1.1.3 What Are the Wider Implications of the Changing Climate?

Coastal and inland ports are typically considered to be critical infrastructure, representing nodes in wider transportation networks. When elements in these networks fail due to extreme weather events, cascading effects can amplify impacts elsewhere in the network, affecting both economic and societal interests. For example, wildfires, floods, or landslides may close the transport corridors to and from ports.

Effective operation of ports and waterways also depends on other critical infrastructure in so-called systems of systems. These include energy; telecommunications and data; water; waste collection and treatment; and flood protection. Such interdependencies can be physical, cyber, geographical, or logical [Hallegatte et al., 2019]. Without back-up provision, extreme weather affecting utilities and service providers could therefore have cascading consequences for ports.

Beyond physical infrastructure, both seaports and ports on inland waterways are integrally connected to wider commercial trade networks [UNECE, 2022]. The COVID-19 pandemic illustrated how disruption at ports has the potential to severely compromise global supply chains and waterborne trade – both maritime and inland – with associated geo-political and economic consequences at all scales [IPCC, 2022 ; UNCTAD, 2022]. Extreme weather events can have similar consequences.

1.1.4 The Need for Action

'Underfinanced, underprepared', the 2023 Adaptation Gap report from the United Nations Environment Programme [UNEP, 2023] highlights that inadequate investment in, and planning for, climate change adaptation leaves the world exposed.

"Current climate action is woefully inadequate to meet the temperature and adaptation goals of the Paris Agreement[7]. While global average temperatures are already exceeding 1.1°C above pre-industrial levels, current plans reflected in the nationally determined contributions (NDCs) are putting us on a path towards 2.4°C-2.6°C by the end of the century."

UNEP, 2023

The Inter-American Development Bank [IDB, 2021] describes the consequences of failing to act in the face of such challenges as 'potentially catastrophic'. Ports in small island developing states (SIDS), for example, are at high and growing risk of coastal flooding and operational disruptions from as early as the 2030s [Monioudi et al., 2018 ; UNCTAD, 2018b]. Developing countries typically face multiple climate change-related challenges. However, nowhere is immune, and the interconnectedness of global transport networks and supply chains means that impacts in one location can have knock-on effects elsewhere.

Some of the projected changes in climate parameters are uncertain [PIANC, 2022] and there will be regional variations, but the overall message in the IPCC (2022) and other reports is unambiguous. Climate change is a significant risk to business. If the consequences of climate change-related operational shutdowns, physical damage and associated financial losses are to be minimised, ports and waterways globally need to prepare themselves for changing climatic boundary conditions and adjust their operations and infrastructure designs accordingly.

1.2 Climate-Related Risks, Responses and Associated Costs

1.2.1 How Are Risks Changing?

Ports have always been exposed to risks associated with extreme hydrometeorological and oceanographic conditions, but climate change is significantly increasing many such risks. It is also introducing new ones. A risk analysis of climate change impacts including coastal

[7] A legally binding international treaty on climate change was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, in December 2015.Its goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" pursuing efforts "to limit the temperature increase to 1.5°C above pre-industrial levels." See: **https://unfccc.int/process-and-meetings/the-paris-agreement**.

flooding, sea level rise and heat stress under a high-end warming scenario (RCP8.5[8]) on the operation of more than 2,000 ports worldwide concluded that – in the absence of adaptation – the number of ports at high, very high or extremely high risk will increase significantly by 2100 [Izaguirre et al., 2021]. In particular, using the authors' definition of multi-hazard climate risk, the number of coastal ports considered to be at 'very high risk' would increase from 44 (3.8 %) historically, to 283 (14.4 %) by 2100.

In most cases, the current spatial pattern of risk matches the existing spatial distribution of multi-hazard conditions. For example, the Caribbean and Pacific Islands' ports are in tropical cyclone-prone areas characterised by high exposure and high vulnerability. However, by 2100, the impact of other factors including mean sea level rise and extreme heat, will bring ports in the Indian Ocean, Mediterranean, Indonesia and Arabian Peninsula into the 'very high risk' category. Furthermore, if more rapid ice sheet melting accelerates rates of sea level rise, such impacts will be experienced decades earlier [IPCC, 2022].

Beyond the risk analysis presented in their paper, Izaguirre et al. (2021) acknowledge changes in local hazards such as fog or ice. Changes in wave agitation or sediment transport are also important, potentially compromising port operations such as loading and unloading; changing siltation or scour characteristics and hence dredging requirements (Photo 2); and affecting the stability of structures among other impacts. A report by the Environmental Defense Fund [EDF, 2022] assesses how ports and shipping will be impacted by sea level rise, increased storm intensity, extreme heat, and inland flooding and drought. This reports also concludes that significant adverse impacts on port assets and operations should be expected.

Photo 1and 2. Climate-related changes including more frequent storms can affect sediment dynamics, requiring additional surveying and impacting dredging requirements. Photo 1 on left shows channel edge marker buoy, in its charted position but aground after a storm in the Mersey, UK, April 2024. (Photos: Peel Ports Group, UK, and Jan Brooke, PIANC)

The analysis in the following sections of this Technical Note supports these authors' observations. Ports and waterways worldwide are already experiencing changes in extreme wind and wave conditions, as well as in precipitation characteristics impacting both river flows and flood severity/frequency. Considering the wide range of potential future effects, very few ports and waterways will be unaffected by the changing climate. Owners, operators and

[8] The most widely-used climate change scenarios remain those based on 'Representative Concentration Pathways' (RCPs) greenhouse gas (GHG) concentration trajectories developed by the IPCC. Four pathways describe four different climate futures, depending on the quantities of GHG emitted in years to come [IPCC, 2013]. The RCPs are labelled according to a low to high range of anthropogenic radiative forcing values in the year 2100 (2.6, 4.5, 6.0, and 8.5 W/m^2, respectively). The more recent IPCC AR6 report (2021) uses different processes and terminology to describe scenarios, but it remains the case that a range of possible climate futures must be considered.

investors therefore need to strengthen the resilience[9] of both new and existing infrastructure and operations, and to ensure investment is fit for purpose.

"Climate adaptation is a strategic move not a charitable act. It ensures resilience, risk management, and supply chain support in the face of the climate crisis. Governments, corporations, and impact investors [that] fail to incorporate climate adaptation measures into their strategies are not only missing out on returns, but also endangering their value chains."

Goldstandard.org, August 2023[10]

1.2.2 What Can Port and Waterway Operators Do?

For new-build infrastructure, adaptation involves designing to withstand, adjust to or otherwise accommodate projected changes including extreme events, while also paying attention to the resilience of linked transport systems and supply chains [IDB Invest, 2021(a)]. For ports that are, or will become, important energy hubs, attention to climate change resilience should help avoid disruption to their decarbonisation mission. For existing ports, adaptation may mean retrofitting or replacing existing infrastructure, or it may involve improving operational resilience by identifying and addressing vulnerabilities [PIANC, 2020a]. For existing facilities, climate risks also need to be mainstreamed appropriately into corporate strategies and into organisations' risk registers so threats and opportunities can be identified, and responses developed.

Not all adaptation interventions require expensive physical infrastructure, at least in the short- to medium-term [PIANC (2020a) ; UNCTAD (2017) ; EDF (2022)]. Where resources are limited (e.g. in developing countries, at smaller ports), soft and/or low-tech adaptation measures such as vulnerability mapping, contingency planning, early warning systems and enhanced maintenance programmes can represent vital but relatively inexpensive steps to help reduce climate risks to existing infrastructure. Twenty-four hours' warning of a storm or heatwave, for example, has been reported to reduce losses by 30 % [WRI and GCA, 2019], with potentially significant associated savings. Improved resilience and adaptive capacity achieved through engineered redundancy, back-up resources or flexible operational procedures [PIANC, 2022] also has a vital role to play, along with institutional, governance and planning/land-use mechanisms.

For many ports and waterways, effective adaptation will require a combination of hard and soft measures [PIANC, 2020a ; Becker et al., 2013]. In the Netherlands, for example, Port of Rotterdam's Flood Risk Management Programme[11] illustrates such a mix, including:

- crisis management measures, involving emergency, recovery and crisis management plans and the preparation of emergency facilities, to allow a flood event to run its course in a managed and controlled way, with functions and processes restarted again quickly thereafter;

[9] Resilience refers to the capacity of an asset, operation or system to cope with a hazardous event, trend or disturbance (IPCC, 2022); to anticipate and plan for such eventualities; to resist losses or absorb the impact of disturbances; to rapidly recover afterwards; and to adapt to short- and long-term stressors, changing conditions and constraints as quickly as possible (PIANC, 2022). Measures that strengthen physical, technical. or operational resilience are important elements of climate change adaptation.

[10] https://www.goldstandard.org/blog-item/business-case-climate-adaptation-why-it%E2%80%99s-profitable-investment

[11] https://sustainableworldports.org/project/port-of-rotterdam-flood-risk-management-programme/

- preventive physical measures to reduce the risk of coastal and riverine flooding including barriers and bank structures;
- spatial adaptation to manage flood risk by preparing sites and assets for inundation - for example by locally raising vulnerable systems or sites, or 'waterproofing' buildings and assets.

Insofar as hard (or structural) engineering interventions are concerned, Hanson and Nicholls (2020) consider the cost implications of new, climate-resilient port areas. New port areas along with new ports are likely to be required globally, to accommodate future climate-driven demands alongside other changes in trade, commodities, and populations. The authors estimate overall global investment costs for port adaptation to sea-level rise and the provision of new areas by 2050-2100, to be US$ 223 to US$ 768bn. Of this, US$ 13 to US$ 53bn relates to the adaptation of existing ports. The remainder is indicative of the required scale of investment in new ports and new port infrastructure over the coming decades[12].

EDF (2022) identify three main types of hard adaptation response that could be adopted by existing ports: elevate, defend, or retreat/relocate. They summarise papers citing costs for elevating existing port areas by approximately 1.0 m to 2.0 m, that range from US$ 30 million to US$ 240 million and exceptionally US$ 4,000 million per square kilometre[13]. Examples of costs for defensive infrastructure (dykes, seawalls, floodgates, breakwaters, drainage, etc.) similarly vary significantly, but the examples cited for individual ports or groups of ports range from tens to hundreds of millions USD.

1.3 Technical Note Objectives

Climate change inaction often has a cost. Inaction in this context does not only refer to a failure to raise, strengthen, or modify infrastructure. Inaction costs can also result from:

- failing to maintain existing infrastructure and systems
- failing to monitor to understand trends, support early warning and inform decisions
- failing to assess risks, or
- failing to prepare

Climate change inaction does not only affect the operation of the port or waterway. It also affects the individuals and societies that depend on its effective operation, including local or national economies. However, there is no one-size-fits-all solution to climate change adaptation. This is because there is no one-size-fits-all port or waterway. The location of the port or waterway, its function in the local and national economic context, its ownership and management or governance model, and many other factors will influence what should be included in an adaptation business case assessment, and how the return on investment in adaptation can be evaluated.

This Technical Note recognises these differences. By discussing a wide range of potential losses, benefits, and costs, it aims to help owners, operators, and investors:

[12] While this Technical Note focuses on levels of preparedness to adapt existing ports and port infrastructure, it is worth noting that all four plausible future trade scenarios examined by Hanson and Nicholls (2020) showed a significant increase in demand for new ports and new port operational area by 2050. The required investment in such new infrastructure therefore represents another critical challenge for the wider transportation sector.

[13] Costs vary both by region and the extent to which other reconstruction and similar works are included in the total, reflecting the assumptions used by different authors.

- identify the potential consequences of failing to act, and
- collate information that is appropriate to support their unique business case for investment in adaptation and strengthened resilience.

The Note provides an insight. It is intended to provoke discussion and – ultimately – to enable appreciation of the context and content needed to scope a business case assessment.

1.4 Technical Note Structure

This Technical Note is part of a suite of PIANC technical publications that support climate change adaptation of waterborne transport infrastructure. Task Group 3 [PIANC, 2023] reviews the available data and provides an overview of climate change drivers and impacts. Working Group 178 describes a methodology for climate change adaptation planning for ports and inland waterways [PIANC, 2020a]. PIANC PTG CC Technical Note No.1 (2022) supplemented the WG 178 guidance by elaborating on the management of climate change uncertainties in selecting, designing, and evaluating options for resilient navigation infrastructure. Now, Technical Note No.2, complements these publications by exploring the potential costs associated with the changing climate. It discusses the consequences of climate change inaction and explains how understanding the losses-avoided principle can be used to determine the scope of the business case for investment in appropriate adaptation and resilience measures.

To facilitate understanding of the potential consequences of failing to act to strengthen resilience, Section 2.0 and Annex 1 of this Technical Note refer to several recent surveys of the effects of extreme or atypical hydrometeorological or oceanographic events on port and navigation infrastructure and operations. These consequences, and associated costs or losses, provide an illustration of the type of impacts that will become more frequent because of climate change.

Section 3.0 of the Note discusses the factors currently limiting adaptation action in the ports and navigation sector, and the conditions needed to enable such action. Section 4.0 describes existing and evolving drivers for climate change adaptation action. These include projected increases in the frequency and severity of extreme events and their impacts, including on economies and societies via supply chain issues. Other changes of relevance to the waterborne transport sector are discussed: initiatives within the insurance and finance sectors; the growing focus on climate risk disclosure; evolving government commitments; and changes in regulatory and legal requirements.

Section 5.0 explains how this information can be used to scope and assess costs and benefits to support the business case for investment in adaptation and resilience action. Section 6.0 provides an overview of the assessment scoping process, reminding the user of the main questions to consider.

As explained above, the Technical Note is deliberately not prescriptive, rather its purpose is to facilitate understanding of what to investigate, assess and quantify, and the respective costs and benefits of investment in adaptation and resilience interventions.

2 CLIMATE CHANGE AND EXTREME WEATHER IMPACTS

2.1 Consequences and Costs of Extreme Hydro-Meteorological and Oceanographic Events

2.1.1 Direct and Indirect Costs and Losses

Gradual or slow-onset changes[14] in sea level, air and water temperature and seasonal precipitation among others, will impact port and waterway infrastructure, meaning medium to long-term design modifications and other measures including operational modifications will be needed. Determining how gradual changes will affect a port or waterway requires consideration of an appropriate range of climate change scenarios and monitoring to understand local rates of change (PIANC, 2020a, 2022), but their practical implications are then to some extent predictable. Risks and therefore potential damage or losses will be determined by the exposure of the site, asset, or operation to the hazard (change) in question and the vulnerability of the same (PIANC, 2020a).

Climate change will also increase the frequency and severity of extreme weather events. These events have a wide range of consequences, including both direct and indirect costs and losses. Direct economic damage occurs during or immediately after the event. Taking an extreme storm as an example, direct effects may include damage to infrastructure such as sea walls or breakwaters; channel sedimentation; flooded buildings; or damage to/loss of stored commodities. Total disruption-related costs and other losses will depend on the nature and scale of damage, and how long clean up and repairs, etc. take. Table 2 in Section 4.2 illustrates such situations.

Newman and Noy (2023) provide a useful summary of *indirect* economic losses explaining that such losses include declines in economic value-added due to the direct economic damage. Examples of indirect losses are wide-ranging. Taking a flood as an example, "they could include microeconomic impacts such as revenue loss for businesses when access routes are inundated by floodwater, meso-economic impacts such as temporary unemployment in the affected area, or even wider-ranging macroscale supply-chain disruptions. Indirect economic losses can often spill out beyond the affected area, and indeed even beyond the affected country or region's borders. Indirect losses may also have long time lags, making them difficult to quantify". Events that cause more damage will generally also lead to higher losses; the relationship between direct damage and indirect loss is nonlinear, with high-damage events typically causing disproportionately more losses.

For many ports and waterways, understanding the potential consequences of extreme events can therefore be more challenging than understanding the consequences of slow-onset changes. This is particularly the case for those that do not have previous experience of such events.

2.1.2 Navigation Sector Climate Change Surveys

Two sector-specific surveys of port owners and operators carried out in recent years explored the consequences and costs of climate change and extreme weather events. In 2014, UNCTAD (the UN Conference on Trade and Development[15]) undertook research in collaboration with IAPH (International Association of Ports and Harbors). This was published in

[14] Changes that evolve gradually or incrementally over many years

[15] Rebranded to UN Trade and Development in early 2024.

2017. In 2018-19 a survey was organised by PIANC, IAPH and other partners in NavClimate, the Navigating a Changing Climate Global Climate Action initiative, led by PIANC from 2015 to 2021. The main findings of this survey are discussed here and in Appendix 1.

While the detailed questions differed slightly between these two surveys, the following key findings were common to both:

- Notwithstanding that port infrastructure and operations are typically designed to cope with severe hydrometeorological and oceanographic conditions, many survey respondents reported they were already experiencing impacts consistent with climate change projections, including more frequent and/or severe extreme or atypical events.
- Extreme winds, waves and rainfall events were most mentioned as the conditions impacting port assets or operations, along with associated flooding.
- Quantified port-specific damage and clean-up costs ranging from <$100,000 USD to up to $10 million USD were reported in the NavClimate survey responses. A parallel literature search identified several additional events, including some where damage >$10 million USD was recorded[16].
- Across all ports responding to the NavClimate survey, around 1/3 described the post-event clean-up, damage repair, and additional maintenance, etc. as 'significant' or 'critical'.
- For smaller ports, those in developing countries, ports with resource constraints and those without (adequate) insurance, even dealing with damage of < US$ 100,000 can represent a significant challenge.
- It is often more difficult to put a money value on the costs of delays and disruption than on damage repair and clean-up. Nonetheless, around a quarter of those who responded to this question in the NavClimate survey highlighted costs (losses) of more than US$ 100,000. Some reported disruption-related costs of US$ 1 million to more than US$ 10 million. Disruption-related costs of US$ 1 million to more than US$ 10 million were also documented in 22 % of the additional events identified via the parallel NavClimate literature search (see Appendix 1)
- Across all ports, large and small, responding to the NavClimate survey nearly half described the delays and disruption they experienced due to the reported extreme event(s) as 'significant' or 'critical'.

2.1.3 Others' Findings

The NavClimate survey highlighted that, in the short to medium term at least, it is often not the physical damage associated with extreme events or atypical conditions that is the biggest impact, but rather port closures, delays and disruption due to extreme wind, waves, rainfall or flooding. This finding is consistent with other recent publications that highlight the significant cost implications of extreme weather-related disruption or port closures. Verschuur et al. (2022), for example, identify a median operational interruption duration of 6 days, with roughly half of the reported events leading to a complete port closure. For major ports where data were available, total economic losses equivalent to between US$ 3 million and US$ 13 million per day were recorded in relation to operational disruption periods (duration) of between 3 and ten days [EDF, 2022]. UNCTAD (2022) refer to evidence showing that floods have the most substantial impacts on port operations, with an average of 11 affected days compared to 4.25

[16] In most cases, damage will not be limited to port infrastructure, so the total cost of the event will be higher.

for hurricanes. In all cases, longer operational disruptions are experienced if hinterland infrastructure damage compromises port access or connectivity.

For smaller ports, those in developing countries, and others without resource flexibility, the duration of operational disruption can be significantly greater if cost or availability issues constrain their access to the equipment, such as dredgers, required to restore operational areas to their pre-event condition.

2.2 Perceptions of Changes in Extreme Event Frequency or Severity

2.2.1 Navigation Sector Climate Change Surveys

To gain further insight into how extreme events are already impacting ports and waterways, respondents to the NavClimate survey were also asked to indicate whether they agreed with certain statements (see Appendix 1) including about their experience of more frequent or severe extreme or atypical events:

- 41 % of respondents agreed with the statement 'My port or waterway is experiencing these types of events with increasing frequency', and
- 53 % of the reported extreme events were described as 'somehow exceptional, unprecedented or otherwise out-of-the-ordinary'

As with other questions in the survey, these results reflect individuals' perceptions and may not be founded on record keeping or statistical analysis. Notwithstanding this subjectivity, however, other recent sector-specific surveys point to similar experiences. For example, the European Sea Ports Organisation (ESPO) (2020, 2021, 2022, 2023)[17] records that, in 2018, 41 % of the ports completing their EcoPorts Self-Diagnosis Method (SDM) were 'experiencing challenges potentially linked to climate change'. In 2019, this percentage increased to 47 % of ports; in 2020 to 52 %, and in 2021[18] to 53 %. In 2022 and 2023, the percentage dropped slightly to 49 % and 47 % respectively, but it remains the case that around half of the responding ports are experiencing challenges potentially associated with the changing climate.

