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Port Industry Survey on Climate Change Impacts and Adaptation

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Abstract

Ports are critical infrastructure assets that serve as catalysts of economic growth and development. At the same time, they are also exposed to the risk of the impacts of climate variability and change, particularly in view of their location in coastal zones, low-lying areas and deltas. Given the concentration of populations, assets and services associated with ports, the size and value of built infrastructure, and the key role of ports as part of the network of international supply-chains, responding effectively to the impacts of climate change on ports and their land-based access points is of strategic economic importance. Against this background and drawing upon its earlier work, the UNCTAD secretariat carried out an online port industry survey to help improve the understanding of weather and climate-related impacts on ports and to identify data availability and information needs, as well as determine current levels of resilience and preparedness among ports. The present report relates the key findings of the survey, together with some additional information about climate trends and climate-related impacts on seaports and some concluding remarks. The respondent port sample collectively handle more than 16 % of global seaborne trade and can be considered as representative. Although the majority of respondents had been impacted by weather/climate related events, including by extremes, the study revealed important gaps in terms of relevant information available to seaports of all sizes and across regions, with implications for effective climate risk assessment and adaptation planning.

Key words: Climate change, Impacts, Adaptation, Ports, Seaports, Coastal transportation

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1. Introduction and background

Ports are critical infrastructure assets that serve as catalysts of economic growth and development. In addition to playing a key role in international trade, they create jobs, generate wealth and value, contribute to national gross domestic product (GDP) and promote the expansion of related and near-by industries and cities. As a sea-land interface and a point of convergence between various modes of transport, ports act as gateways to trade, providing access to global markets for all countries, including those that are landlocked. With over 80 per cent of global merchandise trade by volume and more than 70 per cent by value being seaborne (UNCTAD, 2017a), ports constitute key nodes in global supply chains and are core to global production processes that rely heavily on manufacturing, outsourcing and low-cost shipping (UNCTAD, 2011).

While ports are at the heart of international trade and globalization, they are also exposed to the risk of climate change impacts, particularly in view of their location in coastal zones, low-lying areas and deltas. They can be particularly affected by rising sea levels, floods, storm surges and strong winds. Given the concentration of populations, assets and services associated with ports - as well as the size and value of built infrastructure - and the crucial role of ports as part of international supply-chains, climate change impacts on ports and their land-based access points, linking the maritime interface with the hinterland, may have serious broader implications; developing effective adaptation response measures is therefore of strategic economic importance.

While the type, range and the magnitude of climate change impacts will vary depending on local conditions, ports are expected to be directly and indirectly affected by climatic changes. Direct impacts are those likely to affect infrastructure, operations and services while indirect impacts include changes in demand for port services resulting from climate change effects on trade, investment decisions, demographics, agriculture production, forestry, energy exploration and consumption as well as fishing activity. Associated risks, vulnerabilities and costs may be considerable, in particular for ports in developing regions with low adaptive capacity, and those in Small Island Developing States (SIDS). With SIDS being sea-locked, climatic factors that may severely impact coastal transport infrastructure and services pose particularly serious threats to national economic development prospects.

Given the strategic role of ports as part of the globalized trading system, adapting ports in different parts of the world to the impacts of climate change and building their resilience is an urgent imperative. A good understanding of the relevant risks and vulnerabilities based on accurate information, including climate and socio-economic data at the local level, is a pre-requisite for informed decision making and well-designed and effective adaptation response measures that enhance the robustness of systems, structures and processes and minimize the adverse effects of climatic factors. In this context, cooperation among a wide range of public and private sector stakeholders at the local, national, regional and international level is required.

Against this background and drawing upon earlier work, the UNCTAD secretariat, in 2014, carried out an online port-industry survey, designed in consultation with port industry stakeholders, including, in particular the International Association of Ports and Harbors (IAPH), to help improve the understanding of weather and climate-related impacts on ports and to identify data availability and information needs, as well as determine current levels of resilience and preparedness among ports. The aim was to gather relevant information which is urgently required for the purposes of risk-assessment and adaptation planning[1], including in particular for ports in developing regions as well as to collate some information on the current state of practice in terms of response measures and adaptation to the impacts of weather and climate-related factors and events.

The present report relates the key findings of the survey, together with some additional information about climate trends and climate-related impacts on seaports. Chapter 2 provides some context on the implications of climate variability and change for seaports, notably by presenting an overview of recent trends and projections on relevant climatic factors as well as an overview of key impacts that climate variability and change

[1] Note that an earlier survey to assess how port administrators felt climate change might impact their operations, what sea-level change would create operational problems, and how they planned to adapt to new environmental conditions found that while respondents agreed that the ports community needed to address the issue of climate change adaptation, most felt relatively uninformed about potential climate impacts (Becker et.al., 2012).

may have. Chapter 3 provides an analytical overview of the key results of the survey and Chapter 4 offers some concluding remarks. Finally, the questionnaire itself and a full summary of results are presented as Appendices A and B, respectively.

1.1. Earlier related activities by the UNCTAD Secretariat

UNCTAD has been working, 'ahead of the curve', on the implications of climate change for maritime transportation, since 2008[2], with particular emphasis on impacts and adaptation needs of seaports and other coastal transport infrastructure. Academic publications include an UNCTAD edited book on "Maritime Transport and the Climate Change challenge", co-published by the UN and Earthscan (Asariotis and Benamara, 2012) and providing detailed insight on a range of the potential implications of climate change for this key sector of global trade; as well as a multidisciplinary academic paper (Becker et. al., 2013), co-authored by experts following an UNCTAD Expert Meeting.

Other relevant initiatives by the UNCTAD secretariat include a number of intergovernmental expert meetings which have focused on the implications of climate change for maritime transport, highlighting in particular the need to adapt to the impacts of climate change. They include an Ad-Hoc Expert Meeting on "Climate Change Impacts and Adaptation: A Challenge for Global Ports", held in September 2011, a Joint UNECE-UNCTAD Workshop on "Climate Change Impacts on International Transport Networks", held in September 2010 - leading to the establishment of a UNECE Expert Group on the subject - and a Multi-year Expert Meeting on Transport and Trade Facilitation with a focus on "Maritime Transport and the Climate Change Challenge", held in February 2009[3]. The implications of climate change for coastal transport systems were also considered at two Expert Meetings with a focus on the transport-related challenges facing Small Island Developing States (SIDS), namely the third session of the Multi-year Expert Meeting on Transport, Trade Logistics and Trade Facilitation, "Small Island Developing States: Transport and Trade Logistics Challenges", held on 24-26 November 2014, and the Ad Hoc Expert Meeting on "Addressing the Transport and Trade Logistics Challenges of the Small Island Developing States (SIDS): Samoa Conference and Beyond", held on 11 July 2014.

Drawing on the above, ongoing and recent work with a particular focus on SIDS includes a technical assistance project on "Climate change impacts on coastal transport infrastructure in the Caribbean: enhancing the adaptive capacity of SIDS" (UNDA 9th tranche)[4], which is being implemented over the period 2015-17. A case-study focusing on two vulnerable SIDS in the Caribbean region (Jamaica and St. Lucia) is being carried out to enhance the knowledge and understanding at the national level and to develop a methodology for assessing climate-related impacts and adaptation options. The methodology will, subject to location-specific modifications, be available for use in other SIDS within the Caribbean region as well as in other geographical regions. Some of the insights gained as part of this technical assistance project, notably regarding the risk of marine flooding in Saint Lucia, are also reflected in Chapter 2 of the present report.

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[2] http://unctad.org/en/Pages/DTL/TTL/Legal/Climate-Change-and-Maritime-Transport.aspx
[3] See UNCTAD, 2009 and UNECE, 2010. Both documents are available at www.unctad.org/ttl/legal. Following the joint UNCTAD-UNECE workshop on the subject, a UNECE Expert Group on Climate Change Impacts and Adaptation for International Transport Networks and Nodes was established. UNCTAD continues to participate actively in this work.
[4] http://unctad.org/en/Pages/DTL/TTL/Legal/Climate-Change-Impacts-on-SIDS.aspx.

2. Climate variability & change implications for seaports

Maritime transport is a most important global industry that facilitates the movement of goods and people (Fig. 2-1). It forms the lifeline of world's trade, as about 80 % of goods have at least one maritime transport 'leg (UNCTAD, 2017a) Transport requires operational and efficient transport networks, with seaports forming the key nodes (Fig. 2-2). Climate Variability and Change (CV & C)[5] could have significant implications for a broad range of seaport operations, infrastructure and assets, requiring well-targeted response measures; efficient, integrated and resilient international transport nodes/networks are of paramount importance for the further economic development, particularly for SIDS and for other groups of vulnerable countries.

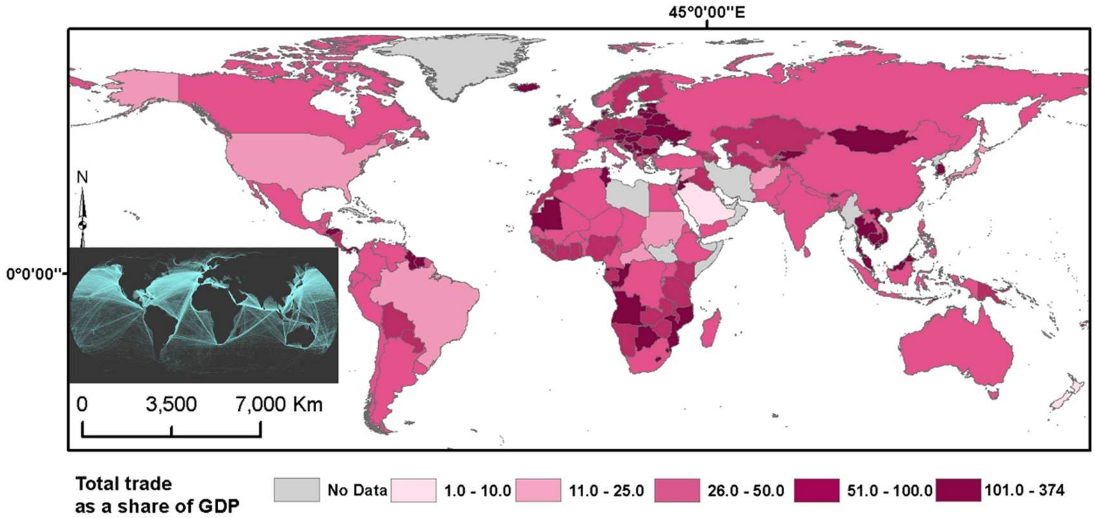


Figure 2-1 Total Trade as a share of GDP in 2012, i.e. the sum of goods and services exports and imports divided by the value of GDP (in 2005 U.S. dollars), aggregated from two World Bank datasets (Merchandise Trade (% of GDP) - 2005-2012; and Services Trade (% of GDP) - 2005-2012 (UNECE, 2015). Inset: Major maritime routes which facilitate this trade are shown[6]

Transportation accounts for a significant fraction of global Greenhouse Gas (GHG) emissions, which are now considered as a most significant forcing for a range of observed climatic changes; high atmospheric concentrations of GHGs absorb large parts of the heat reflected back from the Earth's surface and, thus, increase the Earth's heat storage (IPCC, 2013). Fossil fuel emissions have been increasing steadily since the 1950s and, with the exception of the mildest future climate scenario (RCP 2.6 scenario[7]), are projected to continue growing at least until 2050.

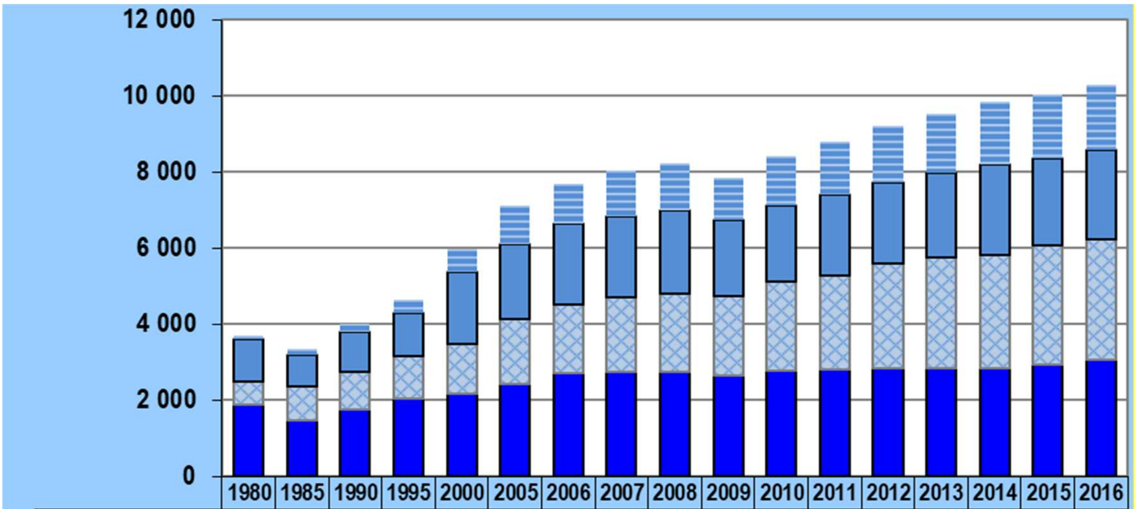
Transport CO_2 emissions show significant spatial variability, with the highest emissions found in the United States of America, the Russian Federation, China, Japan and Brazil, with western Europe, Australia and India also associated with high emissions; by comparison, Africa is characterized by the lowest transport-generated emissions (UNECE, 2015). Despite the key role of maritime transport for international transport and trade, GHG emissions from international shipping presently form only a small part of the total; international shipping

[5] Climate Variability and Change (CV & C) refers to the variability and sustained change of climatic factors relative to a reference period, e.g. the first period with accurate records (1850s-1860s) or periods with widespread, good quality and comparable climatic observations, during which most of the transport infrastructure used today was constructed (e.g. 1961-1990 or 1986-2005).

[6] P. Bridge, WMO, presented at UNECE Expert Group meeting, 2016

[7] In the last IPCC Assessment Report AR5 (2013) forecasts are made on the basis of Representative Concentration Pathways-RCP scenarios. In these scenarios, the CO2 equivalent concentrations for 2100 have been set as (Moss et al., 2010): RCP 8.5, 1370 ppm C02- equivalent; RCP 6.0 850 ppm CO2-equivalent; RCP 4.5, 650 ppm CO2-equivalent; and RCP 2.6, peaking at 490 ppm CO2-equivalent.

contributes only 2.2 % of global CO2 emissions from fuel combustion, being the most energy efficient mode of transportation. Nevertheless, emissions are rising and are projected to grow up to five-fold by 2050 (IMO 2015). In addition, seaports form complex systems and multimodal transport nodes. In the case of larger ports, these are mostly integrated within large coastal urban agglomerates; consequently, ports are associated with a range of environmental effects[8].



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Container	102	152	234	371	598	1 001	1 076	1 193	1 249	1 127	1 280	1 393	1 464	1 544	1 640	1 661	1 720
Other dry cargo	1 123	819	1 031	1 125	1 928	1 975	2 112	2 141	2 173	2 004	2 022	2 112	2 150	2 218	2 393	2 310	2 339
Five major bulks	608	900	988	1 105	1 295	1 711	1 814	1 953	2 065	2 085	2 335	2 486	2 742	2 923	2 985	3 121	3 172
Oil and gas	1 871	1 459	1 755	2 050	2 163	2 422	2 698	2 747	2 742	2 642	2 772	2 794	2 841	2 829	2 825	2 932	3 055

Figure 2-2 International seaborne trade in millions of tons loaded at seaports (selected years), (UNCTAD, 2017a, Review of Maritime Transport 2017)

As mentioned earlier, the location of seaports makes them vulnerable to a range of hydro-meteorological hazards which are influenced by CV & C. In the following sections, recent trends and projections regarding the climatic factors that influence seaports (and their connecting transport networks) are presented, together with their impacts on seaports.