Different questions were asked in the UNCTAD survey. These questions concerned:

- Whether available hydro-meteorological or oceanographic data, including on extremes, show changes over time that could be considered a trend. At the time of the survey (2014), 31 % confirmed a possible trend; with 69 % not identifying such a change.
- Trends in the magnitude of damage and disruption over time. In 2014, of 40 responses, only 15 % indicated that damage and disruption had increased; 18 % that it had decreased; and 50 % noted no change (with the remainder responding don't know or not applicable). However, this question does not translate directly as a proxy for the frequency of extreme events.

Interrogation of the equivalent information collected about additional events via the NavClimate literature search (i.e. information reported in the general press, technical press, and other grey-literature sources) identified language in these reports that stated or suggested

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[17] **https://www.ecoports.com/publications/environmental-report-2020; https://www.espo.be/news/espo-presents-its-environmental-report-2021-ecopor; https://www.ecoports.com/publications/environmental-report-2022; https://www.espo.be/publications/espo-environmental-report-2023**

[18] In 2021, 99 ports completed ESPO's SDM. These ports are from countries applying EU legislation: EU Member States, Norway, the United Kingdom, and Albania. Small ports accounted for around one third of the sample in 2021; in 2022, 42% of the 92 ports completing the survey were small ports (<5 million tonnes handled annually).

the extreme event in question was somehow exceptional, unprecedented, or otherwise out-of-the-ordinary. Such language was used in 36 % of cases (17 of 47 reported events).

73 % of respondents to the 2014 UNCTAD survey (2017) confirmed that their port/terminal had been impacted by weather or climate-related events, including extremes but again, the question was worded slightly differently.

2.2.2 Others' Findings

These perceptions of increasingly frequent extreme events are reflected in reports from other sources. Figure 2, published by global reinsurance provider MunichRe, indicates that while the frequency of geophysical events such as earthquakes has remained largely unchanged since 1980, both temperature-related climatological loss events and extreme (climate-related) hydro-meteorological events have become more frequent. This increase is especially notable since 2010. The insurance sector's perception of climate related risks is important because of the consequences for insurability and insurance costs, both of which are relevant to port and waterway operators. This is discussed further in Section 4.4.

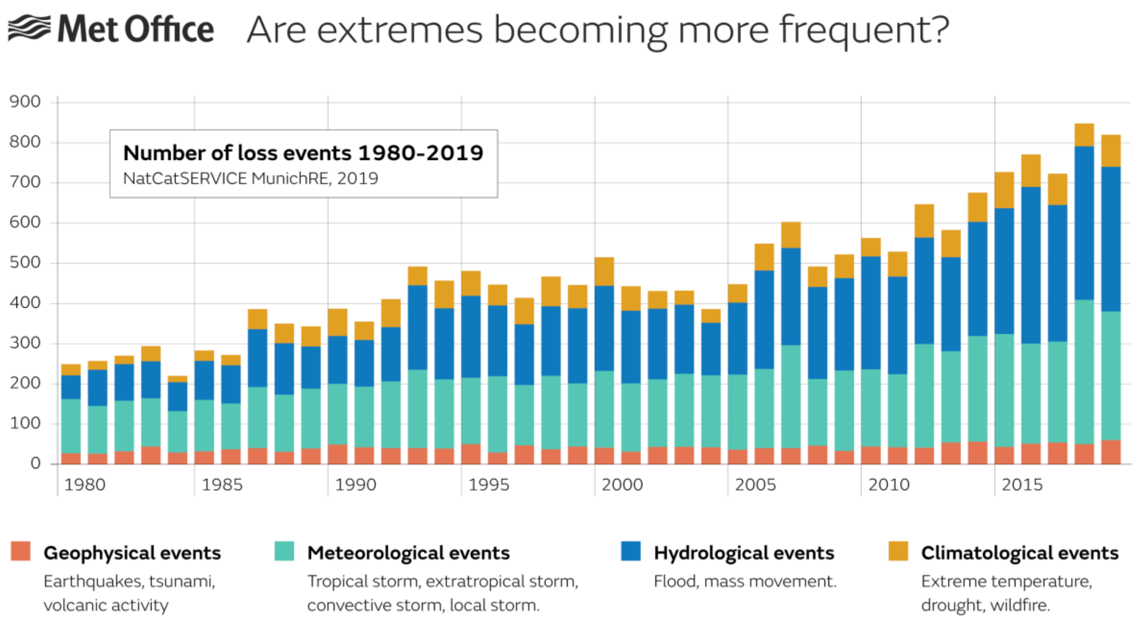

Figure 2: Number of loss events, including climatological and hydro-meteorological events, 1980-2019[19]
(Data source: MunichRE)

Extreme events can incur substantial costs, or losses, extending far beyond the ports and waterways' sector and often running into billions of US dollars. Economic impacts tend to be higher in absolute terms in high income countries where the economic value of infrastructure, etc. is higher (see e.g. Verschuur at al. (2023)) but where more is covered by insurance, making damages calculable in financial terms. A report by Christian Aid (2022) reaches the same conclusion but stresses that the true costs of such events also include lost production, disruption, social consequences and so on. The real costs are therefore much higher and include elements which are harder to quantify.

[19] https://www.metoffice.gov.uk/weather/climate/climate-and-extreme-weather

Looking ahead only at storm-related impacts in the decades ahead[20], EDF (2022) estimate that, by mid-century, global average annual damages to ports will increase relative to current levels by $1.8 to $7.1 USD billion under the high-end RCP8.5 climate change scenario[21]. By the end of the century, they suggest that the additional annual damages to ports associated with storms alone could be $4.5 to $17.7 billion USD[22].

2.3 Climate Change Action to Date

Finally, to understand how ports are responding to increases in the frequency and/or severity of extreme hydro-meteorological or oceanographic events, the NavClimate survey asked each respondent to indicate whether their port or waterway had in place any or all of the following:

Preparatory measures	Percentage responding affirmatively
Number of valid responses >	53
Extreme weather risk assessment procedures in place	57 %
Extreme weather contingency plan in place	42 %
Extreme weather warning system in place	42 %*
All three of these	15 %
None of these	23 %

*While the percentage is the same, these are not the same ports as those with a contingency plan in place: most of those responding affirmatively to these questions have either a warning system or a contingency plan in place. A few have both.

These outcomes should be seen in the light of the 85% (45 of 53) of respondents who reported they had experienced at least one – and in many cases more than one – extreme or atypical events during the five years or so preceding the survey[23]. Notwithstanding these experiences, many ports still did not have basic risk reduction measures in place.

Equivalent information on levels of preparedness was collected by UNCTAD (2017) for the period preceding 2014, and by ESPO the period from 2018 to 2023.

A main objective of the UNCTAD survey was to obtain information on levels of preparedness and resilience, as well as the extent of adaptation planning. Responses highlighted that 60 % of ports and terminals had 'assessed vulnerability', but 40 % had not (which was highlighted by UNCTAD as 'a matter of concern'). This finding is broadly comparable to the 57 % of ports responding affirmatively to the NavClimate survey question, confirming they had a risk assessment in place.

[20] Additional costs will be incurred, for example, as a result of extreme heat related impacts.

[21] Climate change scenarios including RCP8.5 are explained in Section 1.2

[22] The assumptions behind these estimates are explained in EDF's report (downloadable at **https://www.edf.org/media/shipping-industry-and-ports-susceptible-billions-dollars-damage-disruption-climate-change**).

[23] Excluding outliers, these 45 ports experienced an average of 2.4 extreme or atypical events per port.

UNCTAD further identified that about 70% of their respondents had emergency response measures in place. A parallel in the NavClimate survey could be those ports (more than 60 %) reporting that they have in place either a contingency plan or an extreme weather warning system or both.

ESPO, meanwhile, asked ports applying their EcoPorts SDM in the years 2018 to 2023 inclusive, whether they were taking steps to adapt *existing* infrastructure to increase resilience. This elicited the positive responses shown on Figure 3, up from 59 % in 2018 to 70 % in 2023.

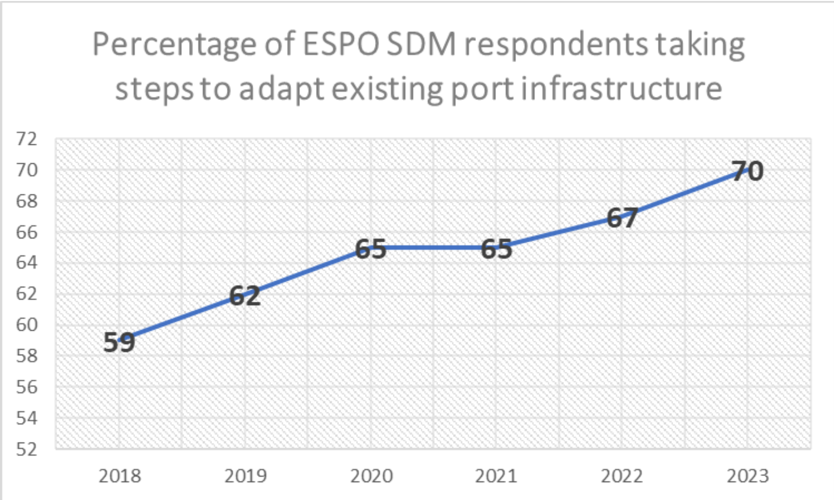

Figure 3: Percentage of EcoPorts respondents adapting existing port infrastructure, 2018-2023

Insofar as new infrastructure is concerned, 76 % of ports responding to ESPO in 2023 confirmed that they are incorporating change adaptation into the planning and implementation of *new* infrastructure projects.

Photos 2 and 3: Surveys suggest that new infrastructure is increasingly being designed with climate change in mind (Photos: Jan Brooke)

UNCTAD (2017) identified that, as of 2014, 41 % of respondents had not yet carried out any work to identify and evaluate potential climate change adaptation measures.

2.4 Overall Survey Findings

Overall, therefore, although there were some differences in the information sought by the various survey questions about preparatory measures, the key messages are consistent. Some ports are better prepared than others, but a potentially significant proportion appear to have taken no adaptation action at all. It is not known whether the latter group are unaware that climate change action is required; are aware but have been unable to implement the necessary measures for example due to financial constraints; or if they have determined that no action is needed.

ESPO's reports suggest a small but steady increase in recent years in the percentage taking measures, but even so nearly one third of ports responding to their survey are still taking no preparatory steps to adapt existing infrastructure. This is consistent with the findings of the NavClimate and UNCTAD surveys that suggest at least a quarter and up to 50 % of participating ports and waterways are either unprepared or not fully prepared for the projected increase in extreme weather frequency or severity.

Furthermore, many of the ports where action *is* being taken are in developed countries. The ports that have signed up to ESPO's EcoPorts SDM are representative of Europe's more aware and better-informed ports; and yet only around two thirds of these ports are already taking action to strengthen the resilience of existing port infrastructure. UNCTAD (2017) highlight that most responses to their survey were received from ports in developed countries. The same was true of responses to the NavClimate survey.

The IPCC (2022) report that developing countries are more likely to experience barriers to climate change adaptation. This generic observation likely applies equally to the ports and waterways' sectors in these countries. The Economist (2020) concluded that "some ports, particularly big ones in rich countries, have built defences but others are often ill-prepared". This article identifies aging infrastructure alongside access to finance as problems – and many developing countries experience both. A lack of awareness or inappropriate or outdated legislative frameworks may also be contributing factors.

Ports and the wider waterborne transport sector are vital to trade and aid, to economies, and livelihoods. Around 80 per cent of global trade by volume and over 70 per cent by value is carried by sea and handled by ports worldwide [UNCTAD, 2018a]. Yet from the available information, it can be concluded that, globally, fewer than half of all ports – and probably significantly less than half – are taking action to strengthen resilience and adapt to the changing climate. This finding is reflected in work by Becker et al. (2018) who concluded that while many port authorities are now explicitly considering climate change risks, only a notable few have actually made the next step toward implementing adaptation strategies.

In March 2022[24], speaking about climate issues more generally, the UN Secretary General warned that "We are sleepwalking to [a] climate catastrophe" … "in our globally connected world, no country and no corporation, can insulate itself from these levels of chaos." These statements are particularly relevant to the transport sector, including ports and waterborne transport. As illustrated by case studies later in this document, the unavoidably interconnected nature of the sector is such that climate change resilience cannot be fully assured until is it ubiquitous.

[24] https://news.un.org/en/story/2022/03/1114322

3 WHAT FACTORS LIMIT OR ENABLE ADAPTATION ACTION?

3.1 Limiting Factors

Among the factors identified as potentially limiting adaptation planning and implementation [IPCC, 2022 ; UNCTAD, 2022 ; WRI and GCA, 2019], the following are relevant to waterborne transport infrastructure:

- ***A lack of climate literacy and limited availability of information and data***. The 2014 port survey by UNCTAD (2017) highlighted a lack of readily available information on climate risk stressors and downscaled data as a factor limiting adaptation action. Since then, access to data including downscaled data, has improved somewhat. PIANC (2020, 2023), for example, highlights a variety of publicly available sources of regional or country level information. Access to more locally-specific data often remains challenging though. Furthermore, projections for the marine data required by ports to support adaptation planning (wave conditions, wind, storms, etc.) are often more difficult to obtain than those for changes in temperature, sea level and precipitation [PIANC, 2020a ; 2022 ; 2023]

- ***Insufficient finance, globally, from both public and private sources***. A lack of (access to) finance continues to constrain adaptation planning and implementation, especially but not only in developing countries. Nonetheless, as indicated in Section 1 and elaborated below, there are many relatively inexpensive operational, management and institutional measures that could be implemented to reduce risks and strengthen resilience, at least in the short to medium term. A lack of access to finance should not, therefore, be used to justify complete climate change inaction.

- ***Inertia in (or inappropriateness of) existing business models***. Many decisions do not currently internalise climate change. Decision making can be difficult when the location and/or timing of a hazard is uncertain or when the benefits of action may be years away. As a result, more immediate priorities commonly take precedence [WRI and GCA, 2019]. Short-term planning horizons can result in both under-allocation (e.g. due to discounting) and misallocation of resources. Especially where the private sector is involved, port and waterway planning cycles tend to have a 5 to 10-year horizon. The life span of port infrastructure and some equipment is typically 30-50 and maybe up to 100 years. The transition on Figure 4 from yellow to deep red represents the likely extent of change in climatic boundary conditions over the design life of an asset. Yet there remains a perception that climate issues are 'in the future'. Coupled with a lack of data or a poor understanding of how resilience can enhance operational performance, profitability and particularly competitiveness, this can often lead to climate change issues being side-lined, or port owners or operators being reluctant to commit to the required investment.

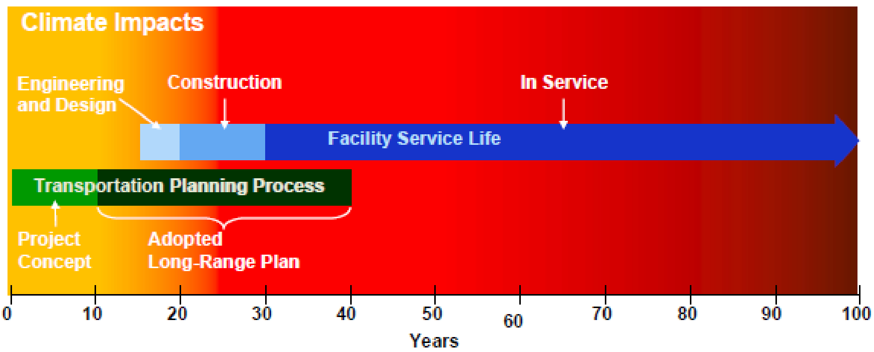

Figure 4: Transportation Timeframes vs. Climate Impacts [Savonis, 2011]

- ***Lack of definitions, metrics and standards***. The absence of consistent, widely adopted and ideally internationally agreed, definitions and metrics from governments, lenders and investors means the concept of resilient investment remains elusive. In other words, there is a lack of clarity/agreement on exactly what constitutes a 'resilient' port or waterway, what indicators should be used, and how resilience can be measured and therefore demonstrated. In the absence of an agreed definition, UNEP (2023) assesses the potential adequacy and effectiveness of national adaptation planning processes using comprehensiveness, inclusiveness, implementability, integration, and monitoring and evaluation as proxy metrics. Practical design and engineering standards have also been lacking, although this is an area where progress is now being made[25] [PIANC, 2020b. ; Brooke et al., 2024]. Even proactive port and waterway operators may therefore find it challenging to design and deliver resilient solutions.

- ***A lack of understanding, awareness or acceptance of the need to transition from incremental to transformational change.*** In situations where technical, geographical, financial or other difficulties limit the extent to which adaptation can be implemented, some types of loss or damage may become increasingly difficult to avoid. EDF (2022), for example, suggest that at the high-end predictions of sea level rise combined with storm surges, many ports could need to relocate in their entirety. While such considerations are critical to those making long-term investments, uncertainties in how quickly the climate will change and when relevant thresholds might be exceeded, can make decision making complicated.

Existing PIANC guidance (on climate change drivers and impacts (2023); climate change adaptation planning (2020a.); managing climate change uncertainties (2022); and resilient waterborne transport systems (2020b.) provides a sector-specific resource to help address some of these challenges. This Technical Note on scoping the adaptation business case assessment is intended to supplement the existing suite of reports, further assisting port and waterway operators in overcoming some of the above limiting factors.

3.2 Enabling Conditions for Adaptation

The IPCC (2022) highlight a broad range of enabling conditions[26] considered as being key to implementing, accelerating, and sustaining adaptation. Some of these reflect experience to date in the ports and waterways' sector:

- Political commitment and follow-through across all levels of government; accelerating commitment through raising awareness; building the business case for adaptation; introducing accountability and transparency mechanisms
- Institutional frameworks, policies and instruments that set clear goals and define responsibilities; mainstreaming adaptation into institutional budget and policy planning cycles
- Economic instruments that address market failures, such as climate risk disclosure
- Enhanced mobilisation of financial resources; building capacity and removing some barriers to accessing finance, for example in vulnerable regions
- Private finance as an important enabler of adaptation; leveraging finance, including through public-private partnerships

[25] For example, **https://committee.iso.org/sites/tc207sc7/home/projects/published/adaptation-standards.html**

[26] Situations that are necessary and sufficient to stimulate change

- Increased attention to monitoring and evaluation (M&E) for tracking progress and enabling effective adaptation; M&E are most effective when (i) supported by capacity and resources, and (ii) embedded in enabling governance systems.

As elaborated in Section 4.0, the extent to which each of these enabling conditions is relevant to an individual port or waterway will depend on its model of ownership, operation and management or governance. Globally, there are many different models within the sector. Kalaidjian et al. (2022) highlight that seaport ownership and governance in the USA, for example, covers a spectrum from full ownership and operation, to landlord and/or regulator, while functioning within a range of private and public jurisdictions, as well as at different scales. Understanding sector-specific adaptation enablers and drivers is therefore vital to investment decision making.

4 ADAPTATION DRIVERS RELEVANT TO THE PORTS AND WATERWAYS SECTOR

4.1 Existing and Recent Adaptation Drivers

Experience suggests that port or waterway adaptation action to date has been stimulated by one or more of three main drivers. Presenters at the COP26 side-event 'Practical Climate Change Adaptation Solutions for Ports'[27], for example, referred to one or more of the following as motivating their climate change adaptation activities:

- A reaction to experience (e.g. to a specific extreme event, or to more frequent extreme conditions, that resulted in delays or disruption, damage or other losses). Driver: to reduce future potential losses.
- A response to government requirements (e.g. the reporting requirements under the 2008 UK Climate Change Act). Driver: to ensure regulatory compliance.
- A matter of best practice. Driver: to reduce reputational and other risks to business and/or to deliver social and corporate governance commitments.

As highlighted in Section 2.4, while action to adapt and strengthen the resilience of existing port infrastructure and operations remains patchy, there is now growing regulatory and financial pressure to 'climate-proof' new projects. Project authorisation requirements may include avoiding or minimising both greenhouse gas emissions and exposure to physical climate-related risks. Climate change impacts, both *on* a project and *of* a project, now need to be assessed as part of an Environmental (and Social) Impact Assessment in many parts of the world[28]. Climate-proofing measures may be identified as being necessary to reduce potential impacts or as an offsetting intervention.

From the finance perspective, there are both dedicated sources of climate finance and an increasing tendency for financiers to seek reassurance that climate-related financial risks have been appropriately considered. Multilateral Development Banks (MDB) are supporting their clients' endeavours to adapt to and mitigate climate risks through the provision of climate-specific finance[29]. There is also a concerted effort to accelerate dissemination of international best practices on climate risk disclosure across the financial sector[30]. The development of analytical tools and indicators for the assessment and disclosure of climate-related risks and opportunities, means that climate risk disclosure is now being mainstreamed into a wide range of investment decisions[31].

All of these developments could, alone or in-combination, have implications for the owners and operators of ports and waterways. Some of these changes are becoming established; others are still evolving. But each one adds to the argument about why ports need to act to strengthen resilience and adapt to the changing climate.

[27] COP26: 26th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, held in 2021. Information on ports' side event see: **https://www.maritimeuk.org/imh-2021/imh-events/practical-climate-change-adaptation-challenges-and-good-practice-solutions-ports/**

[28] **https://climate.law.columbia.edu/content/eia-guidelines-assessing-impact-climate-change-project**

[29] For example, see **https://ukcop26.org/mdb-joint-climate-statement/**

[30] **www.ebrd.com/2020-joint-report-on-mdbs-climate-finance**

[31] For example, UNEP Finance Initiative members ANZ, Barclays, Bradesco, Citi, Itaú, National Australia Bank, Royal Bank of Canada, Santander, Standard Chartered, TD Bank Group and UBS; see **https://www.unepfi.org/news/industries/banking/eleven-unep-fi-member-banks-representing-over-7-trillion-are-first-in-industry-to-jointly-pilot-the-tcfd-recommendations/**

4.2 Increasingly Frequent or Severe Extreme or Atypical Events

As discussed in earlier sections of this Technical Note, both slow-onset changes and increasingly frequent/severe extreme or atypical events are already being experienced in many parts of the world. Several presenters at the 2021 COP26 ports' side-event highlighted how the actions of their port were driven by experience of a particular extreme event(s), or an increasing frequency of severe hydrometeorological or oceanographic conditions, or both. A majority of respondents to both the NavClimate survey and to the ESPO EcoPorts SDM questionnaire similarly confirmed that they are experiencing such increases (Section 2.2).

The case studies summarised on Table 2 (most of which are sourced from UNCTAD (2022)[32]) highlight further examples of action to strengthen resilience and adapt that were driven by the port's experience of extreme wind, waves, sea level rise, rainfall or flooding.

The IPCC's projections indicate that increasing numbers of ports and waterways will be affected by more frequent and/or severe extreme events, including wind, waves and storms, extreme high or low flow events, and extreme heat-related impacts. The need for proactive preparedness measures to reduce losses associated with damage, delays and disruption will therefore only increase.

Examples of common preparedness measures highlighted by the case studies in Table 2 include vulnerability mapping; early warning systems; contingency planning including, for example, alternative access and storage provision; digital tools and solutions; and enhanced maintenance including maintained or improved drainage capacity.

[32] Port of Baltimore, 2010, from **https://www.maritimeuk.org/imh-2021/imh-events/practical-climate-change-adaptation-challenges-and-good-practice-solutions-ports/**

Location	Driver for Adaptation Action	Investments Made and *Lessons Learned*
Port of Seattle, USA, 2021	Response to disruption due to **extreme rainfall** and **high wind speeds**	Improvement and relocation of infrastructure. Implementation of preventative risk assessment processes. *Importance of digital tools including for communication; identification of alternative access routes as a contingency*
Port of Houston, USA, 2017	Response to disruption due to **Hurricane** Harvey. Port re-opened after one week, but wider disruption lasted more than a month. Reconstruction projects took 3-5 years.	Dredging to clear access channels and major terminal entrances (cost US$ 2 million). Hurricane procedures manual developed. Monitoring, maintaining, upgrading of infrastructure. *Importance of alternative supply routes; long-term back up contracts; improved storage safety; digitisation for real time visibility, data sharing and early warning.*
Port of Port-au-Prince, Haiti, 2016	Response to damage and disruption due to **Hurricane** Matthew. US$ 1.9 million damage to transport infrastructure. Damage exacerbated by poor construction standards, insufficient maintenance and limited system redundancy	Connectivity and infrastructure investments. Improved maintenance and operational efficiency. Investment to reduce vulnerability. *Importance of pre-event preparedness, mapping bottlenecks, risk assessment and risk management plans, strengthened support/cooperation.*
Port of Port Vila, Vanuatu, 2015	Response to damage and disruption due to **Cyclone** Pam. US$ 0.3 billion damage to transport infrastructure, exacerbated by poor construction standards. Disruption for up to two weeks	Post-disaster needs assessment identified US$ 34 million recovery and reconstruction project for strengthened disaster resilience including interim provisions (restoring road access, de-silting drains, remedial works) and longer term upgraded disaster resilience and climate-proof designs. *Risk planning and management; value of regional partnerships; vulnerability mapping; preventative measures and rapid response ability.*
Port of New York, USA, 2012	Response to severe damage/disruption due to **Superstorm** Sandy, which caused **flooding** of most of the port and surrounding area. Railway inundated with salt water; 25,000 containers diverted; port closed for one week; congestion for longer	US$ 59 million post-storm investment in 200 flood protection projects. *Value of pre-disaster preparedness including trial exercises enabled effective post-storm response. Importance of clear communication systems and institutional relationships.*

Port of Laem Chabang, Thailand, 2011	Response to disruption due to intense monsoon **rainfall**. Reduced traffic to port as manufacturing impacted by floods; inland water traffic suspended for one month; congestion due to **flooding** at Bangkok Port; container shortages	Formulated strategic connectivity and regionalisation measures; increased market share of short-sea shipping to reduce reliance on road transport. *Investment in climate resilient infrastructure needed including to cope with floods and droughts; improvements in drainage capacity; early warning systems; enhanced hinterland connectivity; digital solutions*
Port of Baltimore, USA, 2010	Response to **Hurricane** Isabel, extreme **rainfall** events: recognition of vulnerability of port facilities and operations to changing climate conditions	Some terminal functions relocated from flood plain; some areas elevated to add resilience; climate-proofing guidance prepared for new facilities; storm water management systems installed. *Prioritise investments by need, level of risk and potential impact; reuse dredge material for natural resilience projects; identify resilience partnerships*
Port of Gulfport, USA, 2005	Response to disruption caused by the six-day **Hurricane** Katrina that lasted for six months; damage costs of US$ 51 million; 70 % fall in port revenues	Deepening/widening channel; elevating operational areas. *Importance of digital tools including for communication; chain performance dashboard role in understanding logistics chain; cooperation with other ports to provide alternatives.*

Table 2: Adaptation and resilience action taken by ports in response to previous extreme weather events

4.2.1 Reputational Risks

In the absence of appropriate interventions, future extreme events will not only compromise port and waterway operations more frequently: adaptation inaction can also impact on important co-dependencies. The resilience of the 'port cluster' (logistics and warehousing, manufacturing, heavy industries, energy production and transformation activities) is dependent on the resilience of the port itself [UNCTAD, 2022].

In 2017, UNCTAD reported that, despite experience of severe weather impacts, most ports had not received requests for adaptation response measures from their users or clients. However, attitudes seem to be changing. A growing number of corporate climate-related initiatives are being driven by objectives ranging from managing business risks to delivering on corporate social responsibility commitments. In 2021, for example, nine major international companies including Ikea, Amazon and Unilever signed the Cargo Owners for Zero Emission Vessels pledge[33], committing to using only zero-emission vessels to transport cargoes by 2040. In the face of increasing delays and disruption associated with more frequent or severe extreme weather events (see Section 2.1 and Appendix 1), it is conceivable that such companies will also start to place demands on ports and waterways to demonstrate strengthened resilience. Shipping lines may similarly opt to change their port calls to ensure greater stability, as was seen at Felixstowe, UK, when technology issues with operating systems led to delays and disruption over an extended period from 2018 onwards[34].

Ports that do not act to strengthen resilience risk losing business. For inland waterways, a lack of resilience may result in reverse modal shift, from waterways to road or rail (see Section 5.5). While commercial and competition considerations mean care may be needed in how measures to address vulnerability are communicated, particularly to private stakeholders [Kalaidjian et al., 2021 ; Kalaidjian et al., 2022], the importance of effective management of climate change risks is increasingly being acknowledged. In 2022, for the first time in its 25 years' operation, the 92 members of the European EcoPorts Network placed climate change at the top of the European ports' environmental priorities list[35]. Climate change remained as the top priority in 2023 [ESPO, 2023]. The noticeable effects of climate change; growing investment-related requirements to climate-proof port infrastructure; and ensuring compliance with climate legislation were among the reasons contributing to the increasing priority of this issue.

4.3 Awareness of Supply Chain Consequences of Extreme Events and Other Incidents

Beyond the port cluster, ports and waterways play a critical role in supply chains and therefore in ensuring food and energy security, as well as wider economic security/stability. The COVID-19 pandemic brought the issue of supply chain disruption to the global stage but there is also growing evidence of such disruption resulting from extreme weather events. Examples include:

- Hurricane Katrina in 2005, which not only shut down major Louisiana ports such as Gulfport (Table 2), but led to disruptions in global grain supply, resulting in significant export losses for the United States; affecting dependent supply chains; and raising commodity supply prices [Verschuur et al., 2022]

[33] https://www.cozev.org/

[34] https://www.lloydsloadinglist.com/freight-directory/news/More-services-lost-from-Port-of-Felixstowe/72774.htm#.Yjyr4zXLcdU

[35] https://www.ecoports.com/publications/environmental-report-2022

- Hurricane Maria, in 2017, which impacted port functions, energy and communications, resulting in disruption of the USA pharmaceutical supply chain for many months [Lawrence et al., 2020]
- Hurricanes Sandy in 2012 (Table 2) and Ida in 2021, where the port closures of New York and New Jersey, and New Orleans and area respectively contributed to widespread impacts on transport supply chains [IPCC, 2022]
- Extreme flooding in Thailand in 2011 which caused disruption to manufacturing supply chains and a global shortage of semiconductors, directly and indirectly impacting the ports of Laem Chabang and Bangkok (Table 2) and resulting in a consequent slowdown in computer manufacturing globally [IPCC, 2022 ; UNCTAD, 2022]

Severe droughts impacting the Panama Canal in 2019 and the Paraguay Paraná Waterway in Argentina in 2020-2021[36]; and extreme high flows and flooding on the Mississippi River in 2019 are among notable inland waterway-related events that caused significant consequential disruption at inland ports and along the supply chain in recent years.

Photo 4: Many inland waterway ports and navigation operators will need to prepare for more frequent extremes of both high and low flow (Photo: Jan Brooke)

All these examples illustrate how extreme or atypical conditions impacting ports and waterways should be considered in the context of other industrial and logistics installations. Some such installations may be affected by the same event(s), amplifying supply chain disruption. The costs of supply chain disruption are typically magnified manyfold when compared to the cost implications for the individual port or waterway. Verschuur et al (2022) highlight that every US$ 1 flowing through a port contributes an average of US$ 4.3 to the global economy. Actual values vary according to the position of port within supply chains and are influenced by the relative importance of domestic versus international and forward versus backwards supply chain linkages.

[36] https://www.ina.gob.ar/alerta/index.php?seccion=8

4.4 Evolving Good Practice in the Insurance Sector

Records from the insurance sector such as those summarised in Figure 2, confirm that recent years have seen a marked increase in the number of meteorological and hydrological loss events[37]. Many of these weather catastrophes fit in with the expected consequences of climate change, making greater loss preparedness and climate protection a matter of urgency[38].

To manage extreme weather risks, it has long been the case that organisations such as port or waterway operators have chosen to pay to transfer certain risks to insurance companies. In 2017, UNCTAD noted that most ports responding to their 2014 survey had not observed any climate-related changes in insurance premiums and/or levels of insurance, but this situation is evolving. While damage costs might be covered through insurance in the short term, insurers are likely to increase premiums or deny cover if individual operators do not act to limit their exposure to climate change risks [EDF, 2022][39]. Others note that if the insurance industry does not price resilience effectively, a potential incentive mechanism to stimulate investment in resilience may be missed [UNCTAD, 2022].

Initiatives are underway within both the insurance and financial sectors on how best to handle climate-related risks. McKinsey[40], for example, cite more frequent catastrophic events and systemic climate change-related impacts as a reason for insurers to modify their business models. The objective is to avoid the situation where insurance against such risks becomes either unaffordable for customers, infeasible for insurers, or both. They suggest that insurers should stress-test their exposure to climate risk, re-balance their portfolios and use their understanding of risk to help other organisations mitigate and adapt.

Several different types of action can be taken to help reduce or even avoid the need for insurance claims, including the following.

- Increase the focus on preventing or limiting damage. Even without waiting for pressure from insurers, port and waterway planners and designers arguably have a key role to play in damage limitation. So, too, do others developing and implementing improved construction standards or land use planning or similar policies.
- Offer rebates or reduced premiums for demonstrated resilience. A model is provided by the USA Community Rating System. This voluntary incentive programme encourages sustainable floodplain management practices that strengthen resilience beyond the minimum requirements of the National Flood Insurance Program[41], enabling participating communities to access discounted flood insurance premiums.
- Set up partnerships to manage and avoid risk. The case studies in Box 3 illustrate how setting up partnerships to deliver nature based-solutions (NbS) might help reduce insurance premiums by contributing to limiting certain climate-related risks.

[37] For example, **https://www.munichre.com/en/risks/natural-disasters-losses-are-trending-upwards.html**

[38] **https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2022/natural-disaster-losses-2021.html**

[39] It is also of note that the insurance sector faces some of the same challenges as project owners and designers in relation to the use of historic data [PIANC, 2022]: insurance policies that are based only on historical data may not reflect the full cost of future climate risk (**https://www.mckinsey.com/industries/financial-services/our-insights/climate-change-and-p-and-c-insurance-the-threat-and-opportunity).**

[40] **https://www.mckinsey.com/industries/financial-services/our-insights/climate-change-and-p-and-c-insurance-the-threat-and-opportunity**

[41] **https://www.fema.gov/floodplain-management/community-rating-system**

NbS Reducing Wildfire Risks, Including to Transport

- A report prepared by The Nature Conservancy and Willis Towers Watson [TNC, 2021] demonstrates how ecological forest management aimed at reducing the risk of severe wildfires could significantly reduce insurance costs. In this case, modelling the impact on insured assets of controlled burning and ecological thinning of overgrown forests enabled researchers to quantify insurance premium savings. Such techniques reduce risk – equating to a decrease in insurance premiums of 41 % for homes and a range of decreases for commercial property. In fire-adapted forests, the likelihood of extreme wildfires affecting communities was also reduced. The report goes on to suggest that these savings could contribute to funding or financing further investments in sustainable forest management, creating a 'virtuous circle'. Such an approach is potentially relevant both to port and waterway assets within fire risk areas, and to ports where critical transport corridors run through areas of high wildfire risk.

NbS Strengthening Protection Against Storm Damage, Flooding and Coastal Erosion

- A partnership approach can be applied to the protection and maintenance of coastal habitats such as mangroves or saltmarshes that function both as a significant natural store of carbon, and as a buffer protecting assets against storm damage. In 2023, for example, a UK insurance company announced a £ 21 million (US$ 26 million) partnership[42] with the UK Wildfowl and Wetlands Trust, to contribute towards combatting climate change by developing best practice in saltmarsh restoration.

(Photo: Jan Brooke, PIANC)

- This initiative recognises the vital role of saltmarshes in absorbing wave energy and enhancing natural protection from flooding and coastal erosion. It also highlights how the remaining areas of saltmarsh provide over £ 1 billion (around US$ 1.25 billion) in flood resilience benefits to UK homes [Environment Agency, 2023]. In 2019 alone, the estimated value of flood mitigation by saltmarsh was £ 62 million (approximately US$ 77 million) in England and £ 9 million (US$ 11 million) in Wales[43]. In line with PIANC's Working with Nature philosophy [PIANC, 2018], several UK ports already use dredged material beneficially, contributing to sustaining the ecosystem services associated with saltmarshes and other intertidal habitats [Manning et al., 2021]. It is not known whether any of these are linked to the insurance sector but work in the UK conservation sector suggests the potential may exist.

Box 3: Partnership-based NbS Initiatives to Reduce Insurance Claims and Lower Premiums

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[42] **https://www.aviva.com/newsroom/news-releases/2023/06/aviva-to-support-restoration-of-shrinking-saltmarsh-habitat-to-combat-climate-change/** Accessed 15 June 2023

[43] **https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/saltmarshfloodmitigationinenglandandwalesnaturalcapital/2022** Accessed 16 June 2023

Another relatively new insurance-related product is the resilience bond[44] which raises capital specifically for climate resilient investment. Resilience bonds can link conventional insurance for public organisations to the capital investments they make in resilience interventions aimed at reducing the level of loss from (e.g. climate-related) disasters. Such initiatives may be of relevance to some port and waterway operators.

4.5 Evolving Position of the Finance Sector

Major financing institutions are increasingly focusing on resilience, either as a precondition of providing a loan or finance, or as a criterion to be demonstrated by an applicant in the process of securing investment. Some are also setting up dedicated finance streams for projects committed to decarbonisation, climate change resilience, or both. Such initiatives are important because IPCC (2022) and others highlight access to appropriate finance as being critical in enabling adaptation action (see Section 3.2).

In Europe, climate change mitigation and adaptation are key components of the EU taxonomy[45]. This classification system aims to help the European Union (EU) scale-up sustainable investment by providing companies, investors, and policymakers with clear definitions on what comprises a 'sustainable' economic activity, as well as with procedures to demonstrate compliance. The taxonomy is intended to create investment security, protect private investors from greenwashing[46], and enable companies to become more genuinely climate friendly. Several port, waterway and related activities are considered as 'sustainable' economic activities insofar they substantially contribute to climate change adaptation and do no significant harm to the other environmental objectives (climate change mitigation; biodiversity protection; water resources protection; pollution prevention and control; and circular economy). The listed activities have a sustainable financial investment label, providing investors with confidence to offer or increase investment. At the time of writing (early 2024), discussions are ongoing whether this list of activities can be extended for instance to include sustainable forms of dredging.

The Organization for Economic Cooperation and Development [OECD, 2020] highlights national level action on sustainable finance definitions and taxonomies in four other jurisdictions: China, Japan, the Netherlands, and France. All four include climate change mitigation objectives in their green bonds or green lending initiatives. Japan, the Netherlands and France also set adaptation objectives. South Africa (2022) and Indonesia (2022) similarly incorporate climate change considerations into green taxonomy classifications for economic activities supporting environmental protection and management.

In the meantime, the Global Financial Markets' Association and others (2021) have stressed the need for global harmonisation, including the role of science-based taxonomies as key enablers in scaling-up climate-aligned finance and ensuring activities are in line with the Paris Agreement goals.

Internationally, the following initiatives may also be of potential relevance to some ports:

- The UN-convened Sustainable Blue Economy Finance Initiative focuses on links between private finance and ocean health in line with the Sustainable Blue Economy Finance

[44] **https://gca.org/what-are-resilience-bonds-and-how-can-they-protect-us-against-climate-crises/** Accessed 3 February 2024

[45] **https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en**

[46] Misleading or deceptive claims by an organisation intended to demonstrate an environmentally responsible public image.

Principles[47] launched in 2018. It aims to ensure investment, underwriting and lending activities are aligned to UN Sustainable Development Goal 14 (SDG 14) 'life below water'.

- The criteria developed by IDB Invest (2021b.) which help identify 'blue financing' opportunities for port investment, including to meet objectives such as strengthening the climate-resilience of port infrastructure (through green infrastructure and nature-based solutions), and reducing greenhouse gas emissions. Blue bonds are described as representing an innovative way to fund ocean and water-related solutions, creating sustainable business opportunities, and signalling responsible ocean stewardship to the market.

Insofar as dedicated climate finance is concerned, the World Bank launched its Action Plan on Climate Change Adaptation and Resilience[48] in 2019. This included a commitment to double adaptation financing to equal its financing commitment to reducing greenhouse gas emissions, while also supporting countries' efforts to systematically manage climate risks at every phase of policy planning, investment design, and implementation.

In 2021, World Bank reported on the development of a rating system to create incentives for, and improve the tracking of, global progress on adaptation and resilience[49]. Other banks are taking similar action. In 2021, the share of investments by the European Investment Bank that went to climate action and environmental sustainability projects was 51 %. In 2022, it rose to 58 %[50]. While anecdotal evidence suggests that the waterborne transport sector has not been a major recipient of such investment to date, the inclusion of the sector in sustainable finance taxonomies is a positive move.

4.6 Climate Change Risk Disclosure and Reporting

In parallel to the shift in financing priorities, there has been a significant increase in climate risk reporting activity within both businesses and financial institutions in the years since the 2015 Paris Agreement. Several countries are introducing regulations to require climate-related risk disclosure.