2.1 Recent trends and projections on relevant climatic factors

2.1.1 Climate factor trends

Globally-averaged, near-surface temperature is the most cited climate change indicator, as it is directly related to the planetary energy balance and increases in Greenhouse Gas-GHG emissions, as well as many climatic impacts and risks (IPCC, 2013). Although global temperature has not increased in each consecutive year (or decade), a long-term warming trend is clearly observed, mostly in the past 40 years (Fig. 2-3a). Atmospheric temperatures have increased, whereas oceans also show significant increases in heat content (Dieng et al.,

[8] Fuel combustion emits directly Carbon monoxide (CO), volatile organic compounds, Sulfur and Nitrogen oxides ((SOx and NOx) that could generate 'photochemical smogs' and acid rains, as well as carbon particulates that cause respiratory problems. At seaports, road freight vehicle loading/unloading can increase pollution, particularly as vehicles tend to pollute more during the first few km of their journey (UNECE, 2015). Although new technology/cleaner fuel formulations will continue to cut emissions, the increasing number of loading/unloading vehicles in seaports and connecting road networks may counterbalance these benefits. Transportation noise in and around ports can also have harmful health effects at seaport urban agglomerations; low-noise road surfaces, effective noise barriers and low noise tyres can help reduce noise levels. Seaports can also have major environmental impacts during their construction, upgrading and maintenance. Generally, the environmental effects of seaports on their local environment is an issue to be tackled. In recent years, several initiatives from the industry as well as relevant environmental regulation have appeared that take these issues into consideration (Inoue, 2012).

2017) which has resulted in their thermal (steric) expansion and, thus, in sea level rise[9]. Sea ice covers have been declining, with the Arctic sea ice extent having decreased by more than 40 % since the first satellite records (1979) (NOAA, 2017). 2016 was the warmest year in the instrumental record, breaking the previous records of 2015 and 2014, with observations being consistent with a steady trend in global warming superimposed on random, short-term variability (Rahmstorf et al., 2017)[10]. In early 2016, the global temperature was about 1.5 ^{0}C above that recorded in the early industrial revolution and more than 0.4 ^{0}C higher than that recorded in 1998 which was a strong El Niño year (Simmons et al., 2017)[11]. Although 2015 and 2016 temperatures could have been influenced by El Niño conditions (NASA, 2016), land surface temperatures in 2014 (a neutral El Niño year) were also 0.88 ± 0.2 ^{0}C higher than the 1961–1990 average (WMO, 2014).

Global mean sea-level rise (MSLR) has increased sharply above its background rates of the past 2000 years (e.g. Horton et al., 2014). Since 1860, global sea level increased by about 0.20 m (average period rate of 1.3 - 1.8 cm per decade), but with a discernible acceleration in recent decades (Fig. 2-3b). Currently, satellite and tide gauge observations suggest a global sea level rise of 3.3 ± 0.25 cm per decade since 1993 (Church et al., 2013). There is however, regional variability, with some regions experiencing greater sea-level rise than others as, for example, in the western Pacific. In these regions, seaports and other transport coastal infrastructure are vulnerable particularly when their high rates of mean sea level rise combine with extreme storm surges/waves, as was the case along parts of the Philippines coast during the (2013) typhoon Haiyan (Esteban et al., 2015).

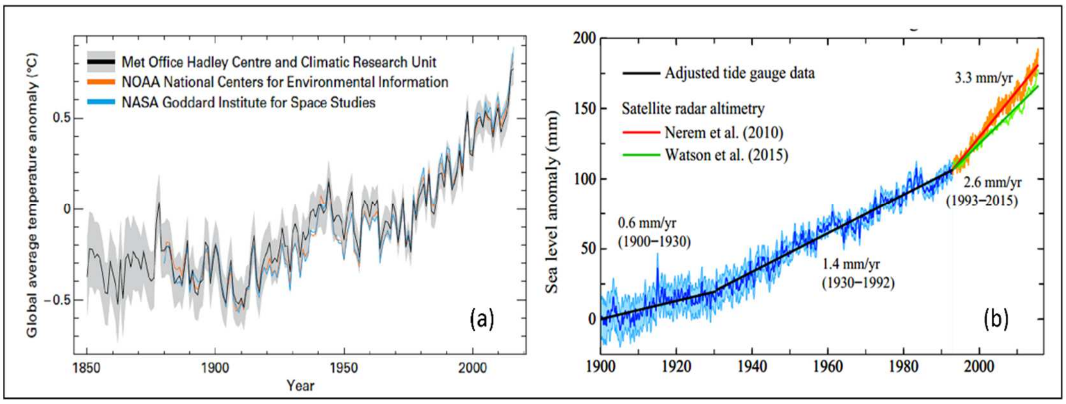


Figure 2-3 (a) Global average temperature anomalies for the period 1850-2016 relative to the reference period 1961–1990 for 3 major datasets[12]. Grey shading indicates the uncertainty in the HadCRU dataset, UK Met Office Hadley Centre (From WMO, 2017). (b) Estimated sea level change (mm) since 1900. Data through 1992 are tide-gauge record (Hansen et al., 2016).

Global land precipitation observations show mixed long term trends and strong regional variability, with an increasing trend being discerned in middle and high latitudes (IPCC, 2013; EPA, 2015). With regard to mean wind intensity, trends are not easily discerned in the instrumental record; in any case, wind impacts are mostly

[9] Mean sea level increases due to the combination of (a) ocean thermal expansion, (b) ocean water mass increases from the melting of the continental Greenland and Antarctic ice sheets (GIS and AIS), glaciers and ice caps; (c) isostatic adjustment; and (d) changes in land water storage (Hanna et al., 2013).

[10] Since the 2000s, there appears a slowdown in the rate of the global mean surface temperature rise, termed as 'the global warming hiatus'. In 2003–2013, both global land and sea surface temperatures (LSTs and SSTs) increased at a lower rate than in the previous decades (Dieng et al., 2017). The slowdown was attributed to uncertainties related to other temperature change forcing: volcanic eruptions, changes in atmospheric water vapor and industrial aerosol concentrations, heat redistribution in the oceans, solar activity and the variability of ocean climate (e.g. El Niño and La Niña events (Yan et al., 2016). Recent research (e.g. Karl et al, 2015; Simmons et al., 2017) has, however, questioned the occurrence of the trend hiatus, suggesting that re-analysis of corrected/updated datasets indicate that higher global temperature trends in this period than those reported in previous studies.

[11] An alarming development in view of the 2015 Paris Agreement the aim of which is to 'hold' the global average temperature increase to well below 2 ^{0}C above pre-industrial levels (UNFCCC, 2015).

[12] In the WMO (2017) analysis, the latest versions of the datasets GISTEMP, NOAAGlobalTemp and HadCRUT of NOAA, the NASA and the UK Met. Office Hadley Centre, respectively, have been used. The combined dataset extends back to 1880 (http://library.wmo.int/opac/doc_num.php?explnum_id=3414).

associated with extreme events like tropical and extra-tropical storms. Arctic sea ice (minimum) extent has rapidly declined since 1979 (13.3 ± 2.6 % per decade), whereas Antarctic sea ice extent has remained mostly stable in the same period (WMO, 2017). Most minimum extent records occurred in the last decade, with the 2016 sea ice extents dropping to record lows (NSIDC, 2017). Finally, permafrost temperature has increased in northern regions by up to 2 ^{0}C since 1980 and its thickness decreased by 0.32 m since 1930 (IPCC, 2013), leading to permafrost thaw and significant transport infrastructure damage (UNECE, 2013).

Extreme events (e.g. storms, floods/droughts and heat waves) constitute particularly dangerous climatic hazards. Societies are rarely prepared to face extreme weather events efficiently, as they have become reliant on predictable, long-term climatic patterns (MetOffice, 2014). Currently, climate extremes show patterns consistent with global warming. In many regions, observations show increases in both the intensity and frequency of hot temperature extremes and decreases in cold extremes (IPCC, 2013). Tropical and extra-tropical storms may also respond to a warming climate by becoming even more extreme (MetOffice, 2014). Their impacts on coastal transport infrastructure could be very severe, particularly due to the extreme sea levels (ESLs)[13] they induce (Hallegate et al., 2013). In recent years, storms have been particularly devastating. In 2013-2014, the highest storm surge levels since 1953 were recorded along the coasts of the Netherlands and the UK (WMO, 2016), whereas the effects of the catastrophic 2017 hurricane season (e.g. Harvey, Irma and Maria hurricanes) have yet to be fully accounted for.

A clear trend regards the increasing frequency and intensity of heavy precipitation events (and associated floods) in many parts of Europe and North America (IPCC, 2013). Between 1980 and 2014 river floods accounted for 27 % of fatalities and 32 % of the economic losses related to natural disasters (Munich Re, 2015). In Europe, annual water discharges have been observed to increase in the north and decrease in the south, a trend projected to hold in the future (EEA, 2015c). Heat wave frequency and intensity have also increased: a 3-fold increase since 1920s has been observed in the ratio of the observed monthly heat extremes to that expected in a non-changing climate (Coumou and Rahmstorf, 2012).

2.1.2 Climatic factor projections

By 2100, mean atmospheric surface temperature is projected to increase by up to 3.7 °C, depending on the Representative Concentration Pathway (RCP) scenario (IPCC, 2013). The ocean will also warm under all RCP scenarios. The highest ocean surface warming is projected for the subtropical and tropical regions resulting in conditions that can force/maintain stronger tropical storms. By 2100, ocean warming in its upper 100 m is projected at about 0.6 °C, under RCP2.6, to 2.0 °C, under RCP8.5; thus, ocean warming will continue for centuries (due to the long time scales of heat transfer from the surface to the deep ocean waters) even if GHG emissions were to be stabilized. Climate will not change uniformly. Temperatures close to the poles are projected to rise faster than at the equator; temperature rises relative to the reference period of more than 10 °C are predicted for arctic areas in 2100 under the RCP8.5 scenario (IPCC, 2013).

Predictions of mean sea-level rise are constrained by uncertainties regarding, for example, the response of the continental ice (i.e. the Greenland and Antarctic ice sheets and the glaciers) to increasing temperatures (De Conto and Pollard, 2016). IPCC (2013) has projected a likely sea level rise by 2100 (compared to 1986–2005) of up to 0.98 m for the RCP8.5 scenario (IPCC, 2013), a significant increase from the previous IPCC assessment (IPCC, 2007). However, sea level projections based on alternative approaches, suggest much higher mean sea level rises (e.g. UNECE, 2013; Horton et al., 2014; Dutton et al., 2015). It should be noted that there is a large spatial variability in the observed (and projected) sea level rise (e.g. Carson et al., 2016) and that sea-level rise will not cease in 2100, but will continue for centuries, as thermal expansion and melting/dynamic ice loss in Greenland and Antarctica will continue well into the future (Jevrejeva et al., 2012).

[13] Climate related marine flooding is driven by extreme sea levels (ESLs), which form the sum of the mean sea level (MSL), the astronomical tide level (η_{tide}) and the episodic coastal sea level rises (η_{ce}) due to storm surges and the coastal wave set up. Regarding the two latter ESL components, storm surges are temporary increases in coastal sea levels caused by changes in atmospheric pressure and strong winds, such those associated with tropical and extra-tropical storms. Whereas wave set up is the increase of the mean sea level observed at the coastline during energetic wave events due to high wave breaking (U.S. Army Corps of Engineers, 2002).

Precipitation is expected to change in a complex manner, with some regions becoming wetter and others dryer. The frequency of heavy precipitation events will increase over many regions in the future, particularly in high/tropical latitudes; heavy rainfall events are even predicted (with medium confidence) to become stronger and more frequent in regions where total rainfall is projected to decrease (MetOffice, 2014; EEA, 2015c). For example, although the UK is predicted to become (overall) drier by 2100, heavy rainfall events (more than 30 mm in an hour) associated with flash flooding may become up to 5 times more frequent (MetOffice, 2014). Climate models also project regional droughts for the southwestern North America, the Caribbean and other subtropical regions by the mid to late 21st century, but decreases in drought intensity/duration for the Mediterranean and parts of North America (IPCC, 2013).

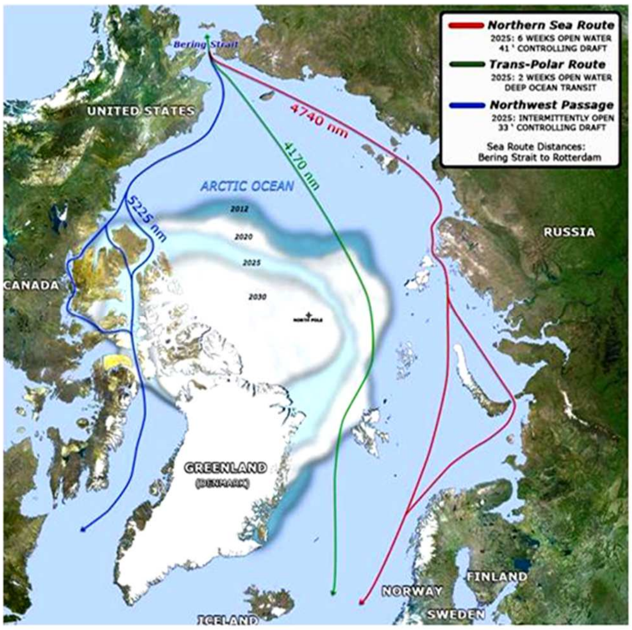


Figure 2-4 New Arctic shipping routes. (U.S. Climate Resilience Toolkit, 2015)

Climate models also project 10 to 30 % mass reduction of the glaciers and ice caps by the end of the century as well as continued thawing of permafrost (AMAP, 2012). Current warming rates at the European permafrost surface are 0.04 – 0.07 ºC per year (EEA, 2015a) with the permafrost extent in 2100 expected to decrease by up to 81 % under the RCP8.5 scenario (IPCC, 2013). Such changes could impose technical challenges in the development/maintenance of transport infrastructure in the Arctic regions (UNECE, 2013), particularly new seaports to facilitate the new Arctic routes that will become navigable (Fig. 2-4). For 2081-2100, sea ice extent reductions of up to 34 % (in February) and 94 % (in September) are projected compared to the average extents in 1986-2005 under the RCP8.5 scenario (IPCC, 2013).

Regarding extreme climatic events, hot and cold temperature extremes are projected to increase and decrease in the future, respectively, under all emission scenarios; the greater changes are expected in the sub-tropical and mid-latitude regions (Coumou and Robinson, 2013). It is likely that the frequency/duration of heat waves (prolonged periods of excessive heat) will increase, mainly due to the increasing mean temperatures; in many regions, the frequency of the current 20-year heat wave event will be (at least) doubled, while the occurrence of a current 20-year cold event will also be considerably reduced (e.g. EEA, 2015b).