In 2017, in recognition of financial markets' need for clear, comprehensive, and high-quality information on the impacts of climate change, the Taskforce on Climate-related Financial Disclosures (TCFD) released recommendations intended to help companies provide information to support informed capital allocation[51]. In the European Union, the 2019 Regulation for Sustainability-related Disclosures in the Financial Services Sector, introduced transparency rules for financial institutions, including expectations on due diligence reporting. In 2022, with the Climate-related Financial Disclosure Regulations, the UK Government became the first G20 country to require the largest businesses to disclose climate-related risks and opportunities in line with the TCFD recommendations[52]. In March 2022, the United States securities regulator put forward a similar proposal requiring US-listed companies to disclose their climate-related risks and greenhouse gas emissions[53]. From January 2023, climate-related disclosures were made mandatory in New Zealand for some large publicly listed companies as well as insurers, banks, investment managers and others. Other countries are following these examples. Furthermore, even where they are not required to do so, businesses can choose to

[47] https://www.unepfi.org/blue-finance/the-principles/
[48] https://www.worldbank.org/en/news/press-release/2019/01/15/world-bank-group-announces-50-billion-over-five-years-for-climate-adaptation-and-resilience
[49] https://www.worldbank.org/en/topic/climatechange/brief/3-things-you-need-to-know-about-adaptation-and-resilience
[50] https://www.eib.org/en/about/priorities/climate-action/index.htm
[51] https://www.sec.gov/news/press-release/2022-46
[52] https://www.gov.uk/government/news/uk-to-enshrine-mandatory-climate-disclosures-for-largest-companies-in-law; https://www.legislation.gov.uk/uksi/2022/31/contents/made
[53] https://www.sec.gov/news/press-release/2022-46

follow the TCFD recommendations as a matter of good practice and to facilitate informed investment decision making.

Table 3 illustrates applications of the TCFD recommendations by Port of Newcastle, Australia [Port of Newcastle, 2022] and Peel Ports Group in the UK [Peel Ports, 2023]. Also in Australia, Port of Melbourne's 2022 Sustainability Report states their climate change management approach has been informed by the recommendations of the TCFD and highlights an ambition to align with these recommendations by 2024. Port of Geelong registered as a TCFD 'Supporter' in 2023. At the time of writing, ports elsewhere in the world are similarly embarking on analyses in line with the TCFD recommendations.

Location	**Driver for Adaptation Action**	***Main findings***
Port of Newcastle, Australia, 2022	*Climate change is a strategically significant issue for the Port of Newcastle (PON); PON seek to mitigate against environmental, legal and reputational risks; increase Board oversight; enhance employee engagement; and positively influence customer behaviour. Climate scenario analysis was completed in line with TCFD recommendations and the Australian Climate Measurement Standards Initiative (CMSI)*[54]	*Two market forces and policy scenarios were explored. Analysis identified examples of physical risks as prolonged high temperatures and drought affect wheat and grain exports; extreme wet weather increasing dredging requirements; and damage to assets increasing insurance premiums. Transitional risks included: loss of tenants and under-utilised land assets as coal imports/exports reduce; an increasingly stringent regulatory landscape; and inability to access (or increased cost of) finance. The impact of reduced volumes through port, and potential increases in operational expenses were quantified and a possible increase in debt margin acknowledged.*
Peel Ports, UK, 2023	*Peel Ports Group (PPG) recognises that ports are inherently vulnerable to the effects of climate change. PPG therefore considers climate change as part of ESG and sustainability reporting. This also includes complying with new TCFD-based requirement for climate risk reporting (made mandatory for Britain's largest companies in 2022) and contributing towards UN Sustainable Development Goal 13 on climate action.*	*Peel Ports' ESG and Sustainability report highlights that PPG: has identified chronic and acute climate-change related risks; has worked with third party experts to complete high-level climate risk assessments for all port locations; will complete adaptation plans for each port location by 2025; will include TCFD aligned disclosure in financial year 2022-2023 accounts, one year earlier than the mandatory requirement; has set up a Climate Change Committee which reports to the Executive Board; measured scope 1 and 2 emissions; will measure scope 3 emissions; and has set science-based targets aligned with the net-zero standard from the Science Based Targets Initiative (SBTi).*

Table 3: Case study of climate change risk identification and disclosure action

While other organisations and institutions are embarking on similar risk identification and disclosure actions using both decarbonisation and climate resilience indicators, the OECD (2019)[55] points out the significant challenges affecting the coverage and quality of such disclosures, including in relation to the adequacy and consistency of data and metrics. OECD suggest that better climate disclosure requires moving away from static, compliance-based reporting to due diligence reporting models. The latter ensure disclosure of how climate issues

[54] https://www.cmsi.org.au/
[55] https://www.oecd.org/cgfi/forum/Disclosure-and-Due-diligence-for-Climate-related-Risks-background-session-note-CGFI-Forum-2019.pdf

are integrated in governance, strategy and risk management and identify what practical actions have been and can be taken. Despite these challenges, OECD also highlight how reporting on climate due diligence can demonstrate the level of ambition and robustness of a company's or investor's approach to managing climate risks, in turn providing a level of reassurance to financial institutions.

4.6.1 Incremental vs. Transformational Change

Port and waterway operators will be affected differently by these evolving risk disclosure initiatives depending on their governance/ownership/management model; their expansion ambitions; and their exposure to different types of climate-related risks. While many infrastructure owners and operators will have the option to manage business risks through a planned programme of adaptation, some may face losses and damages that become increasingly difficult to avoid, with potential implications for their competitiveness.

When making long term investment/financing decisions, it is important to understand whether incremental change will be sufficient to sustain an asset for its design or operational lifetime. It may also be important to consider whether it is realistic to sustain the operation of the entire port in its current location. In some cases, transformational change such as asset or port relocation[56] may be a better long-term option than raising, strengthening, or otherwise modifying infrastructure. While construction of a new port at a higher elevation may be less expensive than raising an existing port, EDF (2022) caution that other costs such as land purchase and/or the wider economic implications for local communities also need to be factored into a decision on whether in-situ adaptation or relocation is the preferred approach in the face of the changing climate. For most of the major ports around the world, there has been significant public investment in supporting (transport) infrastructure. If port relocation means the loss of existing and/or a requirement for new interconnecting infrastructure, this will substantially increase the overall relocation cost.

Transparency on risk characteristics, existing levels of resilience, and future adaptation options is thus of relevance not only to the port or waterway itself, but to financiers, development banks, aid agencies and other multi-laterals, the insurance sector, and a variety of related organisations.

4.7 Government Commitments

Under the Paris Agreement, national governments as signatories are required to prepare, submit, and update their Nationally Determined Contributions (NDCs)[57]. NDCs include actions set out in climate action plans that aim to cut emissions and adapt to climate impacts. Parties to the Agreement need to update their NDCs every five years.

An analysis by SLOCAT[58] (2022) of the extent to which transport in its widest sense is covered in countries' NDCs identified that:

- Transport adaptation targets and actions are still relatively limited but are increasing: in 2022 it was reported that 57 of the second generation NDCs (around 40 %) included transport adaptation measures, compared to 22 % in 2016.

[56] IPCC (2022) define transformational changes as significant changes in structure or function that go beyond adjusting existing practices
[57] **https://www.un.org/en/climatechange/all-about-ndcs**
[58] The Partnership on Sustainable Low Carbon Transport

- Only six second-generation NDCs (from Antigua and Barbuda, Burundi, Cambodia, Kenya, Liberia, and Papua New Guinea) have set transport adaptation targets. These include targets to climate-proof infrastructure and develop more robust and resilient (public) transport systems.
- Transport adaptation content in NDCs is typically very general, with a focus on road transport. To date, little attention has been paid to waterborne transport.
- Just over half of the adaptation actions comprise structural and technical measures; the remainder are mostly institutional/regulatory, or information/education based. Targets and actions to strengthen institutional capacity are limited.

SLOCAT also point out that the NDCs provide an opportunity for countries to communicate their need for international support. Especially for low-income countries, incorporating transport (including port and waterway) adaptation targets into their updated NDCs offers a potentially significant benefit in terms of access to international finance.

In addition to (or sometimes as part of) their commitments under the Paris Agreement, many governments have passed laws, introduced regulations, or developed other legislative instruments to address climate change mitigation/decarbonisation; adaptation/resilience; or other climate-related topics. The Grantham Research Institute at London School of Economics and Political Science (UK) and the Sabin Center at Columbia Law School (USA) have compiled a searchable database that covers climate and climate-related laws[59]. Many of these national climate-related laws and policies are directly or indirectly relevant to the ports and waterways sector.

Table 4 provides two case studies[60] of port adaptation initiatives driven by climate-specific legislative requirements.

Location	Driver for Adaptation Action	*Lessons Learned*
Port of Liverpool, UK, 2021	Response to legislative requirement, the 2008 UK Climate Change Act. This Act invites critical infrastructure providers to report to government on climate change risks and their preparedness to deal with these risks.	*Report identified need for measures to address potential wind/wave/sea level damage risk to lock gates and to bollards; increased dredging requirements; potentially compromised berthing or quayside operations or pilotage practices. Assessment process highlighted the importance of monitoring and of understanding inter-dependencies/risk of cascading failures.*
Port of San Diego, USA, 2019	Response to legislative requirement, the 2013 California State Assembly Bill 691. This Bill required some organisations to evaluate their vulnerability to sea level rise and prepare strategies demonstrating their adaptation proposals.	*Process highlighted importance of stakeholder engagement and partnerships and the benefits of a whole-of-government-approach. Key messages: multiple solutions are needed; adaptation may require a paradigm shift; don't be distracted by uncertainty.*

Table 4: Adaptation and resilience action taken by ports in response to legislative requirements

[59] https://climate-laws.org/
[60] Source: https://www.maritimeuk.org/imh-2021/imh-events/practical-climate-change-adaptation-challenges-and-good-practice-solutions-ports/

In many countries, climate change adaptation policy is still evolving, but there is a slow, steady increase in coverage – not only under the Paris Agreement, but as a response to many of the drivers discussed above including changes in the financial sector. National as well as international policy and regulation will play an increasingly important role as a driver for port and waterway climate change adaptation action (see also UNCTAD (2020)).

4.7.1 Climate-Proofing New Developments

Consideration of climate change issues is increasingly required as part of the authorisation process for new developments. In Europe, for example, Directive 2014/52/EU explicitly requires that potential climate change issues – both mitigation (decarbonisation) and adaptation – be evaluated as part of an environmental impact assessment. Technical guidance for the climate-proofing of infrastructure was published by the European Commission in 2021[61].

4.8 Legal Challenges and Liability Issues

A recent analysis of some of the commercial law implications of climate change impacts on ports by Asariotis (2023) indicates that some of the consequences of adaptation inaction – such as delays, supply chain disruption, and economic losses – could lead to business failures and to costly and protracted legal disputes. Increasing climate and weather-related risks and impacts may result in a greater incidence of cargo loss or damage; heightened risks for the carriage of deck cargo; or pose challenges for the safety of berthing, loading or discharge operations. The risks of maritime accidents, environmental pollution, groundings, and bunker oil spills may also increase.

Such risks have implications for the performance of commercial contracts, as well as for the rights, obligations and liabilities of contracting parties engaged in international transport. The author suggests that judicial approaches to established legal concepts and their interpretation may need to evolve to a 'new normal' under the changing climate. To mitigate exposure to potentially extensive commercial losses and litigation, contracting parties should consider carefully worded specialist clauses that accommodate future risks and provide for a suitably balanced commercial risk allocation in the light of these changing circumstances.

[61] Commission Notice - Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (OJ C 373, 16.9.2021, p. 1). **https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:C:2021:373:TOC**

5 SCOPING THE BUSINESS CASE FOR ADAPTATION

5.1 Context

The World Economic Forum's 2024 Global Risks Report [WEF, 2024] lists extreme weather events and critical change to Earth's systems as, respectively, the first and second highest global risks over the period to 2034. Businesses, globally, need to respond.

"Adaptation should not be seen as a cost, but as an investment. Our State and Trends in Adaptation 2021 report[62] also shows that, in Africa, adaptation pays off. Adaptation is good business. For example, investments in climate-smart agriculture can give as much as four dollars in benefits for every dollar invested. Moreover, the costs of inaction are ten times higher than the cost of action. Adaptation is a smart investment."

Patrick Verkooijen, CEO, Global Center on Adaptation, addressing the meeting on the 16th replenishment of the African Development Fund, 8 April 2022[63]

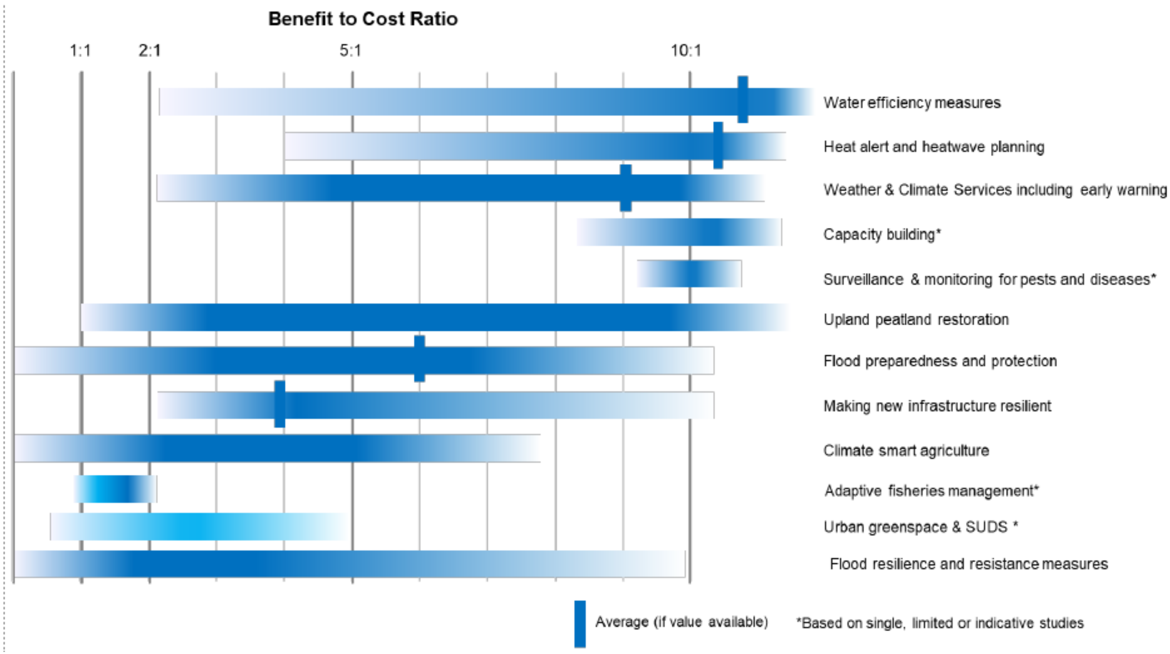

Figure 5: Benefit to cost ratios for adaptation for selected CCRA3 risks [Watkiss et al., 2021][64]

There is growing evidence that adaptation is a smart business decision: early investment in climate change adaptation can deliver very good value for money. Reported cost to benefit ratios typically range from 1:2 up to 1:12. In other words, every US$ 1 invested potentially results

[62] **https://gca.org/reports/sta21/**
[63] **https://www.afdb.org/en/news-and-events/speeches/high-level-remarks-global-center-adaptation-ceo-prof-patrick-verkooijen-meeting-16th-replenishment-african-development-fund-50897**
[64] Notes from Watkiss et al. (2021): Figure [5] shows the indicative benefit:cost ratios (BCR) and ranges for a number of adaptation measures. It is based on the evidence review undertaken in the CCRA3 Valuation study, which was co-funded by the EU's Horizon 2020 RTD COACCH project (CO-designing the Assessment of Climate CHange costs). Vertical bars show where an average BCR is available, either from multiple studies or reviews. It is stressed that BCRs of adaptation measures are highly site- and context-specific and there is future uncertainty about the scale of climate change: actual BCRs will depend on these factors.

in a net economic benefit of up to US$ 12. The ratios in Figure 5 reflect the outcomes of the evidence review undertaken as part of the valuation study in the third UK Climate Change Risk Assessment [Watkiss et al., 2021]. Many of the measures assessed by Watkiss et al. are directly relevant to ports and waterways. For example (although site-specific characteristics will ultimately determine the exact value of both benefits and costs) Figure 5 indicates that actions such as capacity building, early warning systems, heatwave planning, flood preparedness, and making new infrastructure resilient could deliver benefit to cost ratios of between 4:1 and 10:1.

5.1.1 Reminder: Aim of the Technical Note

This Technical Note is intended to help the reader identify the factors that are the most appropriate to the business case for adaptation planning and intervention given the nature of their organisation and the scale at which it operates.

Different types of organisations may have some common motivations for action, such as meeting health and safety requirements or ensuring regulatory compliance. The process of making the financial or economic case for investment, however, may be very different. A private sector port company operating a single port, or a group of ports, will likely be concerned primarily with factors impacting micro-economic aspects such as costs, benefits and return on investment in the context of supply and demand. Competition, profit, incentives, and opportunity cost may also be important. A state organisation or public waterway administration may be more concerned with factors impacting macro-economic aspects: economic output, inflation, employment, and societal wellbeing, as well as with the need to justify expenditure in a more political context. Sources of finance, including any climate-related conditions determining access to finance, will arguably be of interest to most organisations at some level.

Whatever the specific driver(s) for action, those preparing a business case will typically first need to identify, articulate, and ideally quantify risks and vulnerabilities relevant to their organisation at some or all of the following scales:

- At the level of the facility or asset (port, waterway, and associated infrastructure) and/or
- At the transportation system level and/or
- In a supply chain context and/or
- In the wider safety, social and environmental context

Making the case for future-proofing ports, waterways and the wider supply chain via strengthened structural, operational and institutional resilience, also requires owners, operators and investors to be cognisant of some or all of the following:

- The likelihood that the port or waterway will experience both slow-onset changes and more frequent and/or severe extreme or atypical hydrometeorological or oceanographic events
- The projected magnitude and characteristics of such changes
- The potential consequences of these changes for assets and operations, as well as for port or waterway users, customers, terminal operators, industries, logistics companies and so on
- The implications of such events for connecting infrastructure, utilities, service providers and other interdependent activities
- The wider consequences of damage and disruption for the supply chain

- The evolving position of financiers, investors and insurers[65]
- The growing focus on climate risk disclosure
- The requirements of, and for some the potential opportunities associated with, international and national climate-related targets, laws and policies.

The following sections of this Note provide high-level guidance to assist owners, operators and investors develop the scope of a business case. Other potentially relevant information is also signposted.

5.2 Understanding the Risks

Climate change brings risks to physical infrastructure and operations as well as to business continuity. These risks can impact on the effectiveness of an organisation's governance, its competitiveness, and its reputation. All of these have associated financial implications, and such risks can be cumulative.

Understanding exactly how climate change is likely to impact a port or waterway can be challenging. There have been improvements since 2014 when ports responding to the UNCTAD survey highlighted difficulties obtaining the information needed to assess risks and to design appropriate and cost-effective adaptation measures [UNCTAD, 2017 ; PIANC, 2023]. However, there are still some significant gaps, both in data and in climate literacy more generally [IPCC, 2022]. Even where data now exist, uncertainties may remain. Nonetheless, this Technical Note stresses the potentially significant costs and consequences of failing to take appropriate action (i.e. the costs of inaction). It also highlights the growing evidence of the benefits of taking early adaptation action.

Ports and waterways must therefore find a way forward, recognising and accommodating uncertainties [PIANC, 2022] and avoiding maladaptation (see definitions in Box 4).

Concept	Explanation
Maladaptation	Maladaptation refers to an action, or inaction, that leads to an increased risk of adverse climate-related outcomes such as increased vulnerability, increased greenhouse gas emissions, or diminished welfare. Maladaptation is usually an 'unintended consequence' [IPCC, 2022]. Examples include situations where: • an inadequate or inappropriate response to an expected change in a climate-related parameter results in the under- or over-design of an asset, culminating in a stranded asset or a wasted investment • an intervention leads to an increase in risk at another location; or • an inflexible solution (e.g. a design that cannot be modified if climate-related variables do not change in the projected manner) results in an increase in vulnerability or a reduction in physical or material well-being over time. Maladaptation may occur because a decision has not considered the wider system context, including spatial or temporal scale [PIANC, 2020a].

[65] As noted by UNEP (2023), it is not only engineering and design, but also insurance and lending practices, that are moving towards incorporating climate science into their benchmarks, requirements and guidelines.

Adaptation pathway	Adaptation pathways comprise alternative routes towards a defined objective, or broad directions of change for meeting different strategic outcomes. They may be centred around performance-thresholds or transformation objectives. Adaptation pathways set out sequences of actions (measures, modifications, investments, etc.) that can be implemented progressively, depending on how the future unfolds and on the development of knowledge [Brooke et al., 2024]. They are therefore particularly well-suited to climate change adaptation as their realisation is based on monitoring outcomes and reflexive learning [PIANC, 2022].

Box 4: Explanation of key concepts in effectively managing climate change uncertainties

As noted in Section 1.4, existing technical reports prepared by PIANC's Permanent Task Group on Climate Change already provide some sector-specific guidance to help identify information sources, manage uncertainties, increase confidence, and enable climate change preparedness. Specifically, the following reports preceded the publication of this Technical Note No.2:

- PIANC Task Group 3 (2023) reviews available data sources and provides an overview of climate change drivers and impacts of specific relevance to ports and inland waterways.
- PIANC Working Group 178 (2020a.) sets out technical guidance on the climate change adaptation planning process for ports and inland waterways.
- PIANC Technical Note No.1 (2022) supplements the WG 178 guidance by elaborating on the management of climate change uncertainties in selecting, designing, and evaluating options for resilient navigation infrastructure.

5.2.1 Risk Assessment as Part of the Adaptation Planning Process

To make the business case for investment in adaptation and resilience measures, it is first necessary to understand the risks associated with both slow-onset changes in relevant climate parameters and processes (see Figure 1), and potential increases in extreme event frequency or severity. To avoid missing possible less 'obvious' but sometimes very important risks (see Box 5 for example), a staged approach should be taken. Before beginning a risk assessment, it is good practice to undertake certain preparatory steps to define the context, and to identify and collate relevant climate data.

PIANC's WG 178 guidance describes a four-stage methodological framework covering:

1. **Preparatory activities**: setting goals and objectives; agreeing an acceptable level of risk and an adaptation planning horizon; preparing an inventory of critical/susceptible assets and operations; identifying interdependencies; engaging with stakeholders.
2. **Climate data**: collating baseline conditions and trends; gathering information on future climate scenarios; considering joint occurrences (such as high river discharges at the same time as a surge tide, or intense precipitation falling on a catchment already impacted by a prolonged drought). The PIANC Task Group 3 (2023) report can be referenced at this stage.
3. **Vulnerability and risk assessments**: assessing exposure, vulnerability and risks including potential cascading failures; confirming adaptive capacity; understanding *when* impacts might be expected to occur; confirming risk appetite/tolerance; stress-testing; ranking or prioritising risks.

4. **Option evaluation**: quantifying the consequences and associated costs of inaction; identifying, screening, and evaluating possible interventions; focusing on flexibility and adaptive solutions; preparing and implementing adaptation pathways (see Box 4) or adaptation strategies, and setting up monitoring and review processes.

The WG 178 guidance focuses on climate-proofing existing ports and waterways. It includes portfolios of generic and impact-specific climate change adaptation measures and presents several adaptation case studies.

Technical Note No.1 explores good practice for managing climate change uncertainties to reduce the risk of maladaptation, and to help avoid the paralysis that can otherwise blight adaptation decision making. Understanding and delivering strengthened resilience against extreme events, including the ability to withstand joint occurrences and cascading failures, is an important aspect of Technical Note No.1. Stress-testing (e.g. CIWEM (2023)) is another important tool in helping to understand uncertainties.

A comprehensive assessment of potential impacts and appropriate adaptation options will help a port or waterway understand which climate change parameters are most critical and thus to determine a course of action. It can also identify whether (and when) transformational as opposed to incremental change should be considered. Hanson and Nicholls (2020) explore the need to elevate or relocate ports due to sea level rise, but other climate-related factors may similarly determine the longer-term sustainability of an existing or planned new facility. More frequent extreme heat and drought leading to low flow in rivers may ultimately affect operational viability for some ports or waterways; increased flood risk may become an insurmountable problem for others [EDF, 2022].

Climate change-related risks can be assessed at the level of the facility or port as a single organisation; the port as a logistics platform including services provided by third parties (interdependencies); and/or the port as a nodal organisation within the supply chain serving the local or national economy and wider society [IAPH, 2023]. Multiple risks can be prioritised considering, among others, the costs and consequences of inaction; whether a reactive as opposed to proactive approach is acceptable to the organisation; and opportunity cost considerations [UNCTAD, 2022].

Looking further ahead, and at risks at the global scale, indirect social-economic effects induced by climate change (for example changes in areas of agricultural production, industrial activity, or population density) may become critical considerations for the future of certain ports.

Finally, and returning to the local level, while many of the examples in this Technical Note focus on reducing the risk of physical damage to port and waterway infrastructure, and associated disruption due to extreme weather conditions, Box 5 provides a reminder of how climate change can also result in other types of impact – including due to biological or chemical changes – with sometimes significant operational and economic consequences.

Some aquatic habitats have thermal barriers that limit the establishment of invasive alien species (IAS). As water temperatures increase, particularly in winter, due to climate change, IAS will be able to establish, thrive in, or expand their range into, habitats where conditions were not previously warm enough for them to survive or reproduce. More frequent or extreme storms or floods can also transport IAS to new areas.

Water hyacinth (*Eichhornia crassipes*) is an example of an invasive species that can cause problems for navigation when it is introduced or becomes established outside its native range. It forms a dense vegetation cover on the surface of tropical or sub-tropical freshwater bodies. Plant numbers can double in as little as 12 days. Where it is not subjected to extreme low winter water temperatures, water hyacinth can successfully overwinter and regenerate more vigorously the following spring. As a result, the species is expected to expand its range poleward as the climate warms [Price Tack et al., 2018].

Water hyacinth blocks waterways and limits boat traffic, affecting both fishing and trade, with potentially significant economic consequences. In Lake Victoria in Eastern Africa, for example, it can grow to such densities that ships are unable to leave docks [IUCN, 2021][66]. Management measures once the species is well-established can be prohibitively costly, so early action is important. Investment in preventative measures or early biosecurity responses to prevent a full-scale invasion is typically cost-beneficial.

(Photo: Jan Brooke, PIANC)

Box 5: Implications of warmer water temperatures for invasive alien species' establishment

A thorough review of the risks associated with possible future climates, the potential impacts of damage and disruption increasing over time, and the long-term viability of assets and operations as currently located, will enable port owners, operators and investors to plan ahead. Investment can then be targeted both to facilitate business continuity in the short to medium term, and to ensure long-term sustainability.

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[66] **https://www.iucn.org/resources/issues-brief/invasive-alien-species-and-climate-change**

5.3 Recognising and Quantifying the Consequences of Inaction

Whatever the scale of the assessment, failing to act to address climate change-related risks has the potential to incur significant costs or lead to substantial financial or economic losses. Figure 6 summarises the types of costs and losses that may be incurred, and which may therefore need to be considered in a business case assessment. It also acknowledges that adaptation may bring opportunities beyond simply avoiding such losses.

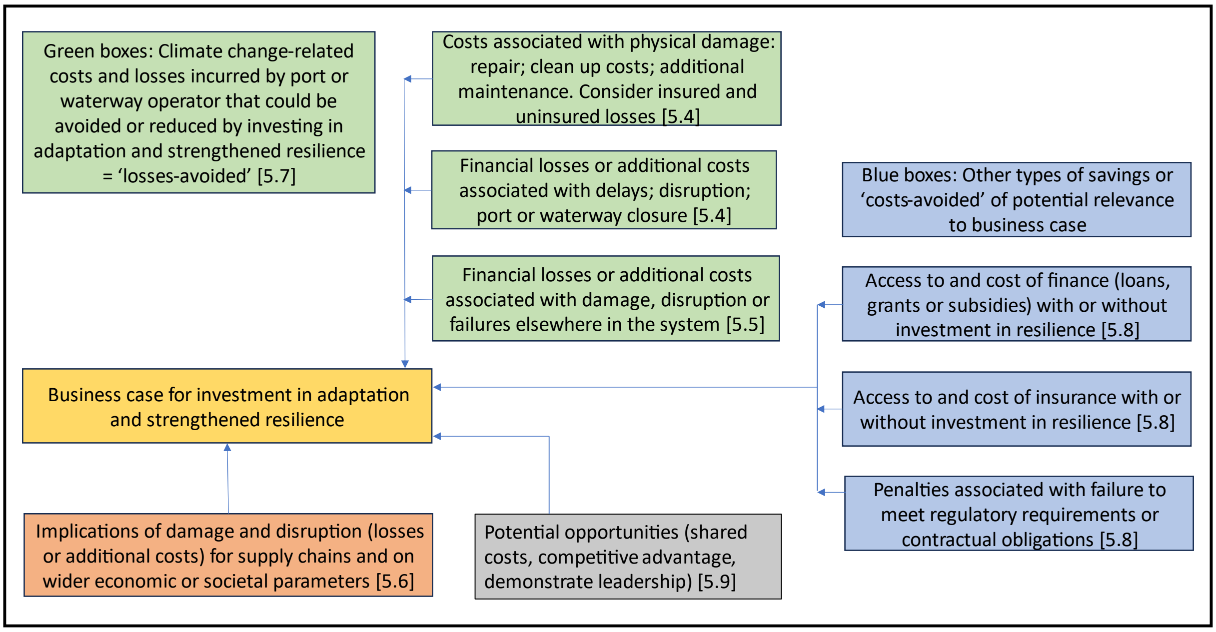


Figure 6: Scoping the business case assessment for investment in adaptation and resilience

Figure 6 illustrates how, in addition to potential direct and indirect costs and losses due to damage or disruption associated with events of different characteristics or magnitudes (elaborated in Section 5.4), interdependencies should also be considered. The following may be relevant in this regard:

- potential disruption or failures elsewhere in the system, affecting the services or activities provided by others, but *on which effective operation of the port or waterway depends* – for example, power or water supply, other transport modes, telecommunications (see Section 5.5)
- wider economic and societal activities that *depend on the effective operation of the port or waterway*, particularly supply chains (Section 5.6).

For some port and waterway operators, investment in adaptation and resilience measures may lead to other types of cost saving (see Section 5.8), or there may be financial, economic, or other opportunities that can be exploited (discussed in Section 5.9).

The remainder of Section 5 elaborates on each box from Figure 6. As acknowledged elsewhere in this Technical Note, a particular organisation's ownership, management, and governance model will ultimately determine which of these considerations are relevant.

5.4 Consequences of Inaction at Port or Facility Level

Port and waterway operations should be able to accommodate slow onset changes in sea level, air and water temperature and seasonal precipitation. They also need to be resilient to atypical conditions or to changes in extreme conditions. Failing to strengthen resilience to absorb effects and recover rapidly following such an event, could result in costs and consequences of the type discussed in Sections 2 and 4.

Where a port or waterway already has experience of an extreme weather event(s), data on the type of costs and losses incurred may already exist. PIANC's climate change adaptation planning guidance (2020) stresses the importance of recording information about weather-related disruption including clean-up, damage repair and additional maintenance costs; the duration of any closures or other operational delays or downtime; and the financial impacts of disruption. This breadth of data is important. If insurance claims (only) are used to help understand the cost of a previous extreme weather event, this is likely to result in a significant under-estimation. Uninsured losses can be substantial but such costs (for example associated with clean-up, local damage repair, emergency supplies, staff time including overtime and temporary labour, and legal fees) tend to be 'hidden' in maintenance and other budgets.

An investigation by the European Environment Agency[66B] covering the period 1980-2022 concluded that, overall, less than 20% of total losses associated with climate-related extreme events were insured. While there was significant variation between countries, in half of the 32 countries surveyed the insured proportion comprised less than 8% of total losses. This is consistent with earlier work in the UK by the Health and Safety Executive (HSE, 1997), who reported that for every £1 (GBP) of insured costs, accidents in the workplace resulted in uninsured losses of between £8 and £36.

The Inter-American Development Bank [IDB Invest, 2021(b)] explores potential evaluation indicators and highlights examples of how the knowledge gained through monitoring and record keeping can be used to understand and quantify the consequences of not acting.

IDB Invest suggest that useful indicators to inform an evaluation can include:

- Number of operational days and associated revenue lost due to (e.g. storm- or extreme heat-related) physical or structural damage; associated expenditure required for repair or replacement
- Number of operational days and associated revenue lost due to disruptions to port access, for example associated with extreme wave or wind conditions; extreme rainfall-related flooding of road/rail networks; or high (or low) flow rates impacting navigational safety or viability on inland waterways
- Number of days with extreme-heat-related constraints on port activity, and hence hours or days of lost revenue due to reduced productivity
- Area of port lost to coastal erosion per year; cost of land claim or land purchase required to retain the status quo
- Area of ecosystem (marsh, mangrove, reef) that acts as a natural storm-protection buffer lost or degraded per year due to climate-related sea level rise, more intense storms, acidification, etc.; cost of replacing this function (and other associated functions that could be affected) with suitable hard or soft infrastructure.

[66B] https://www.eea.europa.eu/en/analysis/indicators/economic-losses-from-climate-related

- Reduction in annual fish catch as water temperature warms and associated loss of revenue; ultimately the financial consequences of the loss of the industry and attracting replacement user groups to the port.

The Central Commission for Navigation on the Rhine's Reflection Paper 'Act Now!' [CCNR, 2021] highlights how these types of impact can also lead to additional logistics losses to terminal operators and port industries, and to carriers, and shippers. The CCNR paper concludes that the consequences of extreme low water affect shippers through lost revenue due to constraints on cargo-carrying capacity and reduced volumes transported, and customers via increased freight rates, as well as port or terminal-related losses. There are also knock-on effects on industrial production and disruption of the logistics chain (see Section 5.5).

5.4.1 Quantifying the Financial Risk

Modelling by Verschuur et al. (2023) assesses the risks to port operations and infrastructure exposed to damages and disruptions from a multitude of extremes and natural hazards. Globally, the authors suggest that more than 86% of ports are exposed to three or more natural hazards. Their model identifies the dominant hazard and expresses the relative risk in terms of the spatial footprint. There is more detail in their paper, but Table 5 provides an overview of their modelling outcomes presented in terms of the risk per square metre of port area. These risks to port infrastructure and operations are largely driven by cyclone wind, and flooding (fluvial, coastal and extreme rainfall-associated).

World Bank Income Classification	Relative risk per square metre of port area	
Ports in high-income countries	US$ 123.4	(US$ 55.7-US$ 379.5)
Ports in upper-middle-income countries	US$ 118.4	(US$ 53.3-US$ 404.7)
Ports in lower-middle income countries	US$ 155.5	(US$ 87.4-US$ 377.6)
Ports in low-income countries	US$ 117.7	(US$ 45.7-US$ 312.1)

Table 5: Relative risk of extremes and natural hazards per square metre of port area

Verschuur et al. conclude that out of 1340 ports studied, 160 face a risk of more than US$ 10 million per year, while 21 ports face a risk of more than US$ 50 million per year. The highest absolute risks are faced by ports in high income countries where there are extensive port areas and high infrastructure densities. However, the relative risk in terms of port area is highest for smaller ports in low- and middle-income countries given the typically lower protection standards as well as lower port elevations and the greatest potential for systemic impacts on economic growth. This latter conclusion is in line with the survey findings described in Section 2.1 and Appendix 1, i.e. that even relatively small damage or disruption costs can impact disproportionately on small ports or those in developing countries.

Where port-specific data on damage or disruption costs are not available to help inform decisions on investment in resilience measures, the potential order-of-magnitude financial consequences of inaction can be estimated based on generic analyses such as that carried out by Verschuur et al., along with information from surveys of the type discussed in Section 2. Avoiding these damage and disruption consequences is a key benefit of investment in strengthened resilience.

Other tools are also available. While not specific to climate impacts, the Ports Resilience Index[67] provides a useful resource for ports interested in understanding their vulnerabilities and the potential consequences of not acting to strengthen resilience. This self-assessment tool serves as a simple and inexpensive method of understanding if ports and the marine transportation sector are sufficiently prepared to maintain operations during and after disasters. The tool is intended for application in the USA, but many of the principles it embodies and the questions it asks are directly or conceptually relevant to ports globally. The results from the tool help the user to pinpoint areas where their organisation may be exposed to (unacceptable) risks, in turn providing evidence to assist in justifying expenditure, or negotiating concessions to enable investment.

5.5 Consequences of Inaction at System Level

Ports and waterways operate within a system of systems. Attention therefore also needs to be paid to the potential consequences if service and utility providers, and other organisations on which the effective operation of the port or waterway depends, are vulnerable to damage or disruption and fail to respond to the increased risks associated with the changing climate.

Figure 7, taken from an assessment of the impacts of extreme weather on the Port of Rotterdam in the Netherlands, illustrates the extent to which port activities and operations are interlinked with, or interdependent on, a range of services and utilities including energy, water, and telecommunications/data.

Figure 8 demonstrates how a failure in one or more such services can cascade through interconnected infrastructure systems, with direct and indirect impacts on other services, operations, and organisations. This Figure depicts a multi-hazard rainfall event associated with Storm Desmond in North-West England in 2015 [Ferranti et al, 2017]. It does not show any direct impacts on a specific port, but the brown boxes highlight how flooding impacted on motorways, roads, bridges, and, due to the failure of the electric sub-station, on the rail system. These are all effects with the potential for knock-on effects on port operations.

[67] **https://toolkit.climate.gov/tool/ports-resilience-index**

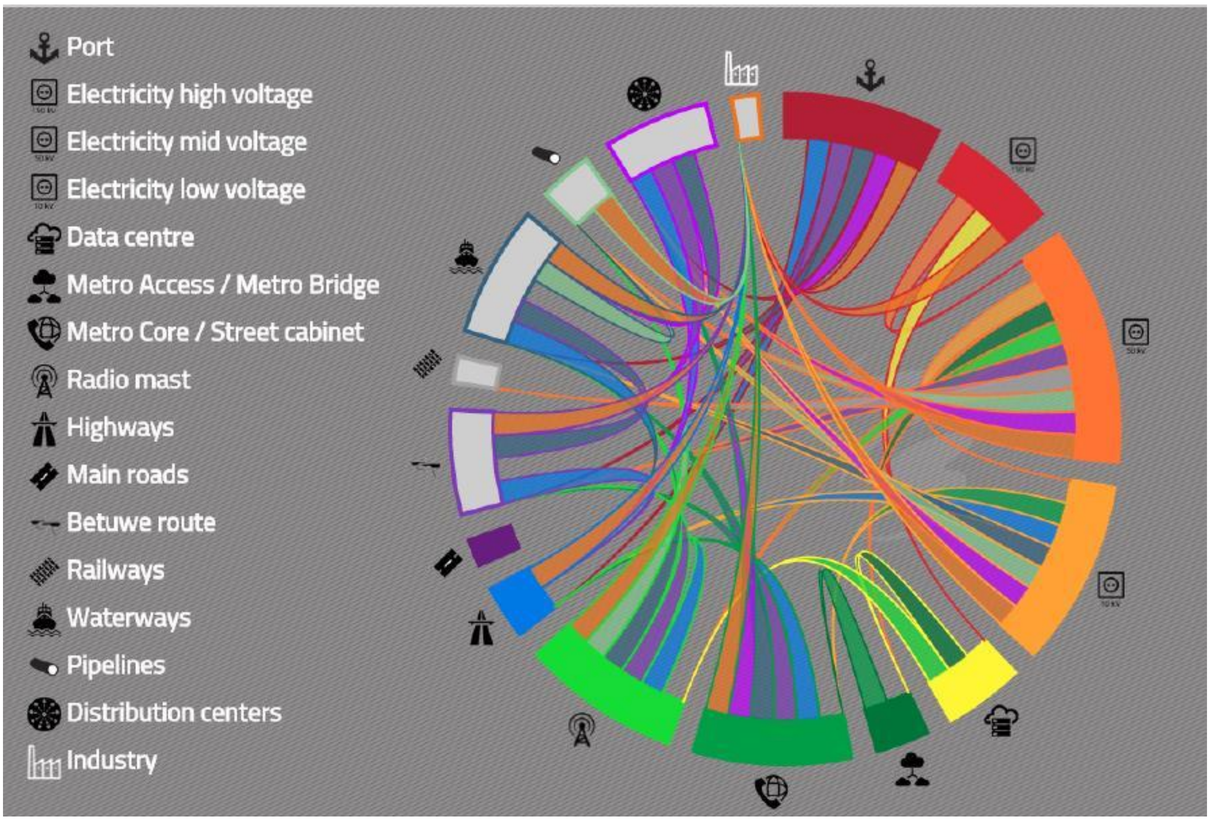


Figure 7: Port of Rotterdam interlinkages between port operations and various services and utilities[68]

[68] **https://www.deltares.nl/app/uploads/2015/04/PB_Impact-of-Extreme-Weather-on-the-Port-of-Rotterdam.pdf**. Created using Circle-Critical Infrastructures: Relations and Consequences for Life and Environment – a tool to support the analysis of domino effects of critical infrastructures. See **https://circle.deltares.org/.**