Extreme coastal sea levels (ESLs) constitute a most significant hazard for coastal activities and infrastructure. Recent research for the European coast has projected that future storm surge levels will increase for the Atlantic, North Sea and Baltic coasts and seaports, whereas the Mediterranean coast is projected to experience minimal changes (Vousdoukas et al., 2016a; Vousdoukas et al., 2017). As parts of the European coast are also exposed to energetic waves (and, thus, high wave set ups[14]), extreme sea levels (ESLs) are predicted to

[14] See fn 15, ibid

change significantly in terms of both levels and return periods (Fig. 2-5). In some regions, where there is also significant coastal subsidence due to human coastal water drainage/groundwater withdrawals, the risk of flooding of coastal transport infrastructure could become very high (e.g. Esteban et al., 2015). For instance, a 1 m combined sea level rise can increase the frequency of a current 100-year coastal flood by about 40 times in Shanghai (China), about 200 times in New York (USA), and about 1000 times in Kolkata (India) (WMO, 2014).

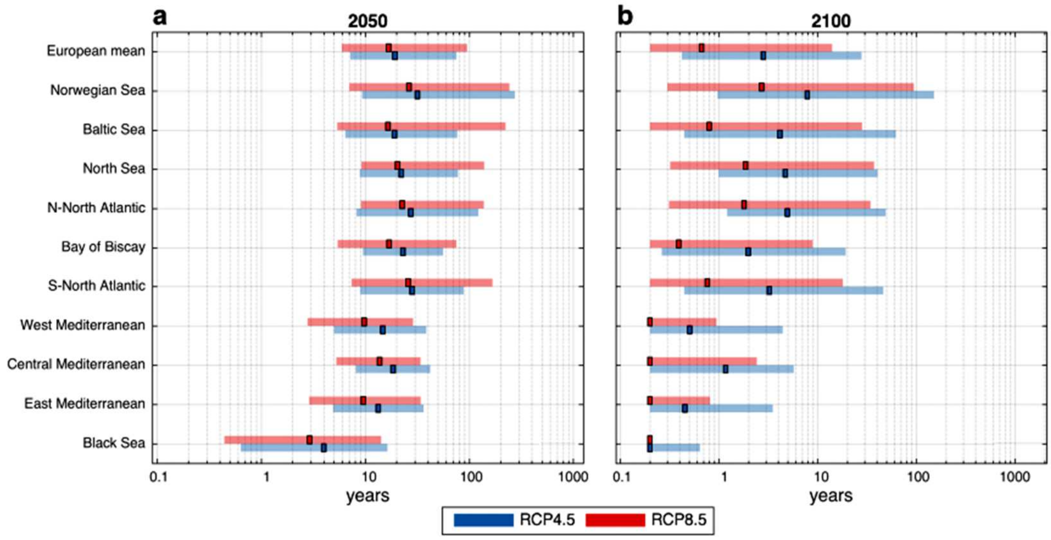


Figure 2-5 Return period of the present day 100-year extreme sea levels (ESLs) for the European coastline, under RCP4.5 and RCP8.5 in 2050 (a) and 2100 (b). Black boxes show the mean model projection and the coloured boxes the model result variability (best-worst case) (Vousdoukas et al., 2017).

Regarding waves, recent modeling results (Mentaschi et al.,2017) suggest an increase of up to 30 % in the 100-year return level of coastal wave energy fluxes (an important seaport design parameter) for most southern temperate coasts, with the exception of Eastern Australia, the southern Atlantic, and the sub-equatorial and tropical Eastern Pacific; by comparison, large coastal areas in the Northern Hemisphere are projected to show negative trends, except the NE Pacific and the Baltic Sea which are projected to show increases of up to 30 %. Substantial changes in the prevailing wave directions are also predicted for some regions.

As temperatures rise, extreme precipitation events will likely become more intense over most of the mid-latitude and wet tropical regions (IPCC, 2013; EEA, 2015c). High resolution climate models also indicate that extreme summer rainfalls could intensify with climate change (MetOffice, 2014). River floods are projected to increase in most regions, particularly if requisite water watershed management schemes would not be put in place (IPCC, 2013; King et al., 2015). Finally, high wind events (and tornadoes), which can cause major operational disruptions and infrastructure damages on seaports are quite difficult to predict; however, it is expected that extreme wind events (such as hurricanes and typhoons) might become stronger due to global warming, and particularly due to the seasonal surface overwarming of the tropical and subtropical ocean (e.g. Emanuel, 2005, IPCC SREX, 2012).

2.2 Climate variability & change impacts on seaports

Sea level rise, storm surges and waves are likely to induce major impacts on coastal transport hubs and networks, including transient or permanent flooding of seaports and connecting coastal roads and rail lines. In addition, large increases in coastal urban and industrial development associated with seaports observed in many regions will test the ability of coastal systems to respond effectively to climatic changes. Recent reviews (UNECE, 2013; 2015) have shown that: (a) coastal transportation assets have been more sensitive to extreme events, such as storm surges/waves, heavy rain and wind events and heat waves, than to incremental changes in the mean climatic factors; (b) transport services are more sensitive to climate stressors than are physical assets, as thresholds for e.g. delaying/cancelling seaport services are often lower than thresholds for damage to infrastructure; and (c) assets are more sensitive to stressors whose occurrence is relatively unlikely in comparison to typical weather variability; -for example, during the 2005 Katrina hurricane, the superstructure of US Gulf coastal bridges were subjected to excessive loading from direct wave impacts due to unprecedented storm surge elevation (USDOT, 2012).

Coastal inundation due to long-term sea level rise will be a significant problem for coastal populations, activities and infrastructure/assets at low elevation coastal zones, particularly in metropolitan areas that also experience coastal land subsidence (e.g. Jakarta (Indonesia), see Esteban et al., 2017). Seaports in such areas are particularly sensitive, requiring costly technical responses (Takagi et al., 2011; Becker et al., 2016). In any case, the most severe implications will be related to extreme sea levels (Vousdoukas et al., 2016a; 2017) including those from tropical/extra-tropical storms, particularly in the case of deltas, small islands and large coastal urban centres (e.g. Dasgupta et al., 2009). Coastal inundation from storm surges/waves can severely impact seaports and connecting transportation systems by (a) rendering them unusable for the duration of the event (for several hours/days) and (b) damaging terminals, intermodal facilities, freight villages, storage areas and cargo and, thus, disrupting intermodal supply chains and transport connectivity for longer periods (USDOT, 2012).

In many regions, port operations are also affected by adverse wave conditions; harbour conditions can become difficult for the safe navigation and berthing of large freight vessels, due to e.g. the penetration of long period waves generated by swell waves propagating in groups (e.g. Rossouw and Theron, 2012). In these cases, particular attention should be paid to potential changes in the intensity and direction of approaching waves; in some areas, these are projected to change significantly in the course of the 21st century (e.g. Mentaschi et al., 2017). The extent/distribution of seaport exposure will be controlled by local characteristics, such as the presence of storm attenuating coastal ecosystems (e.g. wetlands) (IPCC SREX, 2012; Wamsley et al., 2010) and/or efficient water management and land reclamation schemes (e.g. Le et al., 2007).

As many ports and related transport links are located in estuaries, the impacts of CV & C on these environments are also pertinent. In estuaries, sea-level rise generally translates into landward transgression, leading to different (higher) relative water levels and dynamics and, consequently, to increased flooding risk, particularly under the combination of high river flows and storm surges (Karim and Mimura, 2008). At the same time, the seaport tidal regime may also be affected by sea level rise (e.g. Pickering et al., 2012), requiring changes in port infrastructure and in operational time tables. Ports may be particularly impacted by future CV&C due, in particular, to: (a) the long life-time of their key assets which may render existing coastal protection structures in ports obsolete, as these may have been designed for a milder energetic regime; (b) their exposed location and their dependence on trade, shipping and inland transport that are also vulnerable to climatic changes and extreme events (UNCTAD 2011).

A detailed study on the potential impacts of CV & C on the critical coastal transportation infrastructure/assets carried out in Mobile (US Gulf Coast) (USDOT, 2012) has suggested that critical port and connecting facilities are most vulnerable to extreme weather/storms (Fig. 2-6). In the US Gulf coast, critical interconnecting transportation components i.e. seaports, roads and railways have also been projected to be flooded under sea level rise and extreme events. Thus, mean sea level rise of 1.2 m, would permanently inundate over 70 % of the existing port facilities, 2400 miles of connecting roads, 9 % of the railway lines and 3 airports, whereas extreme coastal sea levels (ESLs) of 5.5 m above the current mean sea level would create transient flooding of more than 50 % of the US Gulf Coast interstate and arterial roads, 98% of port facilities, 33% of railways and 22 airports (Karl et al., 2009).

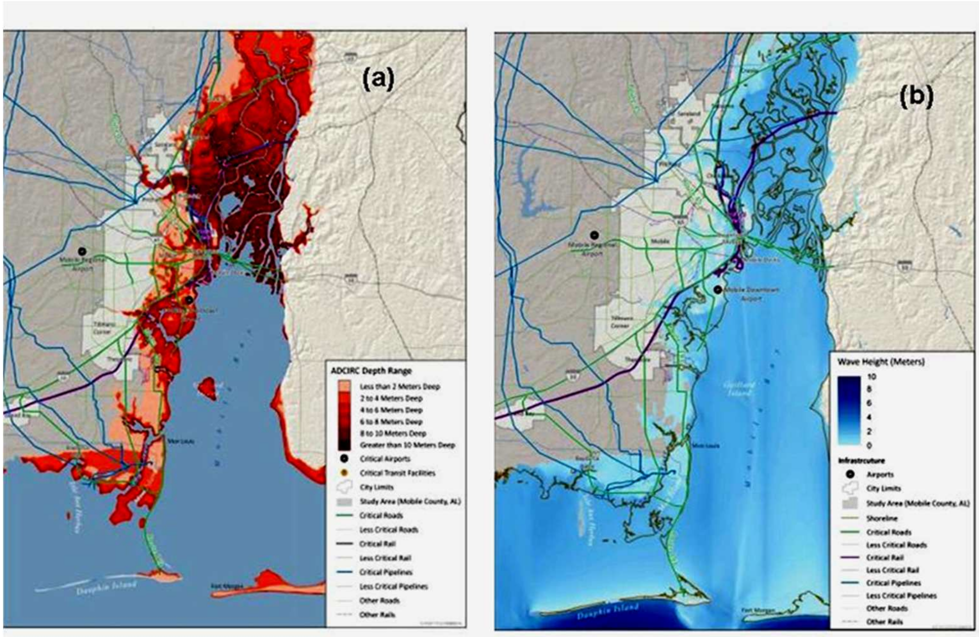


Figure 2-6 Inundation/damage risk of critical transport infrastructure elements at Mobile (US Gulf coast) under a storm surge according to a Hurricane Katrina shifted path scenario and 0.75 m mean sea level rise: (a) storm surge depths (depth in m, relative to the current dry ground); (b) wave heights (USDOT, 2012).

A down-scaled case study of the port Muelles del Bosque, Cartagena (Colombia) has found that CV & C could cause: (i) changes in the level and patterns of shipping traffic; (ii) increased flooding that could affect port operations and damage stored goods; (iii) reduced navigability of the port access channels and; (iv) significant business implications (Stenek et al., 2011). A recent UNCTAD study (UNCTAD, 2017b) with a focus on Caribbean Small Island Developing States (SIDS) has also found that some seaports in the Caribbean are particularly exposed to climatic changes (Fig. 2-7), even under the 1.5 °C global warming scenario, supported by AOSIS in the Paris Climate Agreement[15]. In this area, extreme sea levels (ESLs) will increase significantly with time. The need for requisite seaport adaptation measures is also indicated by the projections relevant to the return periods of the ESLs, which form fundamental design parameters for coastal transportation infrastructure and/or any proposed technical adaptation measures. Under the 1.5 °C warming scenario, which is regrettably projected to be reached in the early 2030s[16] the ESL_{100} of the baseline period (i.e. the 100-year extreme sea level in 1995) will occur about every 10 years, becoming the 1-year event before 2040.

Hydro-meteorological extremes, such as heavy rainfall/floods and droughts are already causing substantial damages to coastal transport infrastructure and services. Changes in extreme precipitation may result in coastal riverine floods that can cause direct damages, requiring emergency responses as well as measures to support the infrastructure's structural integrity (USDOT, 2012). Flooding from intensifying extreme rainfalls/downpours, as well as other associated extreme events (e.g. landslides), will increase disruptions/delays in rail and road transportation, affecting also connections/access to seaports. Increased intensities of tropical storms/hurricanes could lead to evacuations, infrastructure damage/failure and transportation interruptions. Standing flood waters could have severe impacts: for example, costs due to long-term road submersion in Louisiana (USA) have been estimated as US$50 million for 200 miles of the state highways (Karl et al., 2009). Seaport connecting railways could be also severely impacted from track and line side equipment failure, flood scours at bridges/embankments and culvert washouts. Inland waterways that service seaports can also be affected by floods and droughts; floods can lead to suspension of navigation,

[15] The Alliance of Small Island States (AOSIS) have strongly advocated for a cap of 1.5 °C on global warming above pre-industrial levels; This has been included as an aspirational target in the 2015 Paris Agreement (Benjamin and Thomas, 2016).
[16] The date year that the temperature will increase 1.5 ºC above the pre-industrial levels has been projected using the complete ensemble of CMIP5 General Circulation Models (Taylor et al., 2012) and following Alfieri et al. (2017). The analysis projected that the AOSIS 1.5 ˚C temperature increase cap would be regrettably reached by 2033 under the IPCC RCP4.5 and by 2028 under the RCP8.5 (for details, see Monioudi et al., submitted).

silting, changes in river morphology and damages to banks and flood protection works, whereas droughts could also affect services, due to low river levels (Beniston and Díaz, 2004; Jonkeren et al., 2007; UNECE, 2013).

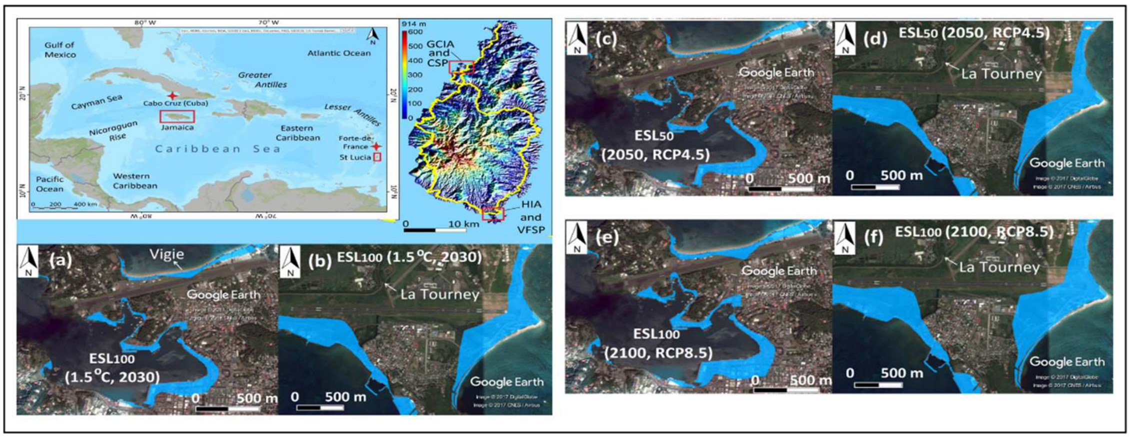


Figure 2-7 Projections of the inundation (flooding) of the of the seaports and coastal airports) of the Caribbean SIDS St Lucia, under different scenarios of Climate Variability and Change (UNCTAD 2017b). Key: CSP,Port Castries; GCIA George Charles International Airport; VFSP, Vieux Fort sea port; HIA, Hewanorra International Airport. (a) and (b): inundation of CSP, GCIA and VFSP and HIA under ESL_{100} for the 1.5 °C warming scenario (2030); (c) and (d) inundation of CSP, GCIA and VFSP and HIA under ESL_{50} (2050, RCP4.5); (e) and (f) Inundation of GCIA, CSP, HIA and VFSP under ESL_{100} (2100, RCP8.5).