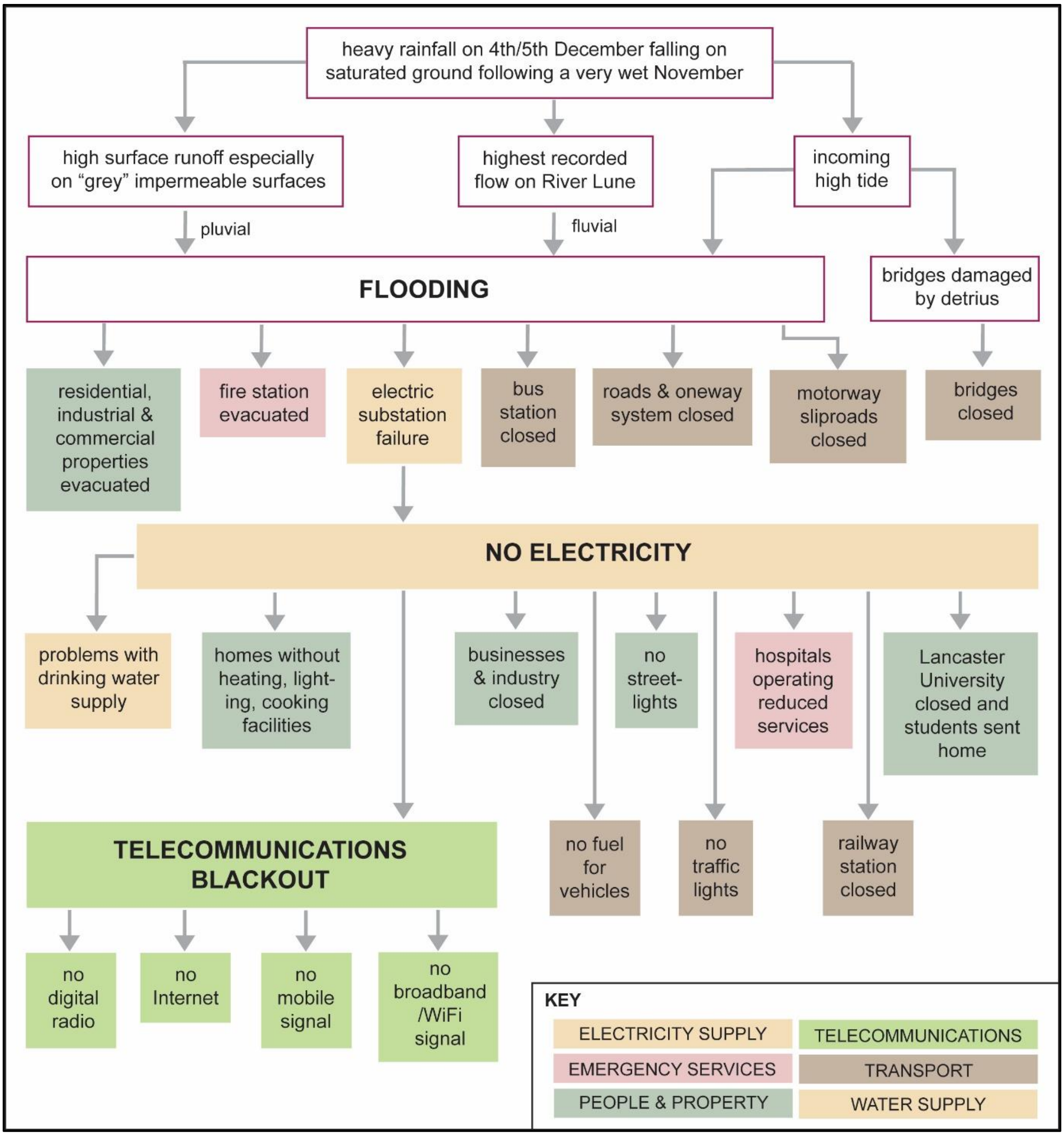
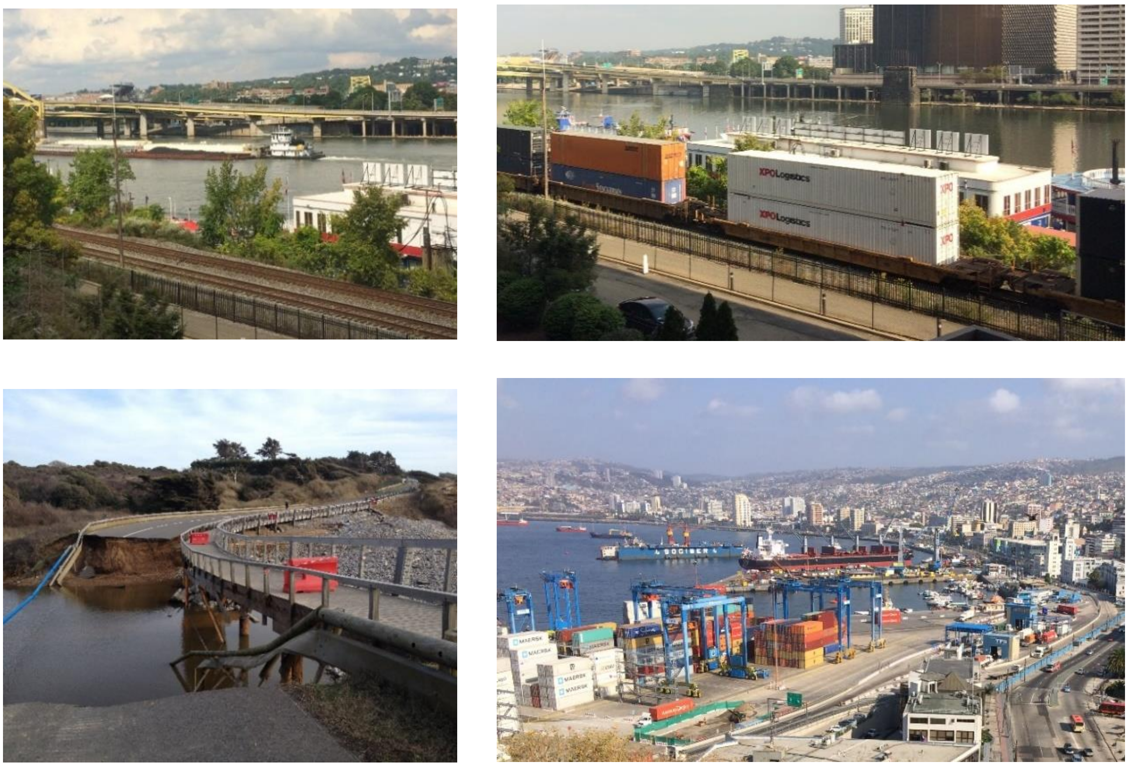


Figure 8: Cascading failures through Lancaster's interconnected infrastructure systems following Storm Desmond in 2015

The economic consequences of cascading failures can be significant. WSP (2020) conclude that the costs of indirect or cascading impacts are between 1.3 and 3 times those of the direct impacts of infrastructure failures, depending on the approaches and models used, and the range of assumptions in the models. The same study, which is based on a partial analysis of infrastructure risks, estimates that by 2050 under a 4°C temperature increase scenario, cascading risk costs will be 5 to 6 times higher than the current baseline.

Most ports are nodes in wider transportation networks. The resilience of other transport modes will therefore be a critical operational concern. A port is only as resilient as its onward transport system, particularly in the immediate vicinity where alternative routes may not be available. Adverse impacts on ground transport networks not only adversely affect freight entering or leaving the port, but also passenger and workforce access.



Photos 5-8: Most ports are only as resilient as their onward transportation systems (Photos: Jan Brooke)

The potential consequences of inaction at this interconnected system level can be understood by referring to both past experiences and future projections. Extreme low water levels on the Paraguay-Paraná waterway in Argentina in 2020, led to a shift in transport of corn from water to road. This necessitated thousands of additional truck movements every day, significantly increasing both transport costs and carbon emissions; impacting on road safety due to additional congestion and disruption; and leading to the further deterioration of already poor road surfaces with considerable maintenance cost implications[69].

For inland waterways, more frequent low water events may also bring the risk of:

- Reverse modal shift [CCNR, 2021], with associated increases in greenhouse gas emissions if – as was the case with the Paraguay Paraná waterway – freight is transferred to truck transport and/or
- Reputational damage if there is a perceived lack of reliability

Road and rail are similarly susceptible to climate change impacts and extreme weather-related damage and disruption. ENDS Europe (26 May 2023) for example, report that in France, where rail is being promoted as a relatively climate-friendly mode of transport, the sector faces significant challenges due to increasingly frequent and prolonged heatwaves. Extreme heat is causing tracks to buckle, power cables to collapse, and railway infrastructure such as signal boxes that rely on electronic components, to malfunction. Mulholland and Feyen (2021) highlight how extreme heat affects roads via melting and rutting. They identify that road pavement standards in some European countries will need to be updated to deal with heat effects. Their risk assessment of the impacts of $2^{\circ}C$ and $4^{\circ}C$ global warming scenarios, indicates that extreme heat in Europe will result in increases in annual road/rail transport operation and

[69] https://www.maritimeuk.org/imh-2021/imh-events/practical-climate-change-adaptation-challenges-and-good-practice-solutions-ports/

maintenance costs of € 1.3 and € 4.8 billion, respectively, with the latter (i.e. 4◦C) corresponding to a rise of around 7 % in the context of 2020 values.

Globally, transport infrastructure in most countries will face equivalent challenges. Hazards include floods and landslides, extreme heat and wildfires, desiccation, melting permafrost, coastal erosion, and many other changes.

5.5.1 Understanding System-Level Risks

Mapping the types of inter-relationships illustrated on Figures 7 and 8 enables interdependencies to be identified to determine whether and how effects on one part of the network or system could detrimentally affect port- or waterway-related activities. The economic, social, and environmental consequences of not acting can therefore be explored and, where practical, quantified. In line with the approach promoted by IDB Invest (2021b.) (see Section 5.4) revenue losses might be used as proxy for any constraints or disruption that result from inaction on the part of the service provider.

For some ports and waterways, taking a cross-sectoral approach to assessing risks and ensuring resilience will be appropriate, even essential. The sustainability of future port operations may depend on adaptation investment being made by other organisations. Without relevant engagement, the total cost of adaptation to the port or waterway operator may increase (e.g. due to a need to invest in back-up provisions to cover a possible third-party failure). Collaborating with other organisations in the logistics chain can therefore facilitate the development of integrated solutions that provide the best return on the investment, in turn helping to secure finance. The development of adaptation strategies under the Port of Rotterdam Flood Risk Management Programme, for example, involved close cooperation between a large number of companies and stakeholders, and culminated in a solution that ensures the port can cope with floods up to 2100, in an adaptive and flexible way[70].

Mapping system-level interdependencies and engaging in discussions with third party operators may also identify a situation where those responsible for maintaining access or otherwise providing the port with critical services or utilities are unable (perhaps because of physical constraints or for financial reasons) to take the action needed to strengthen resilience or adapt. Such a finding could have existential consequences for the affected facility or port.

If it is technically or economically infeasible to ensure resilient road or rail access in the future, this may influence decisions on whether and what type of adaptation action should be taken by the port. Depending on the details of the situation, a decision may therefore be made to invest only in short-term, incremental adaptation measures until the situation is resolved, or the port may decide to develop a new or alternative access route itself. In some cases, however, this realisation may be the trigger for a transformational change involving a decision to relocate a particular facility or even the port itself.

The amount of effort put into mapping system-level inter-dependencies and inter-relationships should be proportionate to the risk involved. In some situations, the exercise may be as simple as preparing a flowchart. In others, it may be necessary to undertake detailed and comprehensive evaluations to achieve the necessary understanding of risks and consequences.

[70] https://sustainableworldports.org/project/port-of-rotterdam-flood-risk-management-programme/

The CEN-Workshop Agreement 'Guidelines for the assessment of resilience of transport infrastructure to potentially disruptive events' [CEN-CENELEC, 2021][71] provides some guidance to help infrastructure managers develop a complete and systematic understanding and measurement of resilience. The guidelines use simulations, differentiated weights, or indicators with equal weights to help identify suitable resilience-enhancing interventions. While these guidelines focus on road and rail, much of what is presented is equally relevant to waterborne transport infrastructure and operations.

Other potentially useful publications in this regard include:

- PIANC's TG 193 publication 'Resilience of the maritime and inland waterborne transport system' (2020b), which highlights best practices and describes a series of decision support tools in relation to short-term, episodic natural and human-related occurrences and the long-term evolution of these stressors. This publication covers stressors affecting resilience both within and beyond the boundaries of maritime and inland waterborne transportation systems.
- A paper by Cradock-Henry, et al. (2020), which describes a systems-based methodology to identify and evaluate cascading climate change impacts and implications.
- The outcomes of the European research project Future Proofing Strategies for Resilient Transport Networks against Extreme Events (Foresee)[72], through which stress-testing methodologies are also being developed.
- A transferable methodology developed by UNCTAD (2018b) as part of a technical assistance project[73] with a focus on ports and airports in Small Island Developing States.

5.6 Consequences of Inaction for Supply Chains and Wider Economic and Societal Wellbeing

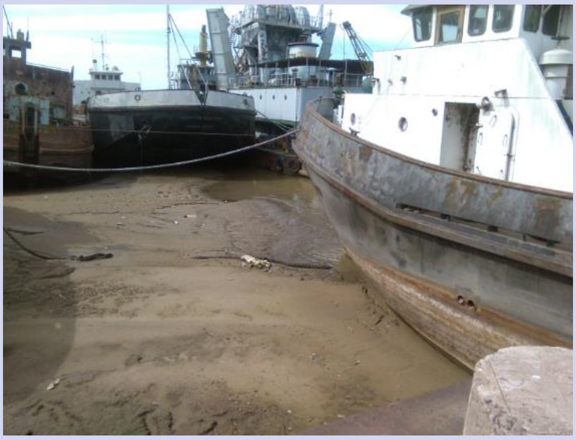
Avoiding losses is a key motivator for action, but there are also other important economic, social, and environmental benefits associated with adaptation [WRI and GCA, 2019]. For some port and waterway owners and operators, it will be relevant to understand, and where practicable quantify, potential extreme weather impacts on supply chains or on wider socio-economic parameters. The COVID-19 pandemic exposed some of the global consequences of supply chain disruption, highlighting raw material shortages, lead time issues, blank sailings, port closures, reduced working hours, equipment or labour shortages, and transport capacity issues [UNCTAD, 2022], as well as important implications for the performance of commercial contracts[74]. So, too, did the 2021 blockage of the Suez Canal by the fully laden *Evergiven* 20,000 TEU container ship in 2021 [I Markit, 2021]. The latter incident led to an estimated US$ 9.6 billion in value of goods being delayed each day[75].

Table 2 and Section 4.3 present several examples of extreme weather events that disrupted transportation systems with significant economic implications globally as well as locally, via both direct and indirect supply chain impacts. Such impacts, which have been modelled and discussed by a growing number of researchers [Verschuur et al., 2020 ; Becker et al., 2018 ; EDF, 2022] do not only affect commerce. They can also have significant adverse political and societal consequences, including affecting food or energy security.

[71] https://standards.cencenelec.eu/dyn/www/f?p=CEN:110:0::::FSP_PROJECT,FSP_ORG_ID:73410,2857081&cs=1508DFABC85E9CE013EC84D5FAD8E9E12
[72] https://foreseeproject.eu/
[73] https://SIDSport-ClimateAdapt.unctad.org
[74] See several analytical reports and training materials prepared by UNCTAD as part of its COVID-19 response, available at https://unttc.org/stream/key-international-commercial-law-implications.
[75] https://www.forbes.com/sites/palashghosh/2021/03/25/experts-estimate-ship-stuck-in-suez-is-blocking-96-billion-in-maritime-traffic-each-dayheres-why-actual-losses-are-harder-to-quantify/?sh=3808d998c944

A port or waterway operator may instinctively see itself only in a very narrow way, as a business, landowner, or trade connector [UN Global Compact, 2023]. But this perception may overlook the port or waterway's strategic, even national, economic importance, for example because of its location or the type of cargo it handles. As illustrated by the issues experienced on the Paraguay Paraná waterway in Argentina in 2020 (Box 6), a lack of preparedness can lead to a trade imbalance with macro-economic implications at national level. It is also the case that certain ports have a role in connecting supply chains across countries. Verschuur et al. (2022) point out how a wider perspective can be vital both to making the business case for investment in climate change adaptation, and in securing finance for the required interventions.

Upper Paraná River km 852



Port of Rosario in Santa Fe province

In 2020, a lack of available depth due to drought led to vessels operating with 50% or less of their cargo on the Paraná waterway, Argentina[76]. Waterborne freight had to be transferred to truck during this event, with significant impacts for the affected agricultural products' supply chains. Argentina relies on the Paraguay-Paraná Waterway (PPW) to export 80 % of its agricultural products, so the low water levels impacted heavily on an important source of income for the country [Naumann et al., 2022]. Further afield, the drought-induced transportation issues on the PPW also had implications for the United States and China, who both buy the region's commodities in bulk[77].

(Photos: Leonel Temer, Dragados y Balizamientos, Argentina)

Box 6: Extreme low water levels on the Paraná waterway, Argentina, in 2020

Verschuur et al (2022) present the results of a modelling framework that aims to improve understanding of the different dimensions of ports' criticality for domestic and global economies that are not currently captured in aggregate port-level trade statistics. The application of their Oxford Maritime Transport model concludes that the top five macro-critical ports handle goods contributing more than 1.4 % to the global economy. 40 other domestically-critical ports handle goods representing more than 10 % of the value of the domestic economy they serve. The modelling also confirms that low-income countries and

[76] https://www.reuters.com/business/cop/mighty-river-muddy-trickle-south-americas-parana-rings-climate-alarm-2021-10-27/
[77] https://saisreview.sais.jhu.edu/integration-meets-insecurity-how-paraguay-is-shaping-south-americas-center/

small island developing states (SIDS) rely disproportionately on maritime trade, with maritime import fractions being 1.5 to 2.0 times higher than the global average.

Avoiding or reducing supply chain implications will therefore be a critical consideration for some ports and waterways. Developing the necessary understanding and then quantifying the port or waterway's role in connecting inter-country as well as national supply chains may be challenging. However, this analysis could constitute a vital part of the business case to secure finance for adaptation in situations where – as in Argentina – port or waterway resilience is imperative for the national economy a particular supply chain supports [UNCTAD, 2022].

Finally, it should be recognised that societal as well as economic wellbeing often depends on the resilience of transport infrastructure. Investment in climate-resilient ports and waterways can generate benefits (opportunities) for related sectors such as shipping, offshore renewables, fishing, tourism, recreation, and other components of the blue economy. Acknowledging and where possible quantifying such benefits may help to justify investment in resilience. It may also highlight opportunities to share costs. These linkages should be highlighted when the case for investment is being made.

5.7 Additional Costs, Benefits and Opportunities

For some port and waterway operators, in addition to damage and disruption costs or losses avoided, there may be other quantifiable cost savings or benefits associated with adaptation action (see Sections 4.4 to 4.8). In particular, the following may be relevant to include in the business case as potential savings or additional costs:

- The organisation's ability or inability to access (sustainable) finance including loans, grants, or subsidies on attractive terms.
- The organisation's ability or inability to access (affordable) insurance.
- The consequences of compliance or non-compliance with relevant regulators' requirements or with conditions of contract, etc.

For other ports or waterways, managing reputational risks or creating brand enhancement opportunities may also be material (and quantifiable) considerations. Contribution to their country's NDCs may similarly be relevant or even necessary.

Climate change is a shared problem. Engaging with a range of internal and external stakeholders including those identified as being at potential risk of the same (adverse) indirect or cascading impacts, can lead to the identification of shared solutions. Shared solutions can also mean opportunities to share costs. As discussed in Section 5.5, integrated solutions often provide the best return on investment.

Embarking on the process of adaptation planning, strengthening climate change preparedness, limiting exposure, and developing and delivering climate-resilience strategies can bring various other opportunities, including:

- Aligning with the sustainability and climate criteria set by financial institutions, leveraging (additional) finance.
- Demonstrating ambition; exploiting new, or consolidating existing, business opportunities once resilience can be demonstrated; greater competitiveness; reputational gains [IDB Invest, 2021b. ; UNCTAD, 2022].
- Showcasing (corporate) leadership; delivering on Corporate and Social Responsibility (CSR) objectives or Environmental and Social Governance (ESG) standards; contributing to the UN Sustainable Development Goals.

In cases where potentially significant benefits of adaptation or strengthened resilience prove more difficult to monetise, care should be taken to select appropriate assessment methods (i.e. to ensure that important benefits are properly recognised in the evaluation process) [PIANC, 2020a ; PIANC, 2022].

5.8 Quantifying the Benefits of Adaptation

By reducing risk, adaptation action delivers multiple benefits, the so-called 'triple dividend'. It avoids economic losses; brings positive gains through risk-reduction, safeguarding investment and enabling increased productivity; and delivers additional social and environmental benefits [WRI and GCA, 2019].

But justifying investment in adaptation interventions is not always easy. In accounting, it can be hard to value what has been 'avoided'[78]. Flood protection practitioners are familiar with the concept of damage-costs-avoided: the principle has been applied for many decades to justify improvements in flood defences. But other sectors, including transportation, are not yet familiar with either the concept of valuing losses-avoided, or the triple dividend benefits principle.

Recent published work that places values on the benefits of adaptation is therefore vital in providing examples that illustrate the adaptation business case.

The World Bank reports that the extra cost of building resilience into infrastructure systems (including transport) in low- and middle-income countries typically represents around 3 % of overall investment requirements [Hallegatte et al., 2019]. In return, reduced disruption and reduced economic impacts yield a benefit of US$ 4 for each dollar invested in resilience.

The World Resources Institute and the Global Center on Adaptation (GCA) (in WRI and GCA (2019)) similarly illustrate the broad economic case for investment in a range of adaptation approaches. They highlight potential benefit to cost ratios by 2030 of between 5:1 and more than 12:1 for strengthened early warning systems, and between 2:1 and 8:1 for strengthening the resilience of new infrastructure. Actual returns will depend on many factors (such as economic growth and demand, policy context, institutional capacities, and the condition of assets) but the headline message is that the rate of return on investments in improved resilience is very high. Indeed, the GCA concludes that early adaptation action 'is in our strong economic self-interest'.

Box 7 provides a summary of the risk and opportunity assessment carried out for the United Kingdom's Climate Change Committee to inform priorities for the government's National Adaptation Programme. This assessment [Watkiss et al., 2021] confirmed that many early adaptation investments deliver high value for money. Benefit to cost ratios ranging from 2:1 to 10:1 demonstrate that substantial net economic benefits can be achieved (see also Figure 5). Significant co-benefits were also identified by the assessment. The conclusions of this assessment highlighted in Box 7 are all of relevance to making the business case for climate change adaptation action by the ports and waterways sector.

[78] **https://www.goldstandard.org/blog-item/business-case-climate-adaptation-why-it%E2%80%99s-profitable-investment**

National case study: United Kingdom. Monetary Valuation of Risks and Opportunities in CCRA3. Report to the Climate Change Committee as part of the UK Climate Change Risk Assessment 3

The UK's Climate Change Risk Assessment (CCRA) programme aims to analyse the risks and opportunities associated with the changing climate. Its purpose is to inform priorities for the UK Government's National Adaptation Programme. As part of the UK's third cycle of assessment (CCRA3), analyses were undertaken of the monetary valuation of risks and opportunities as well as of the indicative costs and benefits of adaptation.

The use of monetary values facilitated understanding of the relative importance of different climate change risks using a common metric (UKP £). It also enabled comparisons of direct impacts within and between sectors. The analyses explored costs and benefits that have direct implications for the economy, and those that do not involve market prices. For the valuation in CCRA3, indicative estimates of monetary values were generated for each risk and opportunity as far as possible, and applied to the 2°C and 4°C temperature increase pathways (globally, relative to pre-industrial), by mid-century and the end of the century. Infrastructure, including transport infrastructure, was included in these analyses.

As is typical with this sort of project, the outcomes contain many provisos including with regard to uncertainty and levels of confidence. Nonetheless many of the general findings are relevant to the transport sector. With regard to the largest **risks and opportunities**, the report concludes that a significant number of known climate threats will have very high (aggregate) economic costs (£ billions/year) in the UK, even as soon as 2050. Among these are river and surface water flooding of businesses and infrastructure, and the impacts of sea-level rise, coastal flooding and storm-surge on the same receptors. Extreme heat impacts on health and wellbeing, and overheating in the built environment will also have high economic costs.

As well as concluding that such impacts will result in large potential costs to business and industry, the report confirms that evidence on these costs has increased in recent years in part because of the growth of climate related financial disclosures (see Section 4.6 of this Technical Note). The report finds that the largest risks in the UK are associated with floods. In addition, indirect risks from extreme events; cascading risks (to infrastructure); and supply chain risks (business) will all potentially incur very high economic costs.

Another key finding of the assessment was that there is a step change in the economic costs of climate change in the UK for a 4°C versus a 2°C future. This re-emphasises the importance of continuing to invest in decarbonisation while also preparing to adapt.

The monetary valuation study in CCRA3 included an evidence review of the **costs and benefits of adaptation action** for all individual risks and opportunities. The findings of this aspect of the report are partial, and therefore indicative. Transferring the results of existing cost-benefit studies of adaptation can be challenging because these tend to be site- and context-specific, and some have high levels of uncertainty. Nonetheless, the review found an increased body of evidence, particularly since previous CCRAs, and identified potentially high economic benefits from further adaptation for many of the CCRA3 risks and opportunities. It confirmed that many early adaptation investments deliver high value for money, including several no- or low-regret[79] 'quick-wins'. Benefit-cost ratios typically range from 2:1 to 10:1 – i.e. every £ 1 invested in adaptation potentially results in £ 2 to £ 10 in net economic benefits (refer to Figure 5 in this Technical Note) and important co-benefits are also highlighted.

As well as reducing potential losses from climate change, adaptation can generate direct economic gains, or result in social or environmental benefits. Overall, the review identified net benefits from taking further adaptation action for almost every risk assessed.

Finally, the report highlights the significant benefits associated with acting early. Delaying adaptation action will make it much harder to tackle future climate risks and may make large future costs inevitable.

There are three key areas where the report concludes early action is well-justified in economic terms:

- Reducing the risks associated with increasingly frequent extreme events through **low- and no-regret actions** which have high benefit to cost ratios.
- Taking early action to avoid locking new infrastructure in to very large future costs. The design life of new infrastructure means assets built over the next five years will operate under a very different climate to today. If future risks are not considered, climate change will cause asset damage or failure, and affect operating costs and/or revenues. **Designing infrastructure to be climate resilient** when it is built is shown by Hallegatte et al. (2019) to have a benefit to cost ratio of around 4:1.
- Maximising **some very low-cost preparatory actions** that can be taken to improve future decisions, effectively providing option values. Specifically, adaptive management plans should be developed for decisions that have long lead times or involve major future change in the future that is uncertain.

[Watkiss et al., 2021]

Box 7: UK Case Study, Monetary Valuation of Climate Change-related Risks and Opportunities

5.8.1 Measuring Adaptation Success

Unlike investment in climate change mitigation where progress can be measured through reductions in carbon emissions, there is currently no widely-agreed or standard way to 'measure' adaptation success. Furthermore, adaptation is primarily a place-based and typically local activity. Developing standardised approaches to provide a basis for credible calculation of avoided-losses can help to overcome some of these difficulties, in turn providing more clarity for both funders and investors.

For road networks, the EU-funded ICARUS project [ICARUS, 2023] produced a guideline for National Road Administrations on using performance metrics (Key Performance Indicators, KPIs) to make the case for adaptation. This approach includes an assessment of the effects of climate hazards on road performance via an analysis of trends in KPIs, and their correlation with climate threats. Furthermore, the guideline recognises that climate change adaptation measures for roads, like those for ports, often yield co-benefits that extend beyond their primary benefits, positively impacting multiple sectors and stakeholders or society. The ICARUS project

[79] Options that generate net economic and/or social benefits irrespective of (rates of) climate change.

output stresses that understanding and valuing these co-benefits is important in maximising adaptation efficiency and effectiveness.

The application of valuation methods, including monetary methods, will typically be associated with some uncertainty. The trade-off between the necessary level of detail and the required resources will always need to be considered carefully. It is therefore recommended that an organisation should give most scrutiny to the type(s) of benefits that are likely to have the greatest influence on decision making [ICARUS, 2023].

Such knowledge about the respective costs and benefits of investment in adaptation action is also important in the event that the benefits of taking adaptive action do not justify the costs. If this is the case, the organisation can make decisions accordingly, knowing the risks that need to be accepted and determining how to deal with the anticipated consequences and costs that result from the changing climate [Defra, 2020].

Assessing Costs and Benefits

The losses-avoided principle or replacement or substitute cost approaches are among the methods that may be used to quantify potential benefits in the light of future changes, including against the assessed probability of events of differing frequency and severity. A scenario-based approach, such as that recommended in PIANC (2022), can be used to understand the potential risks associated with changes in relevant climate-related conditions or with extreme events of differing magnitudes. Quantifying or estimating benefits in this way supports an informed financial or economic assessment.

Methods such as cost-benefit assessment (CBA) or cost effectiveness analysis (CEA)[80], or multi-criteria analysis/robust decision-making or similar methods that explicitly deal with uncertainty, can then be used to facilitate the comparison of adaptation costs to the estimated damage costs and revenue losses-avoided as well as to other costs or savings.

Co-benefits can also be realised, particularly if no-regret or win-win solutions are implemented, or if shared-cost solutions can be identified. For example, introducing engineered or operational flexibility and redundancy to improve climate-resilience may also strengthen a port's ability to cope with other types of threat (e.g. cybersecurity, pandemic). Where monetisation or quantification of a benefit(s) is difficult, methods such as multi-criteria analysis may be preferred, or a qualitative statement may be sufficient to ensure the benefit is acknowledged.

Guidance on methods that can be used to assess and compare the costs and benefits of adaptation investment is still evolving. The ECONADAPT[81] EU-funded research project aimed to build on the knowledge base of the economics of adaptation to climate change to produce a series of practical resources enabling decision makers to support adaptation planning across the European Union. A national level example is provided by the UK publication 'Accounting for the Effects of Climate Change: Supplementary Green Book Guidance' [Defra, 2020]. This develops the conventional Green Book appraisal methodology for UK Government expenditure [HM Treasury, 2022] to account for the effects of climate change when appraising options.

It is usually recommended that some form of cost-benefit assessment be undertaken [Defra, 2020] but a light-touch appraisal using one of the following methods can help incorporate

[80] CBA and CEA can be combined with sensitivity testing and probabilistic modelling, but do not explicitly deal with uncertainty (Defra, 2020)

[81] See **https://econadapt.eu/resources.html**

uncertainty. Real options analysis, robust decision making, portfolio analysis, and iterative risk management methods are useful in this regard. Furthermore, methods that focus on the value (e.g. of resilience) are often more useful in this situation than those which seek only to identify the lowest cost option.

Whenever an analysis is being undertaken, the method selected should be proportionate to the level of risk, and appropriate to the nature of the benefits being assessed. There will therefore be situations in which it is prudent to seek expert advice.

6 OVERVIEW

6.1 Context

The frequency and severity of extreme or atypical hydro-meteorological or oceanographic conditions will continue to increase as the climate changes. Extreme events will exacerbate the impacts of slow-onset changes in air and water temperature, precipitation and sea level, as well as bringing their own challenges. Many ports and waterways are vulnerable, whether to the effects of flooding; to changes in wind characteristics, wave height/frequency, extreme heat, or fog; or to the impacts of increased microbiological corrosion or invasions of damaging non-indigenous species. Extreme low or high flows will lead to reduced navigability and increased disruption at inland ports.

Ports are not only vital transport nodes; they are also integrally connected to wider trade networks. The cascading effects of extreme weather events can multiply quickly, impacting onward transport, energy or water supply, telecommunications and more. These interdependencies mean extreme weather impacts on utilities and service providers could also have significant consequences for ports, waterways and more widely for supply chains.

Very few ports and waterways will be unaffected by the changing climate. If the costs and consequences of climate-related operational shutdowns, physical damage and supply chain disruption are to be minimised, owners, operators and investors need to ensure the resilience of both new and existing infrastructure and operations. A mix of hard/structural and soft or low-tech adaptation measures could be required. Some solutions will require significant investment, but others are less expensive. Alongside structural modifications, the case studies on Table 2 highlight the importance of preparedness measures such as vulnerability mapping, early warning systems, digital tools and solutions, contingency planning including alternative access and storage provisions, and enhanced maintenance including drainage capacity.

6.2 Consequences of Inaction: Key Questions

In order to justify investment in interventions to adapt and strengthen resilience, it is vital to recognise that climate change inaction has a cost. In many cases, this cost will be significant, not only to the operation of the port or waterway, but to the local or national economy and to the individuals and societies that depend on effective and efficient waterborne transport. However, there is no one-size-fits-all solution to making the business case for port/waterway adaptation because there is no one-size-fits-all port/waterway.

In determining the scope of a business case assessment to support investment in climate change adaptation action, a port, facility or waterborne transport operator should therefore consider the relevance of each of the following questions, gather information (quantitative wherever possible but qualitative if necessary), and react accordingly. Further guidance on this process is also provided in PIANC (2020a), PIANC (2022) and PIANC (2023):

- Has a vulnerability and risk assessment been undertaken to understand and quantify **financial loss exposure** for identified hazards and **physical risks** under different climate change scenarios (including the probability of occurrence and maximum loss value) for assets, port or waterway operations and associated lost revenue? Business and reputational risks should also be considered.
- Has an **acceptable level of risk** been defined and agreed by all relevant stakeholders?
- Are the **local consequences of inaction** properly understood, documented, and wherever possible quantified? Such consequences may include the costs associated with damage

repair or replacement, clean-up, additional maintenance, and similar reactive responses; delays, **disruption**, downtime, closures, etc.; and direct local safety, societal and/or environmental consequences.

- Are the system-level consequences of inaction properly understood, documented, and wherever possible quantified? This should consider not only the risk of potential **cascading failures** in interlinked systems but also the indirect social and economic implications for local communities
- Where relevant, are the wider **supply chain** and economic or societal issues consequences of inaction properly understood, documented, and wherever possible quantified?
- Has full consideration been given to relatively low-cost options (such as early warning systems, contingency plans, institutional interventions and operational changes) as well as to possible structural and technological **solutions**?

Where action is needed to avoid, reduce or manage climate change-related risks, the type of data highlighted above is vital to enable the identification and quantification of the benefits of investment in adaptation and resilience interventions. Avoiding damage, disruption or other consequences is a key benefit of investing in strengthened resilience, so the losses-avoided principle or replacement or substitute cost approaches are among the methods that may be used to quantify potential benefits in the light of future changes including the assessed probability of events of differing frequency and severity. The costs of adaptation and resilience strengthening measures can then be compared to the losses-avoided using an appropriate and proportionate method (Section 5.8).

6.3 Other Potentially Relevant Business Case Considerations

In addition to seeking to avoid or minimise climate-related damage and/or revenue losses, there are many other reasons why a port/waterway or associated facility may need evidence to support the business case for investment in adaptation and resilience interventions. To this end, the organisation should also consider which, if any, of the following questions apply. Where a question is relevant, the costs of any additional measures to satisfy the need can be compared to any additional savings or increased revenue associated with having the intervention in place.

- Is there is a **legal or regulatory requirement** to invest in adaptation and resilience interventions and/or is such action is needed in order to avoid compliance failures? Penalties may be incurred at port/facility or national level in the event of inaction.
- Could failure to adapt have **contractual** implications or lead to **legal disputes**, potentially resulting in commercial losses or litigation-related costs?
- Is adaptation and resilience action needed in order to meet national **targets** set out as Nationally Determined Contributions under the Paris Agreement, the UN Sustainable Development Goals, or other objectives?
- Is adaptation and resilience action needed in order to meet CSR, ESG or other **good practice** objectives, or to demonstrate ambition or **leadership**?
- Do climate **risks** need to **be assessed and disclosed,** or climate **resilience proven,** to secure a loan or investment or to leverage finance, including private sector or public-private partnership finance? Penalties may be incurred, finance costs may be higher, or future revenue may be lost if the organisation is unable to secure investment on favourable terms (or at all).
- Is the identification and assessment of climate change impacts required by the **project authorisation process**, for example as part of the Environmental (and Social) Impact

Assessment? Failure to secure authorisation for a project may compromise an anticipated competitive advantage or result in a loss of expected future revenue.

- Does climate resilience need to be demonstrated in order to secure (**affordable**) **insurance**, including business interruption insurance, wind or flood damage, etc.? If resilience cannot be demonstrated, insurance premiums may be higher or some assets/activities may remain uninsured.
- Does the port or waterway's charter or insurance policy require evidence of **business continuity planning and management** (BCPM) [UNCTAD, 2022]? BCPM is often vital to enable the rapid post-event resumption of operations. Insurance premiums may be higher and/or disruption costs may be more significant in the absence of such an initiative.
- Does climate-related **ambition** need to be **demonstrated** to access finance and/or to align with the sustainability and climate criteria set by financial and other institutions, for example taxonomies defining 'sustainable' economic activities? Future revenue may be lost if the organisation is unable to secure such investment.
- Will demonstrated climate resilience enable the organisation to exploit new, or to consolidate existing, **business opportunities**? Competitive advantage may be compromised and/or future revenue may be lost if such business opportunities are missed.
- Could strengthening the port, waterway or facility's climate resilience enable **other organisations** such as clients or customers to exploit new, or to consolidate existing, business **opportunities**?
- Could demonstrated climate resilience offer **reputational gains**, which may not otherwise be realised?

An organisation should give most scrutiny to the type(s) of benefits that are likely to have the greatest influence on decision-making. However, where significant losses-avoided (savings) or revenue opportunities are additional to the benefits highlighted in Section 6.2, they could be used (quantitatively or qualitatively) to supplement the overall 'benefits' side of the equation in helping to make the business case for investment. For example, investing in the adaptation and resilience measures required to avoid revenue losses and damage costs, might also mean a saving on insurance premiums, or access to finance on more favourable terms than would otherwise be the case.

6.4 Conclusion

Climate change is a major business risk. Many ports and waterways need to take urgent action to strengthen resilience to both gradual changes and extreme or atypical events, and to adapt infrastructure and operations accordingly. This Technical Note highlights the consequences of inaction. It demonstrates that the benefits of adaptation typically outweigh the costs of such interventions, often substantially; and provides guidance on the potential scope of a business case assessment.

The Note also recognises, however, that the nature of an organisation and its management or governance model, will influence both what should be included in an assessment, and the appropriateness of different methods to determine return on investment and justify expenditure. Some organisations will be responding to the requirements of a particular financial institution; others will be following government guidance on economic analysis; private sector operators may be particularly concerned about cashflow, revenue programming and budget timescales. Most organisations are likely to need to address competing priorities for limited resources.

The Technical Note is intentionally not prescriptive in this regard. Rather its purpose is to facilitate understanding of the benefits to be gained, and the type of analyses that can be used to identify and quantify these benefits. In this way, it is intended that the Note will support port and waterway owners, operators, investors, and other organisations in considering what can usefully be included in making their own business case for investment in climate change adaptation and strengthened resilience.

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APPENDIX 1

Summary of UNCTAD (2017) and NavClimate (2018-19) ports' sector climate change surveys.

A1.1 UNCTAD Survey

In 2014, UNCTAD carried out a survey, designed in consultation with IAPH[83], to help improve understanding of weather and climate-related impacts on ports, and to determine levels of resilience and preparedness. The results of the survey, published in 2017 [UNCTAD, 2017] provided important contextual information from a representative sample of 44 ports in 29 countries[84] that collectively handled over 16 % of global seaborne trade. These results highlighted that:

- Hazards such as sea level rise, more frequent/heavier precipitation events, extreme heat, changes in wave energy or direction, river flooding and extreme wind events are already experienced by survey respondents; 72 % of those responding to this question confirmed that their ports had been impacted by weather- or climate-related events, including extremes
- Given that climate change is expected to increase the frequency or intensity of extreme events, such hazards are likely to lead to increasing detrimental effects on port infrastructure, operations and services in future
- Gaps in the information that ports need to assess risks and design appropriate and cost-effective adaptation measures (e.g. data on climatic stressors, trends, downscaled projections), may affect their capacity for adaptation planning
- Where the need for adaptation action had been identified, the focus was typically on (high cost) hard engineering measures rather than soft or low-tech solutions such as emergency management plans or processes, or changes in operations.

Overall, UNCTAD concluded that action was needed to increase both the knowledge base and human capacity in ports, including in relation to downscaled projections of risks to port operations and infrastructure under different climate change scenarios. The report also identified the need for follow-up surveys to gauge how both perceptions and levels of preparedness are changing.

A1.2 Survey by Navigating a Changing Climate Global Climate Action Initiative

In 2018, a high-level gap analysis carried out by the partners in the Navigating a Changing Climate initiative[85] (NavClimate) identified a lack of understanding of the consequences of inaction as a potential barrier to justifying investment in climate-resilience. In part this may be a function of the lack of readily available information on climate risk stressors and downscaled data identified by UNCTAD (2017), but other factors also contribute to this situation.