Extreme winds, which have been projected to be more catastrophic in the future (e.g. Rahmstorf, 2012), can cause coastal defense overtopping, infrastructure failure and service interruptions (UNECE, 2013; 2015). Heat waves may limit operations and cause pavement/track damages (Vogel et al. 2017). UNCTAD (2017b) has estimated that in the early 2030s, staff working outdoors at Caribbean seaports (e.g. in Jamaica and Saint Lucia) could be at high health risk from heat and humidity for 2-5 days/year; by 2081-2100, the number of such days could increase to 30-55 days/year. At the same time, energy demand/costs for heating, ventilation and cooling (HVAC) systems will also increase. In the Jamaican seaports, a 1.5 ^{0}C temperature rise will raise energy requirements by 4 % for 214 days/year, whereas a 3.7 ^{0}C temperature rise (2081-2100) would increase energy requirements by 15 % for 215 days/year.

Arctic warming may lengthen the arctic shipping season and introduce new shipping routes (Fig. 2-4). There may be new economic opportunities for Arctic communities, as reduced ice extent will facilitate access to the substantial arctic natural resources as e.g. the hydrocarbon fields of Beaufort and Chukchi Seas, as well as international trade. At the same time, Arctic warming will result in (a) greater coastal erosion due to increased wave activity at the polar shorelines (Lantuit and Pollard, 2008) and (b) increasing costs in the development and maintenance of transport infrastructure due to thawing permafrost[17]. The next few decades might prove to be quite unpredictable for shipping services through the new Arctic routes due to (amongst others): (a) the high interannual variability of the sea ice extent in the Canadian Arctic; and (b) the loss of sea ice from the shipping channels of the Canadian Archipelago that might allow more frequent intrusions of icebergs that would impede shipping through the NW Passage (ACIA, 2005).

In terms of damages/losses, tropical cyclones and related storm surges can cause very considerable damages (in the order of tens of billion dollars) to seaports and surrounding environs. Nicholls et al. (2008) assessed the population/asset exposure in 136 port cities with more than one million inhabitants (in 2005) and found that, by the 2070s, about 120 million people in these cities will be exposed to extreme events, in the absence of effective coastal protection responses. Lenton et al. (2009) included tipping point scenarios and estimated

[17] Permafrost thawing presents serious challenges for transportation, such as settling and/or frost heaves that can affect the structural integrity and load-carrying capacity of seaport tarmac surfaces as well as of those of the connecting road networks (UNECE, 2013).

that, by 2050, asset exposure in the same 136 port megacities will be close to 28,000 billion US dollars. For Europe, Pecherin et al. (2010) have estimated that an increase of 1 m in the ESLs above the current 100-year-storm event[18], would result in direct damages and repair costs of up to €2 billion, excluding operational and connectivity costs.

Table 2.1 Summary of major CV & C impacts on ports

Climatic Factor	Impacts on open sea, estuarine and inland waterway ports
Sea level (mean and extreme)	
(i) mean sea level changes; (ii) increased destructiveness of storm surges/waves; (iii) changes in the wave energy and direction	Damages in port infrastructure/cargo from incremental and/or catastrophic inundation and wave regime changes; higher port construction/maintenance costs; potential modulation of tides causing sedimentation/dredging in port/navigation channels and operational time table changes; effects on key transit points; increased risks for coastal road/railway links; relocation of people/businesses; insurance issues
Temperature	
Higher mean temperatures; (ii) heat waves and droughts (iii) increased spatio-temporal variability in temperature extremes	Damage to infrastructure/equipment/cargo and asset lifetime reduction; increases in the staff health risk; higher energy consumption for cooling terminals and cargo; restrictions for inland navigation that may affect estuarine port competitiveness (e.g. port of Rotterdam); reductions in snow/ice removal costs; extension of the construction season; changes in transport demand
In arctic areas, permafrost degradation and reduced arctic ice coverage	Major damages in infrastructure; coastal erosion affecting road and rail links to ports Longer shipping seasons-NSR; new shorter shipping routes-NWP/less fuel costs, but higher support service costs
Precipitation and Fog	
Changes in the mean and the intensity and frequency of extremes (floods and droughts)	Land infrastructure inundation; damage to cargo/equipment; navigation restrictions in inland waterways; network inundation and vital node damage (e.g. bridges); problems in port equipment operations (e.g. cranes); changes in demand
Increases in fog intensity/duration	Impact on ship and terminal operations (reduced visibility)
Wind	
Extreme harbour winds	Problems in seaport navigation and berthing; operational disruptions due to inability to load/unload

Another study (EC, 2012) provided an initial estimation of the future risk for European coastal transport infrastructure due to the combination of mean sea level rise and storm surges; a combined level of 1 m sea level rise above the current levels was projected to cause direct damages of about €18.5 billion to coastal transport assets. Hoshino et al (2016) have estimated inundation levels and potential costs under the combined mean sea level rise and typhoon storm surges for the Tokyo Bay area and found that costs could be crippling (Fig. 2-8). In Table 2.1, a summary of the impacts projected under CV & C is presented.

[18] Costs assumed in the study: €10 million/km of road surface; repair costs at about €250 thousands/km)

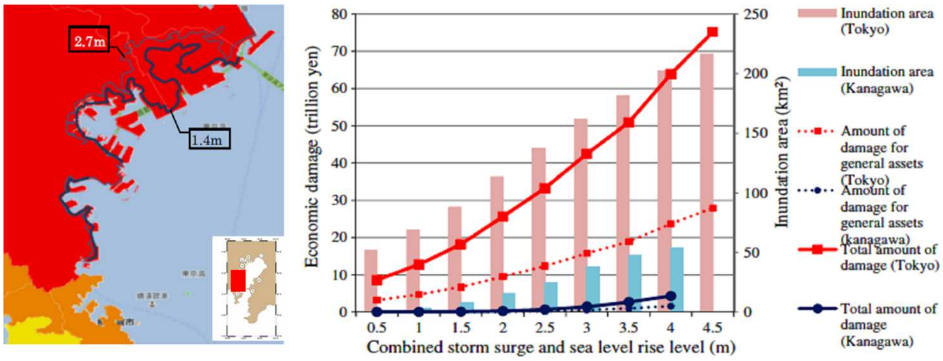


Figure 2-8. Projected port city damages due to combined mean sea level rise and storm surge (Hoshino et al., 2016). Areas at flood risk in the Kanagawa area (Tokyo Bay) for the mean expected storm surge due a typhoon storm in the year 2100 for a 0.59 m (thick blue line) and 1.9 m (thin blue line) mean sea-level-rise (MSLR) and simulated damages for Tokyo and Kanagawa port areas due to combined mean sea level rise and storm surge. 30 trillion yen are about 265 billion US$.

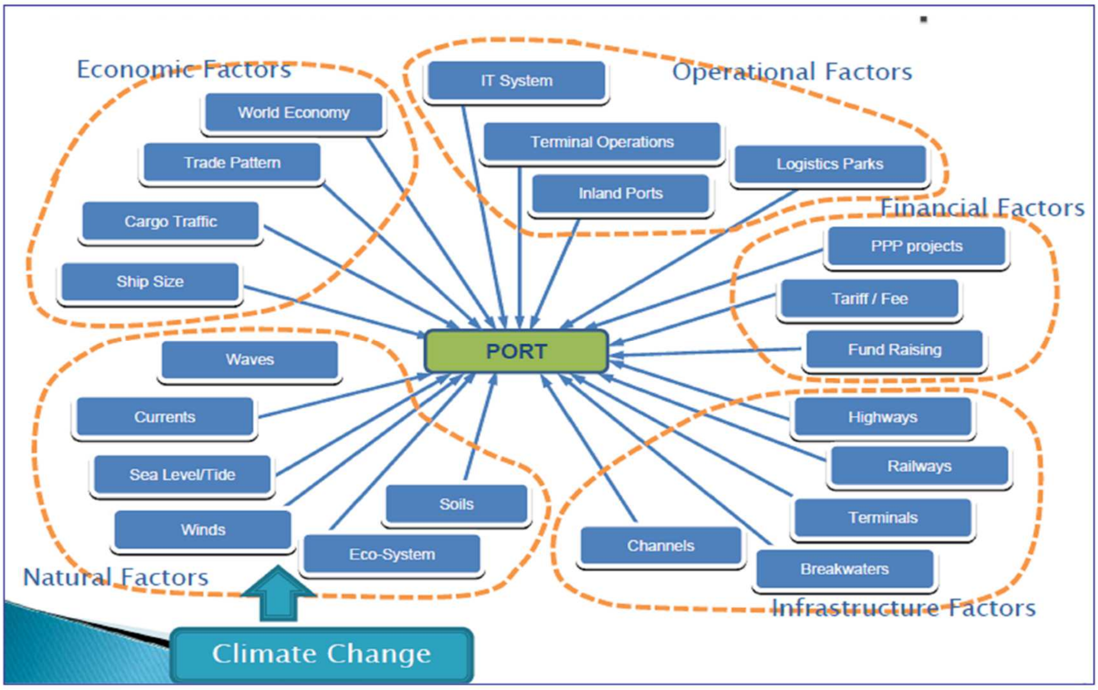


Figure 2-9. Interacting critical socio-economic factors in a port (Inoue, S., 2013. Incorporating Climate Adaptation in Port Dynamism. European Commission Joint Research Centre, The Scoping Workshop on Sea ports and Climate Change, 4th to 5th March 2013, Brussels)

The information presented in this section concerning the expected impacts of CV & C on seaports is not exhaustive and does not take into account indirect impacts[19]. Seaports are complex organizations, with many interacting components that can be stressed by multiple socio-economic factors (Fig. 2-9). A detailed assessment of the climatic impacts on seaports should include projections concerning these different interacting components, as well efficient network analysis to rank their vulnerability in order to prioritize the requisite adaptation responses. Of more general importance is the need to start mainstreaming consideration

[19] Transportation is a demand-driven industry. Climate Variability and Change can have significant effects on almost all sectors of the economy, and thus affect transport services indirectly, through e.g. changes in commodity demand and tourism transportation (UNECE, 2013; UNCTAD, 2017a).

of CV&C in seaport operational and planning decision making processes (see also McEvoy et al., 2013; Ng, et. al. 2016).

3. Seaport survey questionnaire: results

The seaport survey questionnaire was developed by the UNCTAD Secretariat in consultation with experts and port industry stakeholders, including the International Association of Ports and Harbors (IAPH)[20]. The questionnaire was widely circulated to the port industry, with the (online) distribution assisted by industry associations such as the IAPH and the American Association of Port Authorities (AAPA).

The questionnaire comprised 41 questions (Appendix A) and was structured as follows. Part I sought to obtain general information on the profile of respondent ports. Part II included a set of questions designed to obtain historical information on weather and/or climate impacts, whereas Part III sought to obtain information on the availability of information required for the assessment of the vulnerability of seaports to CV & C. Finally, Part IV focused on the resilience and preparedness of seaports as well as on approaches concerning climate adaptation planning. A total of 44 completed questionnaires were received from ports (hereinafter “respondent ports”), with full results shown in Appendix B. An analytical overview of these responses is presented in the following sections. Note that the survey results and their analysis refer to the aggregated information from all respondent ports that have answered the relevant question. Moreover, as indicated in the survey questionnaire (Appendix A), answers and comments are not ascribed to any particular (named) port.

The survey can be regarded as representative, as the respondent ports handle collectively a significant share (16 %) of the global seaborne trade (based on 2017 figures) (see Section 3.1). Nevertheless, there are also limitations to the survey. First, the majority (73 %) of respondent ports were located in developed countries, which may introduce some ‘bias’ in the results; for example; there have been no responses from Caribbean seaports, a region particularly exposed to CV & C (see Section 2.2). Secondly, as the questionnaire was circulated via industry associations to port management, individuals who have provided answers might not necessarily be part of a port department familiar with the specific issues addressed by the survey.

3.1 Part I: Profile of respondent ports

Respondent ports were located in 29 countries representing all regions [Questions 1 and 2 (Q-1 and Q-2), Appendix B]. Most respondent ports were located in Europe (36%), Asia (30%) and North America, with few responses received from Oceania (7%), Africa (5%) and South America (2%). 30 respondents (69% of the total) declared themselves as port authorities, 6 as terminal operators, 5 as private ports, 2 as port management companies and 3 as other organizations[21] [Q-3, Appendix B]. 41% of respondent ports have also indicated their ownership structure, with the majority of those (78 %) being privately operated although 67 % are publicly owned.

Only 39 % of the respondent ports provided answers to Question Q-4 regarding the spatial characteristics (length and elevation) of port breakwaters, although these form fundamental harbour protection features, particularly for open sea ports[22]. Breakwaters as long as 126 km and as short as 0.9 km were reported (in a large European and a small South American port, respectively), with their average length estimated as about 15 km. Breakwater elevation above the highest sea level occurring on spring tides (i.e. the highest tidal water level), was not always indicated, although this forms a fundamental storm protection design parameter for

[20] IAPH comprises some 200 Regular Members – leading ports in 90 countries, who are public port authorities, private port operators, government agencies responsible for ports. Surveys conducted in the past years show that, combining all IAPH member ports, they handle over 60% of the world sea-borne trade in metric ton and over 80% of world container traffic in TEU.

[21] Together, the two port management companies located in Europe and Oceania represent 24 world seaports. While this means that the total number of respondent ports should be 64, responses received by the port managing organizations are treated as unique individual responses. Five of the six terminal operators are located in Asia and one in Europe, whereas all fully privatized ports are located in Europe.

[22] Breakwaters are stone and/or concrete structures constructed with the main purpose to protect the inner harbour(s) from the incoming waves. They are necessary for open sea ports, but may not be requisite protection structures in estuarine ports not exposed to energetic waves.

ports[23]. It should be noted that, although in some cases the absence of response is related to the location of the port (e.g. breakwaters may not be needed in estuarine ports), information on this significant port design parameter appears not to be readily available within the respondent port management structure.

Almost all respondent ports (98 %) addressed the question on their hinterland connections [Q-5. Appendix B], highlighting elements of vulnerability but also resilience. CV & C may affect all connecting transport modes (see Section 2.2), but port connectivity through alternative transport access routes and modes provides redundancy and enhances resilience. All respondent ports reported having road links to the hinterland. However, less than half (47 %) of the respondents, representing all regions, indicated having both road and rail hinterland links and only one third (33 %) reported as having hinterland links through all three modes of connecting transportation (road, rail and inland waterways). It appears that about a fifth of the respondent ports rely only on one transport mode (road) for hinterland connectivity, making them dependent on the resilience of road networks to the variability and change of several climatic factors (Section 2.2).