Most ports will have experience of events that, compared to their normal operating conditions, would be considered extreme or atypical. However, some may already have experienced events that are exceptional even taking into account the environment in which the port is located, and which might, if attribution studies were undertaken, be shown to be climate-change related. Attribution studies[86] are increasingly linking specific extreme weather events

[83] International Association of Ports and Harbors
[84] However, some limitations were noted: for example, the authors highlight that 73% of responses came from 'developed countries; also that questionnaires had been completed by individuals with different port management or operational roles and potentially, therefore, different perceptions of climate-related issues.
[85] NavClimate, a Marrakech Partnership, Global Climate Action initiative led by PIANC from 2015-2021.
[86] For example, see **https://www.metoffice.gov.uk/research/climate/understanding-climate/attributing-extreme-weather-to-climate-change**

to changes in the climate[87], and for certain types of extreme events, the influence of anthropogenic climate change has emerged beyond a reasonable doubt [Swain, D.L. et al., 2020]. Nonetheless there is a dearth of port-specific information, and as confirmed by Kalaidjian (2021), concerns about competition and marketability mean that ports rarely opt to publicise information that could indicate vulnerability.

The relative lack of available information means that some ports may struggle to conceptualise the possible consequences of a climate change-related extreme event(s) – in turn making it difficult to understand and evaluate the potential cost savings associated with investment in adaptation and resilience interventions.

In order to go some way to closing this data gap and help port operators understand the potential consequences of extreme events, the NavClimate partners prepared and distributed a survey similar in principle to the UNCTAD survey but attempting where possible to quantify associated costs. The survey was distributed in late 2018 and early 2019 and gathered information on events during the period 2011-2019.

67 responses were received from around the world, representing all port sizes (from ports handling less than 0.5 million to over 100 million tonnes) and all types of cargo. Ferry, fishing and recreational as well as other types of ports were amongst those responding. More than 40 % of responses were from Europe, but every survey region except Africa was represented[88]. 53 of the respondents fully completed the survey. Eight respondents had experienced zero extreme events but three of these eight nonetheless noted they were experiencing a general increase in the frequency of what they described as severe or atypical conditions.

45 survey respondents reported more than 109 extreme events in total (excluding outliers). 11 of these respondents reported on their general experiences but did not provide details on individual extreme events. In total, details about 49 individual extreme events were provided by 34 respondents.

In parallel to the running of the survey, information was collected and reviewed about extreme events (over the same period and affecting ports) reported in the press, technical press, and other grey-literature sources. In cases where such an event(s) was identified, but no survey response was subsequently received from the impacted port or waterway operator, publicly available information was collated on the nature of the event, its consequences and any reported associated costs. While the limitations of this additional literature search are acknowledged[89], its outcomes nonetheless provided a useful indicator for comparative purposes.

This parallel research exercise identified and provided indicative information for an additional 42 events also during period 2011-2019. The additional events covered 6 of the 7 regions from which survey responses were received (in this case, there were no examples from the Middle East), so provided a similar geographic spread. There was also good representation: across the different oceans, by port size (i.e. volumes handled) and cargo types.

The following sections elaborate on the survey responses relating to the nature, consequences and frequency of both the reported events and those identified through the additional parallel

[87] **https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world/**

[88] As with the UNCTAD survey, however, a majority of responses to the NavClimate survey came from 'developed countries; and it was also clear from the responses that questionnaires had been completed by individuals with different roles and potentially, therefore, different perceptions of climate-related issues.

[89] This was not a rigorous academic research exercise; rather the intention of the literature search was to capture information about other events known to have impacted ports and navigation interests. Even with this research, however, some of these major events could not be included because it was not possible to disentangle port or waterway-related consequences and costs.

research exercise. It is acknowledged that the survey responses reflect the experiences of the individual responding and may be based on perception rather than a comprehensive statistical analysis. As such, the survey outcomes should be interpreted as illustrative rather than definitive.

Respondents to the NavClimate survey most commonly reported that they were affected by extreme winds (50%), waves (30%), rainfall or (unspecified) overtopping (20 % each) (Figure A1). Some also mentioned extreme (inland waters) flow conditions (15 %); extreme cold (10 %) or heat; sediment movements and fog. The additional events covered by the parallel research exercise mentioned extreme winds (80 %), waves (45 %), rainfall (20 %), overtopping (10 %) and extreme cold (10 %)[90].

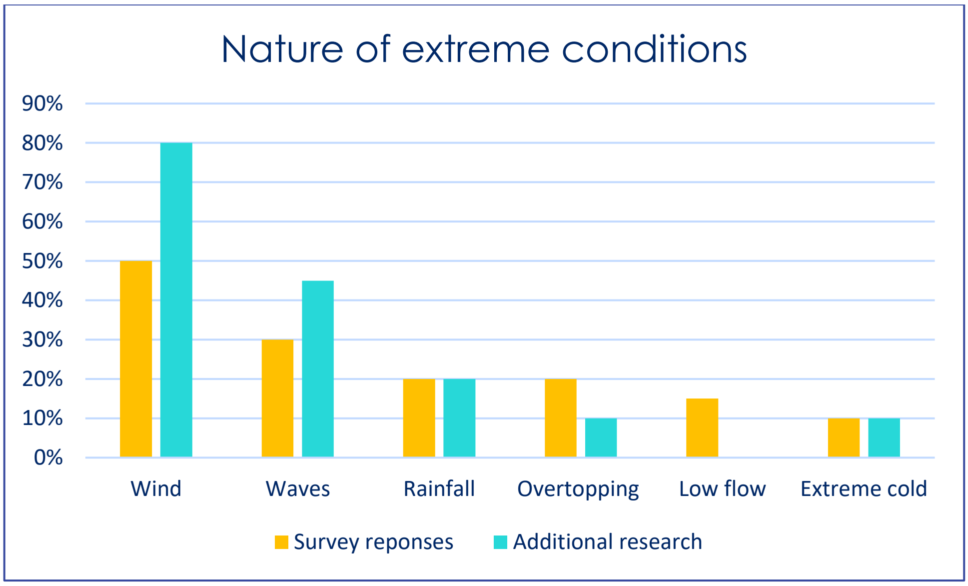

Figure A1: Nature of extreme conditions reported by NavClimate survey respondents

These conditions align with those where climate scientists anticipate an increase in frequency and/or severity. Understanding the potential costs and consequences of such events can therefore assist in justifying investment in strengthened resilience.

A1.3 Damage and Clean-up Costs

In response to the NavClimate survey question asking for an estimate of the total cost of clean-up, damage repair or other measures including temporary measures or additional maintenance, it was reported that, for just over half of the events (25 of 49 events), there was no damage, or damage costs were 'not applicable'. Responses on the other 24 events (i.e. the 49 % of events where damage and clean-up costs were incurred) elicited the following estimates of costs (USD):

[90] The UNCTAD 2014 survey [UNCTAD, 2017] similarly identified the most commonly-reported existing climate-related stressors – in order – as wind (most frequently mentioned), precipitation, storm, fog, waves, river flow, sea level rise and extreme temperature.

Total damage-related costs $	Number of responses	Percentage of events where damage, clean-up etc. costs were incurred
< $100,000	13	55 %
$100,000 to $1 million	6	25 %
$1 million to $10 million	5	20 %
>$10 million	0	0 %

The equivalent information collected about events that had been reported in the press, technical press, and other grey-literature sources (hereafter referred to as the 'literature search') indicated that 14 of the 42 events (around 1/3) had experienced damage, with reported associated damage costs for these events of:

Total damage-related costs $	Number of events identified	Percentage of events where damage, clean-up etc. costs were incurred
< $100,000	3	21 %
$100,000 to $1 million	6	43 %
$1 million to $10 million	4	29 %
>$10 million	1	7 %

The literature search exercise identified a relatively higher percentage of events with higher damage costs: this is unsurprising as events causing less damage, or events impacting smaller ports, are unlikely to receive as much media coverage. Nonetheless, some survey respondents pointed out that, for smaller ports, those in developing countries, ports with resource/available cash constraints and those without (adequate) insurance, even dealing with damage of < US$ 100,000 can represent a significant challenge.

Further examples relating to situations where an event impacts several ports in a region rather than an individual port similarly highlighted significant costs. Hurricane Ike in 2008 is identified as causing US$ 2.4 billion of damages to ports in Texas, while the 2013-2014 floods in the UK damaged port infrastructure worth more than US$ 2.2 million using early 2023 conversion rates [Verschuur et al., 2023]. EDF (2022) report individual examples of total damage costs to infrastructure at different ports due to tropical cyclones since 2015 of between US$ 40 million and US$ 2.2 billion per port or port group.

The NavClimate survey also asked respondents to select a category describing the effect of the clean-up, damage repair, etc. for their port or waterway. This prompted the following responses across all 49 events (Figure A2), i.e. irrespective of whether or not the question about clean-up and damage costs had been answered:

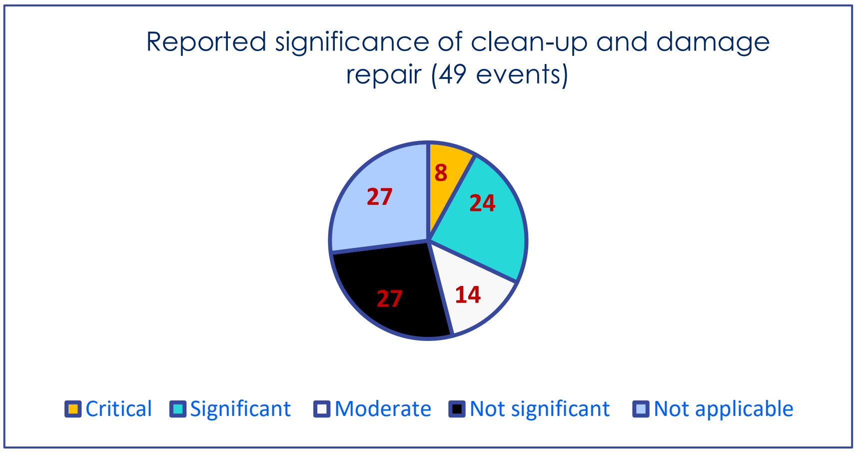

Figure A2: Significance of clean up and damage repair efforts as reported by NavClimate survey respondents

32 % of events were highlighted as resulting in 'critical' or 'significant' damage. The assessment of significance is subjective, and will vary according to factors such as the nature/size/scale of the port, and the availability of unbudgeted funds to cover clean-up or other (uninsured) costs.

The UNCTAD survey (2017), meanwhile, asked its survey respondents to indicate the significance of damage, impacts on operations, delays, interruptions and other impacts. The responses to these questions, captured on Figure A3, suggest that 31 % of respondents had experienced extreme events resulting in 'significant' physical damage, with a further 15 % resulting in 'some' damage. While the questions, and hence the responses, in the UNCTAD survey were different, meaning the results are not directly comparable, there nonetheless appears to be a degree of consistency in terms of how such events are perceived.

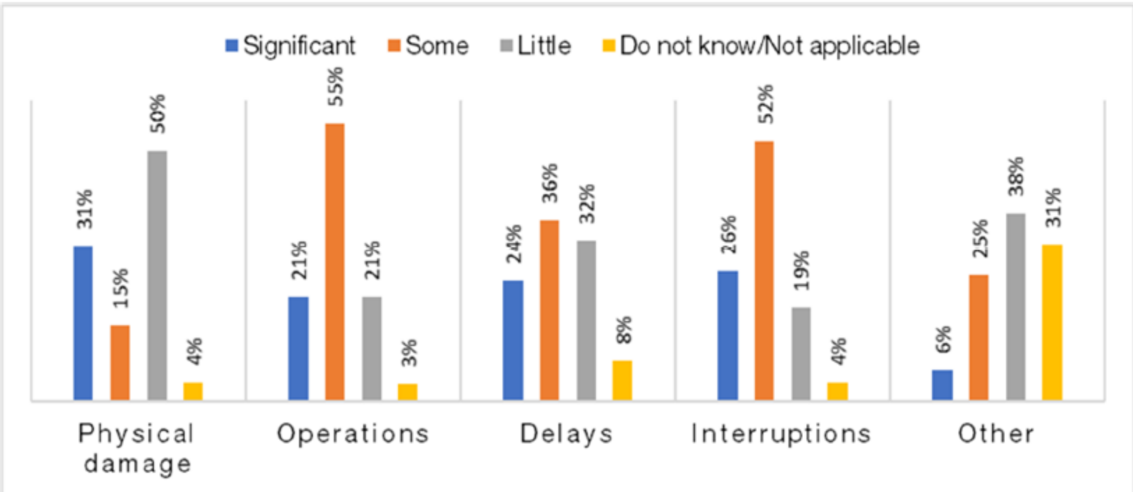

Figure A3: UNCTAD survey responses indicating significance of extreme event consequences

A1.4 Port Closure and Downtime Costs and Consequences

Disruption due to extreme weather can impact on cargo-handling performance and other port activities, in some cases leading to a shutdown of operations in part or all of a port. Post-event, this causes further difficulties as labour and equipment catch-up with both marine and landside operations, with additional consequences in terms of both lost revenues and disruption to the port and its customers. In some cases, such disruptions can cause carriers to reassess their commitments (see also UNCTAD (2022)).

Responses to the NavClimate survey question 'Did the event result in the total closure of the port or waterway?' indicated that there was no total closure in 19 cases (39 %[91]) and a closure of less than 24 hours in 32 % of cases. In 28 % of cases, the extreme event led to a port of waterway closure of 24 hours to more than 72 hours. Interpretation of the information on the additional 42 events identified through the additional literature search indicated that 12 events (29 %) did not lead to port or waterway closure; 17 % resulted in a closure of up to 24 hours; and more than half (54 %) led to a closure of 24 to more than 72 hours. While this percentage is significantly higher than the response to the NavClimate survey, the outcome was not unexpected because (as mentioned above) events with major consequences are, by their nature, more 'newsworthy' and hence more likely to be reported in the media.

Duration of closure (if any)	NavClimate survey		Literature search	
Number of events >	49		42	
No closure	19	39 %	7	17 %
Closure of < 6 hours	9	18 %	2	5 %
Closure of 6-24 hours	7	14 %	5	12 %
Closure of 24-72 hours	10	20 %	9	21 %
Closure > 72 hours	4	8 %	14	33 %
Indefinite closure	0	0 %	0	0 %
No data	-	-	5	12 %

The NavClimate questionnaire asked respondents to provide an estimate of the total cost of closure, delays and downtime in terms of lost business, but excluding the clean-up and damage repair costs already reported above. Many respondents were unable (for example because ports do not always have access to the costs incurred by terminal operators or port-related industry) or were possibly reluctant to quantify these costs. Of the 49 events reported in the NavClimate survey, only 27 responses provided cost estimates. These showed the following spread of estimated total costs (USD):

[91] Some of these events caused delays or downtime even if the port or waterway did not experience a total closure, for example certain berths or terminals were closed, or berthing/loading/unloading operations were subject to delays. Furthermore, organisations such as the Coast Guard or Naval authorities may be responsible for navigational safety and hence for determining whether (access to) a port remains open.

- Total costs up to US$ 100,000 = 74 % of events where closures, etc. were experienced
- Total costs US$ 100,000 to US$ 1 million = 19 % of events where closures, etc. were experienced
- Total costs US$ 1 million to more than US$ 10 million = 7 % of events where closures, etc. were experienced.

Where equivalent results were available from the literature search (cost data were available on only 9 events) these indicated:

- Total costs up to US$ 100,000 = 55 % of events where closures, etc. were experienced
- Total costs US$ 100,000 to US$ 1 million = 22 % of events where closures, etc. were experienced
- Total costs US$ 1 million to more than US$ 10 million = 22 % of events where closures, etc. were experienced.

Anticipating that some respondents might find it difficult to quantify the costs of downtime, the NavClimate survey also included a question asking respondents to select the most fitting qualitative description of the effects of the extreme event-related closure, delays or downtime on their port or waterway. This question prompted the following response (Figure A4):

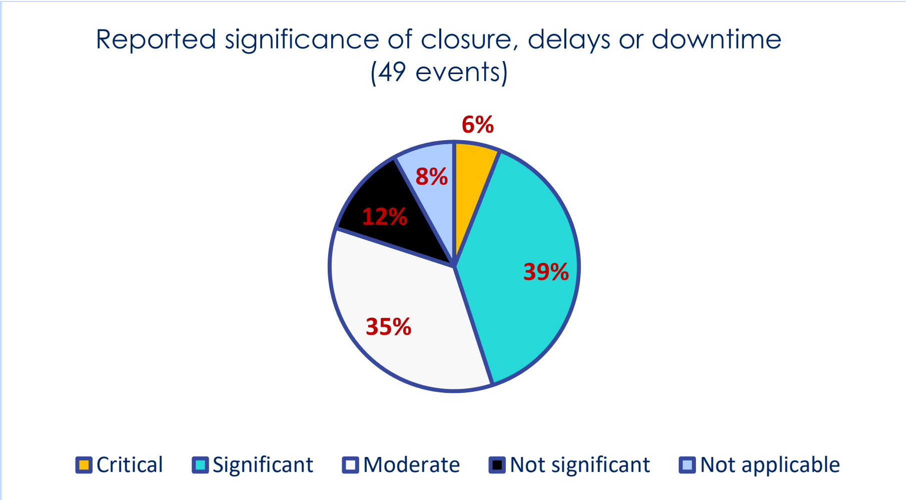

Figure A4: Significance of closure, delays and downtime as reported by NavClimate survey respondents

Notwithstanding the relative lack of quantified cost data, it is apparent that the reported closures, delays or downtime caused by extreme events were considered to be 'critical' or 'significant' in nearly half of all cases (45 %)[92]. Furthermore, it is clear from the responses to this question that the delays and downtime associated with extreme events can have important consequences even if the port or waterway does not experience a total closure.

This is confirmed by EDF (2022) citing research by Verschuur et al. (2020) on port disruption due to tropical cyclones, which used AIS vessel tracking data from 2011-2019 (the same period as the covered by the NavClimate survey). This work identified a median duration of operational interruption of 6 days, with roughly half of the reported events leading to a complete closure.

[92] The 2014 UNCTAD survey (2017) also attempted to gauge the significance of extreme events but using slightly different and distinct descriptions (see Figure A3). This figure might suggest a relatively smaller proportion of ports had experienced 'significant' delays (24 %) or interruptions (26 %) by 2014. However, given the lack of an equivalent measure of the 'overall' effect (and not being able to ascertain whether these figures are additive or largely duplicative) caution is needed because the outcomes may not be directly comparable.

As explained in Section 2.1, for major ports where data were available, total economic losses equivalent to between US$ 3 million and US$ 13 million per day were recorded in relation to operational disruption periods (duration) of between 3 and ten days [EDF, 2022]. UNCTAD (2022) make reference to evidence showing that floods have the most substantial impacts on port operations with the average of 11 affected days compared to 4.25 for hurricanes; longer disruptions may be experienced if hinterland infrastructure damage impacts port access/connectivity. Beyond the immediate impacts on the operation of the port itself, such disruptions can have wider consequential effects on supply chains (see Section 5.6).

Furthermore, Verschuur et al (2023) observe that damage to critical infrastructure networks (road, rail, power) can halt port operations even if the port itself is not damaged.

A1.5 Frequency of Extreme Events

Port closures due to high wind and/or wave events are not new; such incidents have been experienced in ports around the world for millennia. However, as discussed in Section A1.2, there is growing consensus, supported by attribution studies, that such events – and therefore their associated costs and consequences – are likely to become more severe and/or be experienced on a more frequent basis. According to data from Everstream Analytics[93] cited by UNCTAD (2022), 27 % of port disruptions in developing countries were caused by extreme weather.

In order to gain further insight into how extreme events are already impacting ports and waterways, respondents to the NavClimate survey were also asked to consider their own experience and indicate whether or not they agreed with each of the following statements:

Statement	Percentage agreeing
Number of events >	49
My port or waterway is experiencing these types of events with increasing frequency	41 %
This event was somehow exceptional, unprecedented or otherwise out-of-the-ordinary	53 %
The extent of damage/disruption was reduced because an effective warning was received	12 %
The extent of damage or disruption could have been less if an effective warning had been received	6 %
Other organisations, the local community and/or the environment were also affected by this event	27 %

The high percentage of respondents agreeing with the statements regarding extreme or atypical event frequency, and the exceptional nature of the event(s), is consistent both with the climate science and with the findings of similar sector surveys, for example those undertaken by the European Sea Ports Organisation (see Section 2.2).

[93] https://www.everstream.ai

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Cover Picture:

Damage caused by extreme winds associated with storm of 16 December 2023, Port of Bahía Blanca, Argentina