Most of the respondent ports provided information on total cargo throughput (41 out of a total 44) and indicated that they are multi-purpose facilities, with 88 % able to handle containerised trade, 83 % dry cargo, 51 % petroleum products, 46 % chemicals, 20 % crude oil and 39 % gas [Q-6]. 61% of the respondents indicated that they have also passenger facilities, although passenger traffic was not significant in terms of volumes (maximum annual passenger traffic reported was about 20,000 passengers). Annual ship calls in the respondents' ports varied between a high of 31,052 and a low of 103 ship calls and involved different vessel sizes (from less than 1,000 to over 500,000 deadweight tonnage (dwt), including ultra-large container ships of 18,000 twenty-foot equivalent units-TEUs). Based on the throughput volumes reported and according to an existing benchmark to categorize ports by size[24], 44 % of the respondents can be classified as *large* ports, 20 % as *average-sized* and 37 % as *small* ports. The largest respondent, who reported throughput volumes nearing 200 million tons, is located in Asia and the smallest in Europe (cargo volumes less than 500 tons per year). It should be noted that the respondents form a representative sample of the port industry as they handle collectively a significant share of the global seaborne trade (16 % of the total, based on 2017 figures, UNCTAD 2017a).

In relation to future investment plans [Q-7, Appendix B], the response rate was 98 %. An overwhelming majority (93%) of the respondents indicated that they were planning investment in the next five years. Investment was planned by ports of all sizes, with the largest investment reported by an average sized port in the Middle East. Regarding the total value of planned investments ([Q-8], response rate of 85 %), absolute figures range between US$ 2 million and US$ 3 billion, with an average investment value of US$ 455 million; the highest investment (more than US$ 1 billion) were indicated by ports in North America, Europe and Asia. The results also suggest that port authorities plan to invest higher amounts than management companies and privatised ports.

Investment is expected to be allocated across 7 particular cost items (Fig. 3-1), with infrastructure accounting for a large share (54 %) of the total value of the planned investment [Q-9]; some ports indicated that all planned investment would be allocated to infrastructure. It is interesting to note that the respondents plan large share of the investment (16 % of the total) for the construction of new (or the upgrading of existing) sea defenses (e.g. breakwaters).

[23] Breakwater elevation, which controls (amongst others) overtopping by storm surges and waves, is a fundamental port design parameter, and one that will certainly be affected by CV & C. The higher extreme sea levels (ESLs) and waves projected for the 21st century (Section 2.1.2) that will be superimposed on the current highest astronomical tidal level will probably require major breakwater upgrades/re-designs.

[24] See Patrick Fourgeau, "Measuring Port Performance", World Bank, November 2000. According the benchmark proposed, small ports handle up to few million tons, average sized ports between 10 and 20 million tons and large ports over 20 million tons. One-third of the respondent large ports (located in Europe, North America, Asia and Africa) indicated that handle over 100 million tons annually.

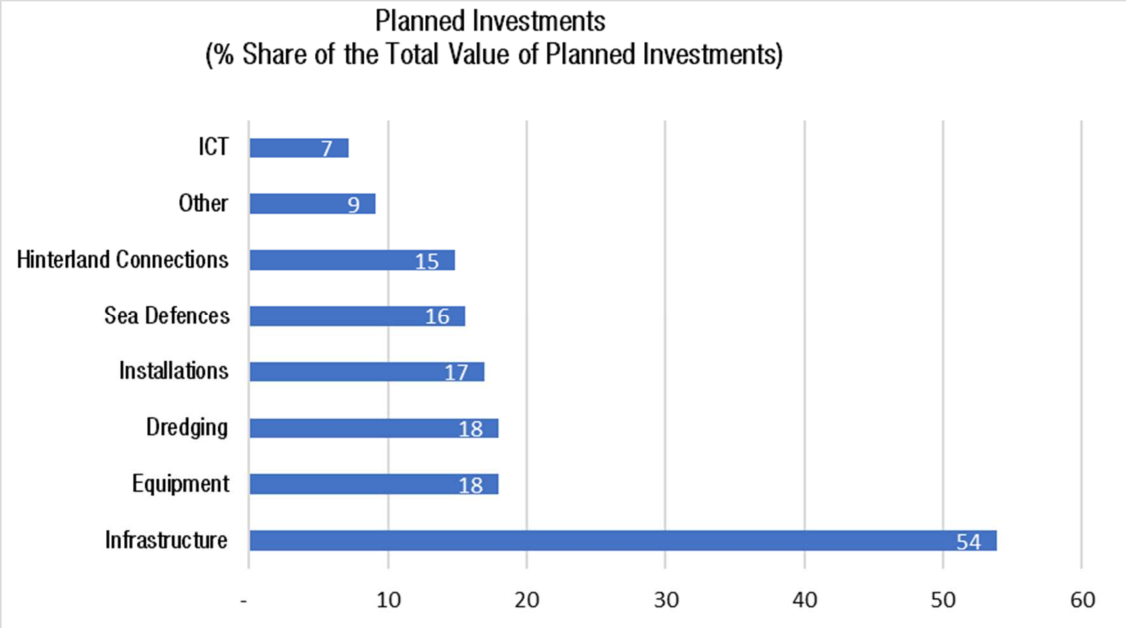


Figure 3-1 Overview of the type of investment as a share (%) of the value of total investment planned by the respondent ports until 2019. The values shown are aggregated from all ports.

Most (83 %) ports who answered the question Q-10 (response rate of 91 %) have reported that their planned investment would take into account weather or climate-related factors [Q-10, Appendix B). Respondents reporting no consideration of weather or climate-related factors in their investment plans are located in Europe (4), Asia (2) and North America (1), although some of those have been already impacted by weather or climate-related events[25].

3.2 Part II: History of weather or climate-related impacts on seaports

A significant majority of respondent ports (72 %) confirmed that their port/terminal had been impacted by weather or climate related events, including by extremes (response rate of 98%) [Q-11, Appendix B]. In terms of geographical distribution, Asian ports, including in the Asia-Pacific region, dominate the list of ports being impacted (33%), followed by European (30 %) and North American ports (27%). 28 % of ports reported no CV & C impacts, with most of those (59 %) located in Europe. Interestingly some respondent ports (of all sizes and across regions) that reported not considering climate and weather factors in their investment plans (see [Q-10] above) appear to have already been impacted by CV & C.

Ports were also asked to indicate the extent and type of impacts (e.g. physical damage; impacts on operations and delays [Q-12]). Response rate to this question was 60 % with Fig 3-2 providing an overview of the responses. About a third of the respondents, representing ports mainly in Europe, Africa and North America, reported having suffered significant physical damage as a result of weather/climate related events, with a further 15 % indicating some physical damage. Most respondents (55 %) indicated that had experienced some impacts and 21 % (most of which in North America, Africa and Asia) reported significant impacts on operations. 24 % and 26 % of the respondents (ports of different sizes, spread across regions) reported experiencing significant delays and disruptions/interruptions, respectively. Generally, responses indicate that the majority of respondents have suffered some or significant impacts of weather/climate related events in terms of operations (76 %), delays (60 %) and disruptions to services/operations (78 %), with around 45 % of respondents having also experienced some or significant physical damage.

[25] It is likely that these impacted ports had already upgraded their defenses and are therefore not planning any further relevant investment in the next few years.

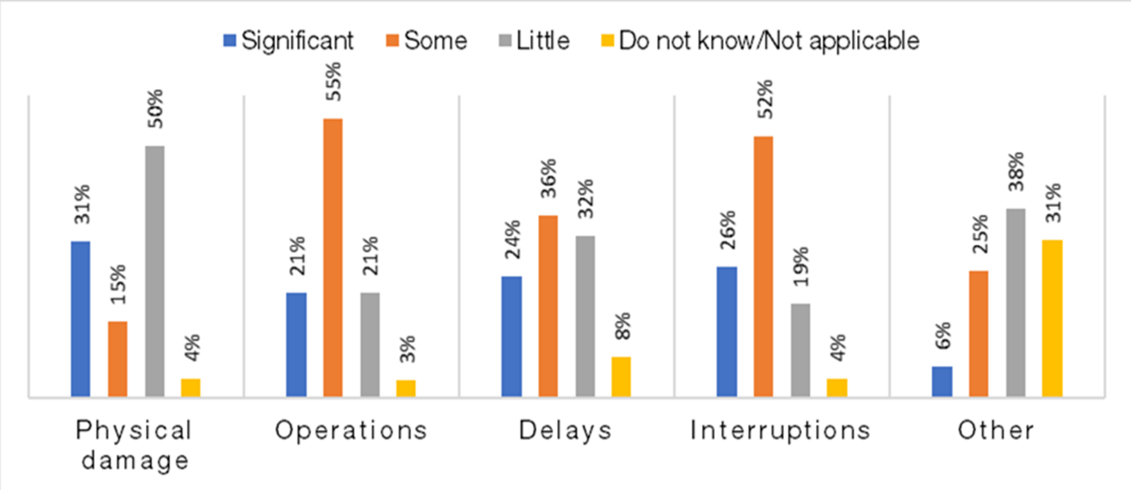


Figure 3-2: Extent and type of damages of respondent ports

Of interest in this context are the weather/climate related factors identified by respondents in respect of past impacts [Q.13]. Survey respondents were asked to provide information on impacts of different climatic factors on different port components. Figure 3-3 provides an overview of the answers received.

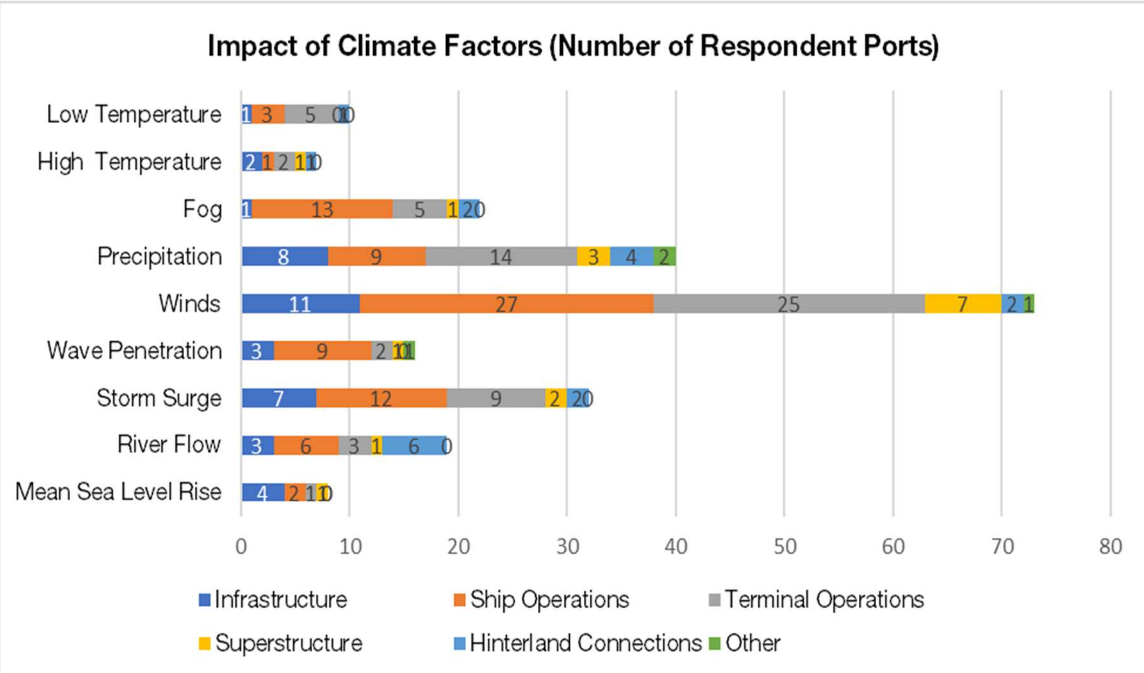


Figure 3-3 Impact of climate factors on port infrastructure, operations and services (Number of respondent ports)

Responses indicate extreme winds as the climatic factor with the most significant impacts[26]. Extreme winds can cause overtopping of coastal defenses, infrastructure and equipment failure and service interruptions (see Section 2.2 and Table 2.1) and were reported to have affected ship operations (27 respondents), terminal operations (25 respondents), infrastructure (11 respondents) and superstructure (7 respondents). Two respondents reported also impacts on their hinterland connections. Port operations appear to have been

[26] See also Mutombo and Ölçer, 2017.

affected in all regions, while impacts on infrastructure were reported mainly by ports of all sizes in North America, Europe, Asia and Oceania; impacts on port superstructure seem to have been experienced mainly in two large North American and European ports and on the hinterland connections in Asia. It should be noted that high winds are quite difficult to predict; nevertheless it has been suggested that extreme wind events (including those associated with hurricanes and typhoons) might become stronger in the future due to global warming (Section 2.1.2).

Responses indicated heavy precipitation as the second most important climatic stressor that has caused problems to respondents across regions, including effects on terminal operations (14 respondents), ship operations (9 respondent ports) and infrastructure (8 respondents). Hinterland connections of 4 respondents (from Europe, North America and Asia with multimodal hinterland connections) were also impacted, albeit to a lesser extent. There were also reports of problems across the regions and affecting ports of different sizes, caused by storm surges; impacts were associated with ship operations (12 respondents), terminal operations (9 respondents) and infrastructure (7 respondents) and to a lesser extent with superstructure (2 respondents) and hinterland connections (2 respondents). Fog was also suggested as a climatic stressor with significant implications for ports, having impacted mostly on ship operations (13 respondents, mostly in North America) and terminal operations (5 respondents) (Fig. 3-3). Other impacts reported were associated with: (a) river flow/level increases inducing flash floods in the ports and connecting networks, or river flow/level decreases affecting the navigability of connecting inland waterways (UNECE, 2013); and (b) wave penetration into the inner harbours, affecting mainly ship operations (9 respondents), infrastructure (3 respondents), terminal operations (2 respondents). With regard to the latter, terminal operation impacts were reported by two large European and North American ports located in the neighborhood of recurrent storm tracks. Few respondents, mainly in Asia, North America and Europe, reported also impacts from mean sea level rise (MSL) on infrastructure (4 respondents) and ship operations (2 respondents). Finally, low and high temperature related impacts were reported by few ports[27].

In order to gain an understanding of the perceived changes in relation to the damages and/or disruptions caused by weather/climate related events, ports were asked to indicate if damages/disruptions over time had increased, decreased or had remained unchanged [Q-14]. Around half of the respondents (91 % response rate) reported that the magnitude of weather/climate related events had remained unchanged over time, whereas 6 respondents (from Asia, Oceania, Africa and North America) reported an increase in the magnitude of damages/disruptions. It is noteworthy that 7 respondents (from Europe, North America and Japan) reported a decrease in the magnitude of their damages and/or disruptions due to specific adaptation measures taken. A large US-based port reported that it used an independent vulnerability assessment that has considered likely future impacts and has incorporated the findings into the upgrading and/or future design of its terminals.

Given that the above results indicate historical weather and climate related impacts, it is noteworthy that only 32 % of respondents indicated that their users/clients had asked for effective response measures to be taken ([Q-15], response rate of 86 %). At the same time, a significant majority (79 % of the respondents) noted that there had been no particular changes in insurance premiums or terms or coverage as a result of CV & C ([Q-16], response rate of 89 %); respondents reporting changes in the insurance conditions (21 %) were mainly located in North America, Africa, Oceania and Europe.

Additional comments by respondents [Q-17, Appendix B] include the following: (i) rising mean and extreme sea levels could significantly impact on port superstructures, underground utilities, vaults, wharves, etc. due to lack of effective breakwaters and other protective infrastructure (comment by a small North American port); protective measures had been taken by a large European port in relation to the deviation/water management of a river the high flows of which had previously inundated the port and the city; an average-sized North American port has already performed a Resiliency & Infrastructure Planning Study to determine potential climate change impacts; a major breakwater expansion/upgrade scheme of a large Asian port involving 6.8

[27] As detailed in Section 2.2, increases in the frequency/intensity of extreme high temperatures and decreases in those of extreme cold events are expected in the 21st century (e.g. Coumou and Rahmstorf, 2012). This will probably result in increases and decreases in staff health risks and energy costs, respectively. It should be also noted, that although snow/ice and permafrost impacts were not included in the questionnaire, few respondents (about 10 %, indicated by the responses for low temperatures) could possibly have been affected; there were not also relevant comments [Q-17].

km of breakwaters and completed in 2012 considered climate variability and change in the planning/design; and self-insurance against weather/climate related impacts is used by a North American Port.

3.3 Part III: Availability of and needs for weather and climate-related information

A major objective of the questionnaire survey has been to assess potential data availability gaps and information needs of seaports in relation to weather/climate related factors. To this end, ports were asked questions on the availability of: (i) past and present data related to selected weather/climate related factors as well as information on potential observed climatic trends in their ports; (ii) the availability of hydrodynamic (flow and wave) information in the approaches to and the basin of the port; and (iii) downscaled forecasts or assessments on the impacts of selected climate factors.

3.3.1 Past and present information on climate stressors

In Question 18 [Q-18], ports were asked to indicate the availability of information on climatic factors relevant to their climatic vulnerability (see Section 3.2). Large percentages of the respondents (including large European, North American and Asian ports) reported lack of (at least, readily available) information regarding very significant port operational and infrastructure design parameters, such as wave height, period and direction (50 %) and average and extreme precipitation (44 %) (Fig. 3-4).

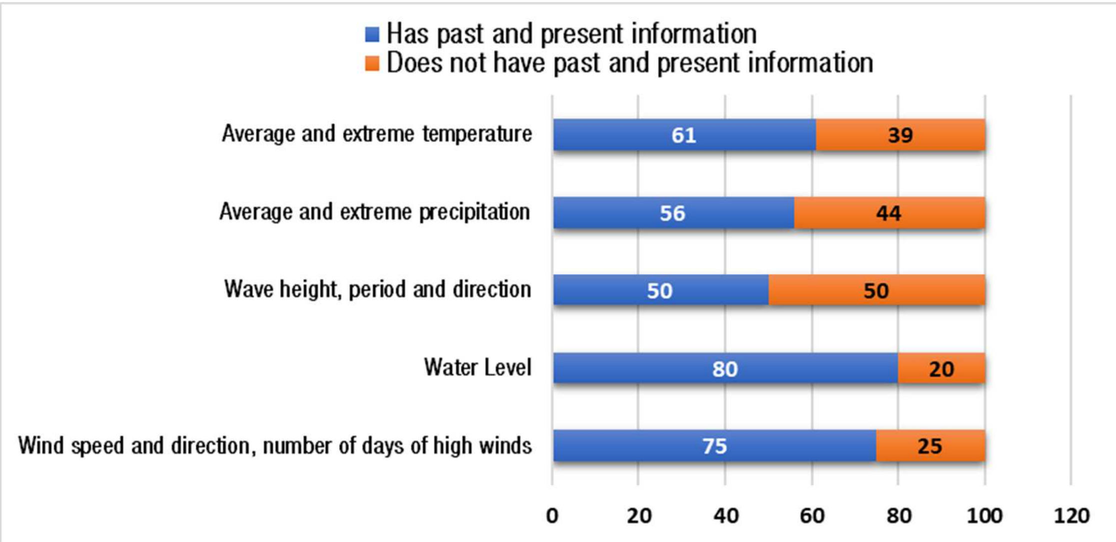


Figure 3-4 Share of respondents (%) in relation to the availability of climatic information by the ports. Response rates to individual question [Q-18] was 91 %.

Even in the cases of the (mean and extreme) sea level and high winds, factors that are related to very significant (at least, operational) constraints, 20 % and 25 % of the respondents, respectively, reported lack of (readily available?) information (Fig. 3-4). It appears that there are information gaps even in the case of ports (e.g. an Asian-Middle Eastern port) that have reported impacts by extreme weather/climatic events. These are surprising results[28], particularly if the high response rates to the question (over 86 % of the total number of respondent ports) is considered.

[28] Not only the costs involved in obtaining these data are rather small (with the possible exception of directional wave and flow data) and easily automated, but also collection of such information will be increasingly required for any port upgrading, both in terms of engineering design and regulation (see, for example, the European Directive 2014/52/EU for the assessment of the effects of certain public and private projects on the environment http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0052&from=EN).

Ports were further asked if any relevant climatic factors showed changes over time which could be considered as trends [Q-19, Appendix B). Results (82% response rate from the 44 respondent ports) show that a significant number of respondents (69 %) reported that they had not discerned any systematic change which could constitute a trend. It is interesting to note that some respondents that did report relevant climatic trends (including North American, European and Asian ports), do not appear to consider the need for requisite adaptation measures, whereas two Asian ports considered adaptation measures as necessary, despite not observing increasing hazard trends [Q-20].

Penetration of long waves into harbours [Q-22] can create significant port operational disruptions (e.g. González-Marco et al., 2008; Rossouw and Theron, 2012). The majority (63 %) of the respondents to this question, however, reported no impacts and only 17 % reported some significant impacts.

Regarding question Q-23 on the availability of information on port hydrodynamics (port currents), the response rate from the respondent ports was 77 %. Responses suggest that most respondents (85%) rely on observations, about 43 % on model simulations, with only a third of the respondents (mostly European and North American ports) reporting that port hydrodynamic information is based on hydrodynamic model simulations validated by long-term observations, which is the most appropriate approach and one that can be utilized for the design of CV & C port adaptation measures (e.g. Gaythwaite, 2016).

3.3.2 Projections of and vulnerability to major climatic stressors

In order to have a clear picture on the availability of projections for selected climate factors, ports were asked to indicate availability of downscaled forecasts/assessments for several CV & C factors [Q-24]: mean and extreme sea level rise; waves; winds; temperature; and precipitation. Figure 3-5 provides an overview the responses.

Overall, responses suggest important information gaps, with the least serious related to the mean and extreme sea level rise forecasts/assessments (information not available to 53 % and 65 % of the respondents, respectively); these results, particularly those for the extreme sea level projections, are explained by the availability of validated hydrodynamic models [Q-23]. The greatest information gaps are related to downscaled information on precipitation (77 %), temperature (75 %), waves (71 %) and wind (68 %). These responses cause concern in relation to resilience and adaptation planning of the respondent ports, given the fact the respondents had ranked these factors high in the list of climatic stressors that had already caused them problems (Fig. 3-3). Moreover, a significant number of respondents reported lack of downscaled forecasts/assessments on two or more climatic stressors.

In terms of geographical distribution, availability of downscaled forecasts/assessments on precipitation and temperature is spread across ports in Europe (including in ports in low lying areas and estuaries), Asia and North America. Respondents reporting availability of downscaled forecasts/assessments on waves and/or winds are mostly located in Europe and North America. Concerning mean sea level rise, respondents having downscaled forecasts/assessments are spread across Europe, Asia, North America and Oceania, while forecasts for extreme sea level (ESLs) are available in European, Asian and North American ports. It should be noted that detailed assessments of the port flooding risk under different scenarios and scales are required (Figs 2-6, 2-7 and 2-8, Section 2.2), in order to plan/design appropriate adaptation measures.

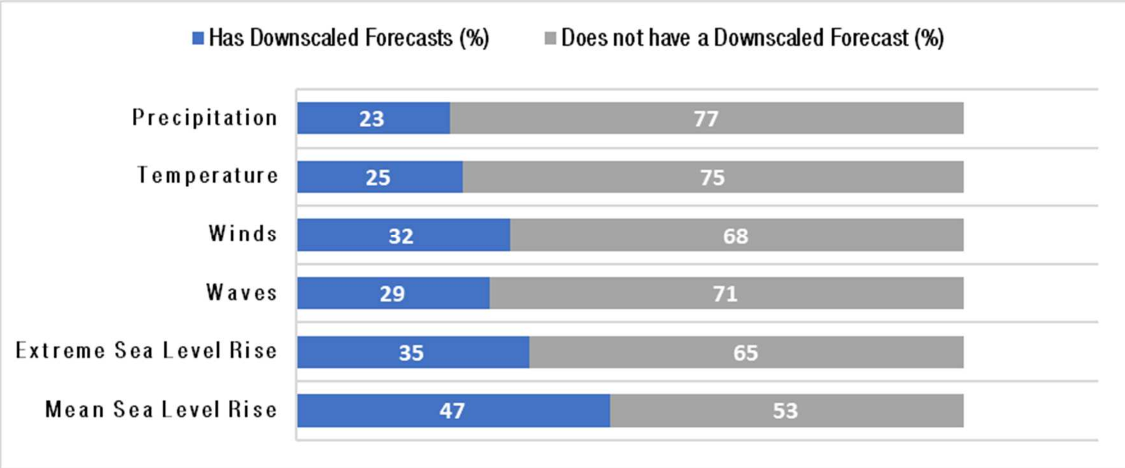


Figure 3-5 Availability of downscaled forecasts/assessments on selected weather/climate related factors (% of respondent ports)

Regarding the timescale of available downscaled forecasts/assessments [Q-24], respondents with downscaled forecasts (a minority) tend to have projections for different time periods (Fig. 3-6). Short and mid-term projections (for 10 and 30 years, respectively) appear be the most available, with the exception of mean sea level rise.

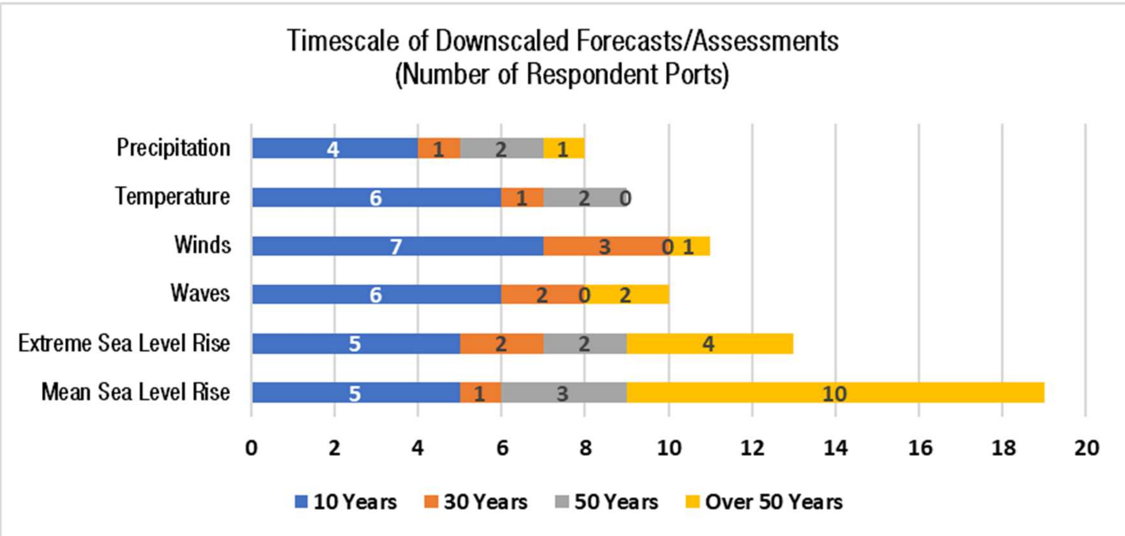


Figure 3-6. Temporal availability of downscaled forecasts/assessments (Number of respondents)

3.4 Part IV: Resilience, level of preparedness and adaptation planning

A major objective of the survey has been to obtain information on the level of preparedness and resilience of the ports, as well as on their status of adaptation planning in relation to CV & C impacts. Questions asked were related to the: feasibility and potential costs of extending and/or upgrading the port sea defenses (e.g. breakwaters); availability of information related to operational and/or failure thresholds for port infrastructure and equipment; availability of emergency response measures; the availability or planning of climate vulnerability assessments; type of climatic stressors and impacts considered in port vulnerability assessments; status of mainstreaming weather/climate related issues in port management/planning; and the status of adaptation response planning and implementation.

Ports were asked about both the feasibility [Q-26] and costs [Q-27] of extension and/or upgrading of port breakwaters. In response to the first of these questions [Q-26, response rate of 59 %), 54 % of the respondents indicated that breakwaters could be upgraded, if required, at manageable costs. However, only 25% of respondents (located in Europe and Asia) provided information about the expected costs [Q-27]; these ranged between a low of 15 million US$ to a high of US$ 118 million.

Ports were further asked to report on the availability of climatic stressor thresholds that could impair the integrity and functionality of infrastructure [Q-28] and equipment [Q-29]. Identification of infrastructure and equipment failure thresholds is crucial in determining the vulnerability of facilities (UNCTAD, 2017b). Response rates for both questions were low (39 and 36 %, respectively), indicating potential information gaps (and/or constraints associated with the internal communication of relevant information), with potentially significant implications for the assessment of ports' vulnerability to CV & C as well as for the planning of requisite adaptation measures.

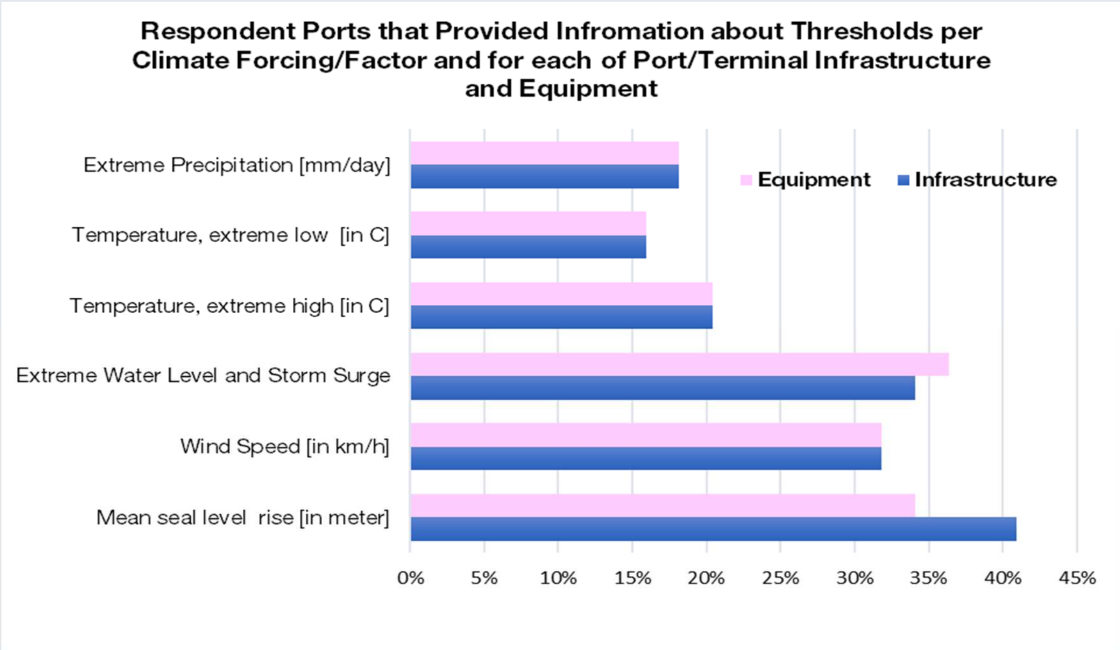


Figure 3-7 Respondents that provided information on climatic stressor thresholds for infrastructure and equipment

Few of the respondents (16 %) provided thresholds for extreme low temperatures, whereas 41 % of the respondents provided thresholds for infrastructure integrity related to mean sea level rise (Fig. 3-7). Reported infrastructure thresholds for mean sea level rise varied between less than one meter to 10 meters, with thresholds of 1 and 2 m being the most commonly reported; equipment thresholds also varied between less than one meter to 5 meters. Regarding wind speeds, reported infrastructure-related thresholds ranged from few km/h to 266 km/h, with the 50 to 100 km/h range indicated as the most common threshold for both infrastructure and equipment (see [Q-28] and [Q-29], Appendix B).

In relation to thresholds related to extreme sea levels, reported thresholds for both infrastructure and equipment ranged between less than one meter and 7 meters, with the most commonly reported values being 3 and 5 m. Most (6) respondents indicated high temperature related thresholds in the range of 36 - 60 °C for equipment, whereas reported thresholds for extreme precipitation were up to 500 mm/day and 1000 mm/day for equipment and infrastructure, with the most common threshold value reported being 100 mm/day.
Ports were asked to indicate if any emergency response measures relevant to climatic stressors were either in place or being planned [Q-30]. Most (70 %) respondents to the question (response rate of 84 %) reported having emergency response measures in place or planned. Similarly, a majority of respondents (60 %) indicated that the port had assessed or was planning to assess its vulnerability to weather/climate related events ([Q-

31], response rate 80%). In any case, it is a matter of concern that 40 % of respondents reported not having or planning relevant vulnerability assessments.

Ports were also asked to indicate the weather/climate related stressors considered in relevant vulnerability assessments (when applicable) of different port components [Q-32]. The results (Fig. 3-8) suggest that respondents seem to focus on sea level rise, storm surges and winds and to a lesser extent on precipitation and wave penetration in their vulnerability assessments mainly for infrastructure and ship and terminal operations. Climatic stressors mostly considered in the infrastructure vulnerability assessments involve sea level rise (16 respondents), storm surges (14 respondents) and wind (9 respondents); by comparison, in the vulnerability assessments of ship operations, the most considered climatic stressor has been winds (12 respondents), followed by storm surges and wave penetration (7 respondents).

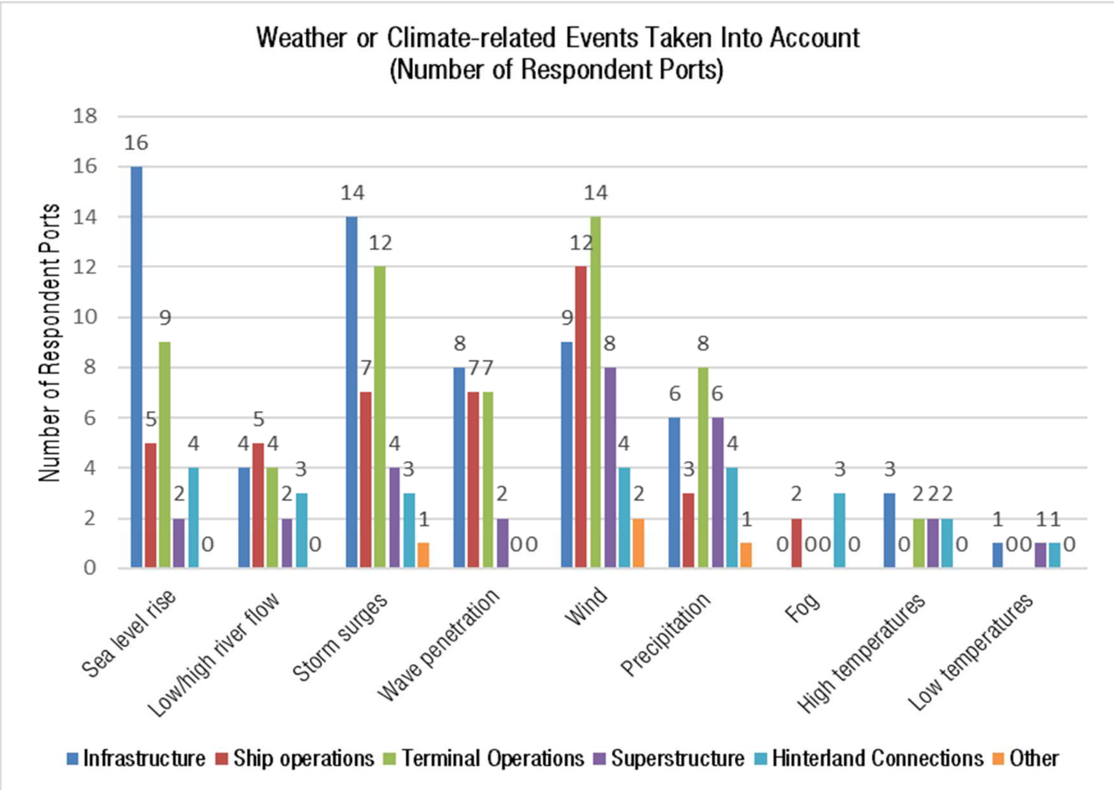


Figure 3-8 Respondent vulnerability/impact assessments (number) that have considered the impacts of different weather/climate stressors on different port components.

In respect of indirect impacts [Q-33], it is interesting to note that a significant share (44 %) of the respondents (question response rate of 59 %) expect impacts on their port due to the effects of CV & C on supply chains, competition, modal shift and industrial production. Around one third of respondents refer in this context to changes regarding investment and energy demand, with few respondents referring to weather/climate induced changes in agriculture (20 %), migration (19 %) and labour shortages (11 %) as likely to impact their respective ports. Figure 3-9 provides an overview of relevant responses.

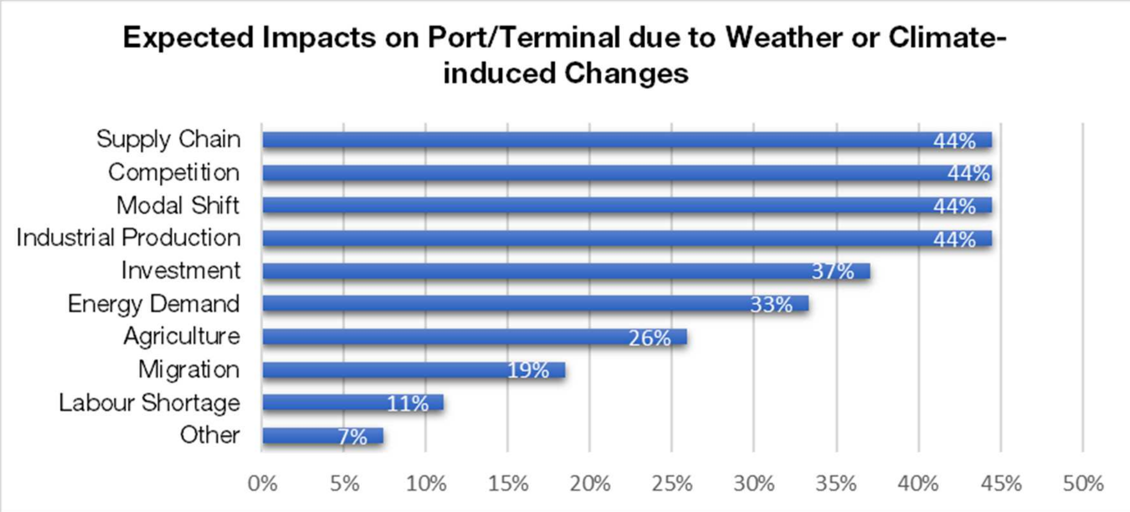


Figure 3-9 Expected (indirect) socio-economic impacts of CV & C on ports indicated by the respondents [Q-33].

Ports were also asked to indicate if they had mainstreamed weather/climate related considerations in planning, design and construction of infrastructure ([Q-34], response rate 77 %). The majority (76 %) of respondents reported that they had mainstreamed such considerations. In addition, a clear majority (59 %) of respondents indicated that they have carried out relevant work, including research, to identify and evaluate possible adaptation measures ([Q-35], response rate 77%). In this context, it is worth noting that a significant proportion (41 %) of respondents *have not* yet carried out any relevant work.

58% of the respondents to a question on the availability of developed or planned corporate adaptation strategies ([Q-36], response rate 75%) answered positively. It is interesting to note that a large proportion (42 %) of the respondents answered negatively; in most cases, the same respondents had also answered negatively in response to [Q-35] which focused on work towards the development of adaptation measures.

When ports were asked to identify areas/aspects covered by implemented or planned adaptation measures ([Q-37], response rate 64 %), they indicated port engineering and planning as the most common fields where adaptation measures were implemented or planned (Fig. 3-10). It appears that respondents consider mostly 'hard' adaptation measures, rather than 'soft' adaptation responses involving e.g. the development of 'fit for purpose' emergency management plans and processes (50 %), or appropriate changes in port operations (32 %) and management (29 %). In this context, it is interesting to note a discrepancy between the answers to this question and those for [Q-24] and [Q-28] (see above) that concerned the availability of downscaled climatic stressor projections and of weather/climate related thresholds the exceedance of which could impair infrastructure integrity and functionality; such information is necessary in order to design efficient and cost effective hard adaptation measures and avoid over-engineering (Narayan et al., 2016; Becker et al., 2016; Fay et al., 2017) .

Around a quarter of respondent ports (27%) responded to a question on estimated or projected total adaptation expenditure [Q-38]. Of these, 58% (a large Asian port, small European and North American ports, a port in South America and others in Asia) provided estimates and figures ranging from US$ 500,000 to US$ 500 million (average of US$ 127.3 million). When asked whether ports had received or expected to receive financial or other assistance in the implementation of adaptation measures from government/non-government sources ([Q-39], response rate 70 %), only 29 % of the respondents, including ports in Africa, Europe and Asia, indicated that this was the case.

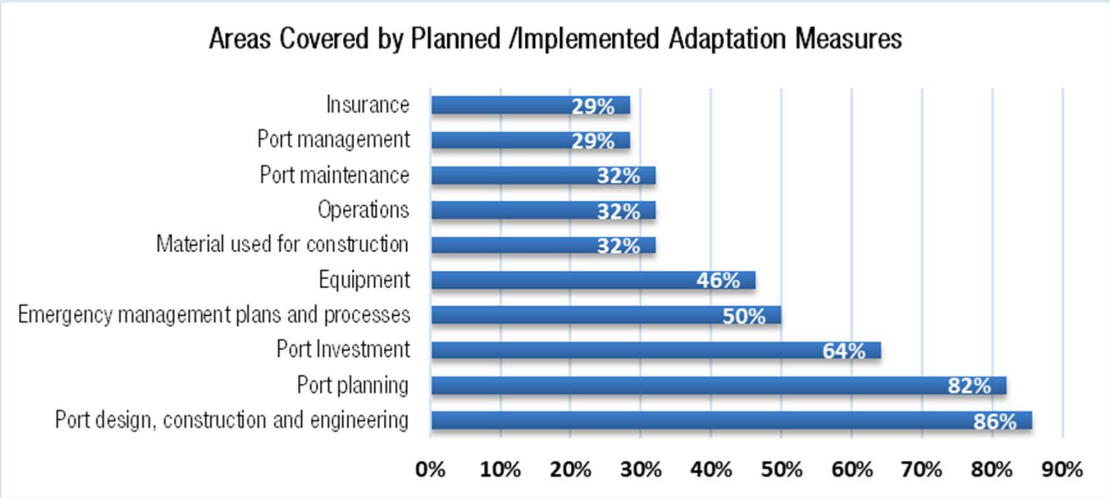


Figure 3-10. Areas covered by implemented or planned adaptation measures [Q-37].

Ports were also asked to provide examples of adaptation measures ('hard' or 'soft') taken that were considered effective, good value for money and examples of good practices [Q-40]. Their responses include the following:

- *Working to measure and account for the carbon footprint of port activities. Renewable energies are being sponsored and studied at the port and by private companies and universities. First port in [Latin American country] that will publish a sustainability report, as part of our commitment to the city and industry.*
- *Real time monitoring of waves and tides [Large European port].*
- *Coastal defenses were erected to prevent flooding due to storm surges, large swells and wind waves [Small North American port].*
- *Following good practices [Large Asian port]*
- *Currently only monitoring for changes. No adaptation is currently planned for implementation [Large US port].*
- *Better forecasting tools for water levels; dynamic under keel clearance management tools; improved bathymetric surveying, tools and data. All are good value and good practices [Large North American port]*
- *Conduct Enterprise Risk Management. To minimize the effect of weather and climate, we built enterprise risk management and Business continuity management. For example if there is idle time when containers fall because of wind (very low, maybe once a year), our management is ready to take steps to improve or cover this event so that business is going as well as usually. [Large Asian Port]*
- *Awareness; Insurance and port design criteria (higher elevation above sea datum). Awareness: climate change and the rise of sea level etc. issues are receiving more attention but not yet by all stakeholders and not yet fully in depth in respect of causes, consequences, remedial measures, preparedness etc. By better awareness of all the above, there would be more, quicker and effective actions in port development planning, management and operations. Insurance: both as spending item for management decision for better protection against potential risks to the port (stronger storms mean higher risks to port assets, ships, cargoes, container...) and also cost item for customers' consideration in choosing and using the port services. Port design criteria: a port's life span could be more than 50 years. So there is a trade-off between higher investment cost by building the facilities on higher elevation (than required under the current construction code/master plan) to sustain higher level/frequency of sea level/tide/wave, and the property damage/business opportunity losses potentially caused by climate change in the future. [Large Asian port]*
- *Development of Robust Planning Codes and Guidelines that incorporate sustainability and climate change related resilience and adaption measures.[Oceanian port]*

In their additional comments [Q-41, see Appendix B] several respondents (Asian, Latin American and European ports) provided information on their approach to climate change mitigation and improving energy efficiency, with some providing nationally relevant information on climate change adaptation needs of transport infrastructure (e.g. in Europe[29]). A large North American port, outlining its approach to the acknowledged need for climate change adaptation, noted: "*It is recognized that Climate Change will impact the Port's future. Anticipated impacts include more intense and frequent wind, rain storms and sea level rise. Adaptation to these Climate Changes will require a combination of Policy, Planning and Engineering responses. Prior to identifying preferred mitigation strategies, it will be necessary for the Port to gain a comprehensive understanding of the consequences of the hazard posed by sea level rise and changes to sea state by conducting detailed studies. Through the studies, the Port hopes to acquire a broad base of technical, policy and planning knowledge to be used to develop a robust and defensible approach to coastal flood and erosion risk.*"

3.5 Summary of findings

In this section, a summary of the above information is presented.

A total of 44 completed questionnaires were received, representing 29 countries across all regions. Most respondent ports are located in developed economies in Europe and Asia, followed by North America (73 % of the total). Respondent ports handle collectively over 16 % of the global seaborne trade, with large ports (i.e. ports with a throughput of more than 20 million tons annually) dominating the sample (44 % of the total). Most of the respondents (69% of the total) declared themselves as port authorities and as multi-purpose facilities, with containerised trade and dry cargo handling terminals reported as available by the majority of respondent ports.

A significant number of respondent ports indicated future investment plans, with infrastructure accounting for the largest share both in terms of the number of ports and the total value of the investment. An overwhelming majority of respondents reported that their planned investment would consider weather/climate related factors. In terms of hinterland access, road networks appear to form the main connecting links, with only a third of the respondents reporting as having all three modes of hinterland connection (road, rail and inland waterways) and a fifth (19 %) reporting only one mode of connecting transport (road).

Most respondents (about 70 %) confirmed that their port had been impacted by weather or climate related events, including by extremes. Most have been somewhat or significantly impacted in terms of operations (76 %) and delays (60 %), with around 45 % of the respondents having also experienced some or significant physical damage. The climatic stressors identified by the respondents as responsible for these impacts included (listed in decreasing order): strong winds; heavy precipitation; storm surges; fog; wave penetration; extreme river flows; mean sea level rise; and temperature extremes. Around 50 % of respondents reported not having discerned any changes or trends in the magnitude of impacts over time, with the remaining divided between perceived increases and decreases of impacts. It is interesting to note that despite extensive past experience of impacts, most respondent ports had not received any related requests for effective response measures from their users/clients, nor observed any changes in insurance premiums and/or levels of insurance.

A major objective of the study has been to assess potential data availability gaps and information needs of seaports in relation to weather/climate related factors. The survey revealed important gaps in terms of information available to seaports. Many respondents (including large European, North American and Asian ports) reported lack of (at least, readily available) information regarding very significant port operational and infrastructure design parameters, such as data on wave height, period and direction (50 %) and average and extreme precipitation (44 %). It appears that there are information gaps even in the case of ports that have reported impacts by extreme weather/climatic events. Regarding the availability of projections for selected climatic stressors, ports were asked to indicate availability of downscaled forecasts and/or assessments. Results suggest that there are also important gaps in climatic stressor projections, with the least serious being those related to the mean and extreme sea level rise (53 % and 65 % of the respondents, respectively). These

[29]http://www.cedex.es/NR/rdonlyres/6F1C362C-B25F-47AB-8E80-AA57FB8144B7/121124/ACCITInformeFinalSeptiembre2013.pdf

responses maybe of concern to respondent ports, in terms of their existing capacity for effective adaptation planning.

A further main objective of the survey has been to obtain information on the level of preparedness and resilience among ports, as well as on the status of adaptation planning in relation to the impacts of climate variability and change (CV & C). Concerning the feasibility and costs of extension and/or upgrading of port breakwaters, the majority of the respondents (54 %) felt confident that breakwaters could be upgraded, if required, at manageable costs (reported as ranging between US$ 15 million and US$ 118 million). Concerning the availability of climatic stressor thresholds that could impair the integrity and functionality of infrastructure and equipment, response rates were low (less than about 40 %), indicating also potential information and/or internal communication gaps, with potentially significant implications for the assessment of ports' vulnerability to CV & C as well as for the planning of requisite adaptation measures.

With regard to emergency response measures relevant to climatic stressors, answers suggested that most ports (about 70 %) have in place or planned emergency response measures. It is a matter of concern, however, that 40 % of respondents reported not having or planning relevant vulnerability assessments.

In respect of indirect impacts, a significant share (44 %) of the respondents expected some impacts due to the effects of CV & C on supply chains, competition, modal shift and industrial production. A majority of respondents indicated that they had mainstreamed weather/climate related considerations in the planning, design and construction of infrastructure; however, it is worth noting that a significant share (41 %) of respondents *have not* yet carried out any work to identify and evaluate potential adaptation measures.

As concerns implemented or planned adaptation measures, respondents identified 'hard' engineering measures as the main course of action, rather than 'soft' adaptation responses, such as the development of 'fit for purpose' emergency management plans and processes, or appropriate changes in port operations and management. Reported costs for existing or planned adaptation measures ranged from US$ 500,000 to US$ 500 million, with an average of US$ 127.3 million. Relatively few ports (about 20 % of the total sample) had received or expected to receive financial or other assistance in the implementation of adaptation measures from government/non-government sources.

4. Concluding remarks

The main objective of the UNCTAD (online) port-industry survey has been to advance and improve the understanding of the potential implications of Climate Variability and Change (CV & C) for ports. Towards this objective, a questionnaire was designed and distributed online to the port industry in order to: gauge the availability of relevant information and the information needs of ports; assess current levels of resilience and preparedness amongst ports; and collate some information on the current state of practice in terms of response measures and adaptation. In order to put the design and results of the questionnaire into context, recent information on the trends, projections and impacts of climatic factors on ports and their hinterland connections has been collated and presented in overview.

Due to their location in low lying coasts and estuaries and the planned longevity of infrastructural assets, ports and their connecting hinterland links are inherently exposed to marine and land hydro-meteorological hazards controlled by Climate Variability and Change (CV & C), such as rising mean and extreme sea levels (ESLs), storm waves, extreme winds and heavy precipitation, riverine floods (and droughts) and heat waves.

The average surface temperature has risen by 1.1 ^{0}C since the late 19th century, with the 2011 -2016 period being the warmest on record. Mean sea level, a fundamental climatic stressor for seaports, has also increased by about 0.2 m since the 1860s, with the rise rate showing a significant acceleration (to 3.2 mm/year) since the early 1990s. Precipitation shows mixed long term trends and strong regional variability, with an increasing trend being discerned in middle and high latitudes. Wind trends can not be discerned in the record and, in any case, wind impacts on ports are mostly associated with extreme events (e.g. tropical and extra-tropical storms). Arctic sea ice (minimum) extent has rapidly declined since 1979, with most melting occurring in the last decade; this may provide opportunities for new shipping routes in the Arctic, but also present significant engineering challenges for port development. Extreme events (e.g. storms and heat waves) constitute particularly dangerous climatic hazards for ports. In many regions, observations show increases in extreme sea levels (ESLs) and the frequency/intensity of heavy precipitation events and of heat waves.

Mean atmospheric surface temperature is projected to increase by up to 3.7 °C in 2100, depending on the scenario. Temperatures will not change uniformly, with those close to the poles projected to rise faster than at the equator. Sea level has been projected (IPCC, 2013) to rise as much as 0.98 m above the (1986-2005) reference level, but estimations based on alternative approaches have suggested even higher mean sea level rises (up to 2 m). However, there is large spatial variability in the observed (and projected) sea level rise, suggesting that downscaled projections are necessary to reasonably assess the (permanent) inundation risk at particular ports. Precipitation is expected to change in a complex manner, with the heavy precipitation events projected to become heavier and more frequent over many regions, particularly in high and tropical latitudes; ports in these areas could be significantly affected. Extreme hot temperature events are also expected to increase in intensity and duration, with the greater changes expected in sub-tropical and mid-latitude regions. Extreme coastal sea levels (ESLs) constitute a most significant hazard for ports and their connecting coastal transport networks. Recent research shows that future ESLs will increase in many regions as e.g. in the northeastern Atlantic coast, in terms of both levels and return periods; this will present several challenges to future port engineering works, requiring appropriate (and, probably, innovative) adaptation measures. At the same time, significant increases (of up to 30 %) have been projected in the 100-year return level of coastal wave energy fluxes (an important seaport design parameter) for most southern temperate coasts as well as for the Northeastern Pacific and the Baltic Sea coasts, with wave direction changes also predicted for some regions. River floods are also projected to increase in most regions, whereas extreme wind events might also become stronger in some regions.

Given this background, the results of the port industry survey provide important contextual information, particularly as the respondent port sample can be considered as representative (collectively the respondent port handle over 16 % of the global seaborne trade).

The results of the survey confirm that the hazards detailed above have been felt already and are likely to affect ports and their infrastructure, operations and services in future. Although the majority of respondents reported that they had been impacted by weather/climate related events, including by extremes, prompting them to consider climatic factors and their impacts in future investments, the study revealed important gaps in terms of relevant information available to seaports. Many respondents (including large ports in developed regions) reported lack of (at least, readily available) information regarding climatic stressors, the trends and downscaled projections of which are fundamental in assessing the climate risk and designing appropriate and cost effective adaptation measures These findings may be of concern to respondent ports, in terms of their existing capacity for effective adaptation planning.

With respect to implemented or planned adaptation measures reported by ports, 'hard' engineering measures have been identified as the main course of action, rather than 'soft' adaptation responses such as the development of 'fit for purpose' emergency management plans and processes, or appropriate changes in port operations and management. It should be noted that 'climate proofing' of ports, i.e. their effective adaptation to climate variability and change could be a science-intensive and financially expensive exercise; costs of planned adaptation measures as high as US$ 500 million have been reported by a respondent port. Of interest in this context is also that only a small share of respondent ports has received any financial or other assistance in the implementation of adaptation measures, suggesting that there is room for improvement in involving all relevant stakeholders.

The results of the present study suggest that urgent actions should be taken to increase both the knowledge base and human capacity in ports with regard to e.g. downscaled projections of permanent and transient risks to port operations and infrastructure under different climatic scenarios. Recently there have been studies that use integrated methodologies to assess such risks as, for example, an ongoing UNCTAD technical assistance project[30] with a focus on the Caribbean, a region which is particularly exposed to climate hazards and has been hit by a succession of major hurricanes during 2017, with devastating effects on transport infrastructure and more broadly, economies in the region.

In any event, the survey results clearly indicate that much further work (including research on both the assessment of risks and the development of effective and innovative adaptation measures in response to changing climatic stressors), is required to effectively address the considerable challenges posed by the diverse implications of climate variability and change. This is of particular importance for ports in developing nations and vulnerable groups of countries, such as SIDS, that are especially exposed and lack appropriate financial and human resources. It is hoped that the results of the survey will contribute to informing and advancing the issue of effective climate adaptation for ports, also with a view to achieving progress on implementation of the international community's comprehensive 2030 Sustainable Development Agenda[31]. In the light of new climate trends and projections, as well as in the light of the recent devastating impacts of extreme weather events in the Caribbean and elsewhere, a follow-up survey could provide further useful information to gauge how perceptions as well as levels of preparedness are developing and changing.

[30] See "Climate change impacts on coastal transport infrastructure in the Caribbean: enhancing the adaptive capacity of SIDS" (UNDA 1415O).
[31] This is includes SDG 1, 9, 13 and 14. For further information, see https://sustainabledevelopment.un.org/?menu=1300.

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Appendix A – Port industry survey questionnaire

UNCTAD Port Industry Survey: Climate Variability and Change - Data

I. PROFILE AND GENERAL INFORMATION

Information provided will be treated confidentially and will be published in an aggregated format only.

Please note that only question 1 is a required field.

***1. Name of port/terminal:**

2. Country

3. Which stakeholder category do you belong to?

- Port authority
- Private port
- Terminal operator
- A management company
- Other (please specify)

4. Please specify the following regarding breakwater(s) - if any - in your port/terminal:

Length (km)

Elevation (m) above HWS (i.e. highest level of spring tides)

5. Please indicate the access routes or hinterland connections to your port/terminal (check all that apply):

- Road
- Rail
- Inland waterways

6. Please complete the following with the latest annual data available:

Number of ship calls

Maximum ship size (dwt)

Total cargo throughput (metric tons) of which:

Crude oil

Petroleum products

Gas (LPG/LNG)

Chemicals

Dry cargo (i.e. bulk, break bulk, general cargo)

Container throughput in TEUs

Passenger throughput

7. Is your port/terminal planning any investments in the next 5 years?

- Yes
- No

8. If Yes, please indicate the total value (in million US$):

9. As applicable, please indicate the share of each of the following in terms of % of total investment value:

Infrastructure (terminal)

Dredging

Installations (e.g. warehousing)

Sea defences

Hinterland connections

Equipment

Information technology

Other

10. Do planned investments in your port/terminal take into account weather or climate-related factors?

- Yes
- No

As applicable, please specify further:

II. HISTORY OF WEATHER OR CLIMATE-RELATED IMPACTS

11. Has your port/terminal ever been impacted by weather or climate-related events including by extremes?

- Yes
- No

12. If yes, indicate the type and extent of impact (check all that apply):

	Little impact	Some impact	Significant impact	Do not know/not applicable
Physical damage				
Operational problems				
Delays				
Interruptions				
Other				

13. Which of the following weather or climate-related factors have impacted your port/terminal (check all that apply)

	Infrastructure (terminal)	Ship operations	Terminal operations	Superstructure	Hinterland connections	Other (e.g. refineries)
Mean sea level						
Low/high river flow						
Storm surges						
Wave penetration						
Winds						
Precipitation						
Fog						
High temperatures						
Low temperatures						

14. Over time, has the magnitude of damage and/or disruption caused by weather or climate-related events ...

- increased
- remained unchanged
- decreased
- decreased as a result of specific response measures taken by your port/terminal
- do not know / not applicable

15. Have users of your port/terminal (e.g. shippers) requested that effective response measures be taken?

- Yes
- No

16. Has your port/terminal experienced changes in insurance level of premiums, terms or coverage as a result of weather or climate-related events?

- Yes
- No

17. Are there any other comments or information you would like to submit regarding this part?

III. AVAILABILITY OF DATA AND INFORMATION NEEDS

18. Does your port/terminal have past and present information on the following?

	Yes	No
Water levels	○	○
Waves (wave height, period and direction)	○	○
Winds (wind speed and direction, number of days of high winds)	○	○
Precipitation (average and extreme precipitation)	○	○
Temperatures (average and extreme temperatures)	○	○

19. Does relevant data (see previous question) show changes over time which could be considered a trend?

○ Yes

○ No

20. If Yes, have or will observed trends necessitate adaptation responses (e.g. in the design of breakwaters, port entrances)?

○ Yes

○ No

21. As applicable, please provide further information:

22. To which extent does long-wave penetration present problems for your port/terminal?

○ Minor ○ Some ○ Significant ○ Not at all

23. Please indicate the basis for information on currents in your port/terminal (check all that apply)

☐ Observations

☐ Modelling

☐ Modelling validated by long-term observations

24. Are downscaled forecasts or assessments about the following climate forcings and factors available for your port/terminal, and if so, at which timescale? (Check all that apply)

	10 years	30 years	50 years	> 50 years	Not available
Mean sea level rise	☐	☐	☐	☐	☐
Extreme sea level rise	☐	☐	☐	☐	☐
Waves	☐	☐	☐	☐	☐
Winds	☐	☐	☐	☐	☐
Temperatures	☐	☐	☐	☐	☐
Precipitation	☐	☐	☐	☐	☐

25. Are there any other comments or information you would like to submit regarding this part?

IV. RESILIENCE, LEVEL OF PREPAREDNESS AND ADAPTATION PLANNING

Resilience in this context means the robustness and durability of infrastructure, services and operations as well as the ability to recover from an incident quickly and at minimal cost. **Adaptation** in this context means actions by ports to decrease their vulnerability, or increase their resilience to weather and climate-related impacts.

26. Can breakwater(s) be upgraded at manageable costs if sea level and/or wave regime change in your port/terminal?

- ○ Yes
- ○ No

27. If new breakwater(s) will be required, please indicate the approximate costs in US$:

[ ]

28. At which thresholds do you anticipate that integrity and functionality of infrastructure in your port/terminal will be significantly impaired?

Mean sea level rise [in metres]	
Extreme water levels/storm surges [in metres]	
Wind speed [in km/hr]	
Temperatures, extreme high [in C]	
Temperatures, extreme low [in C]	
Extreme precipitation [mm/day]	

29. At which thresholds do you anticipate that integrity and functionality of equipment in your port/terminal will be significantly impaired?

Mean sea level rise [in metres]	
Extreme water levels/storm surges [in metres]	
Wind speed [in km/hr]	
Temperatures, extreme high [in C]	
Temperatures, extreme low [in C]	
Extreme precipitation [mm/day]	

30. Are emergency response measures for climate-related threats in place or planned in your port/terminal?

- ○ Yes
- ○ No

31. Has your port/terminal assessed or is it planning to assess its vulnerability to weather or climate-related events?

- ○ Yes
- ○ No

32. If Yes, which of the following have been considered when assessing vulnerability and impacts? (Check all that apply)

	Infrastructure	Ship operations	Terminal operations	Superstructure	Hinterland connections	Other (e.g. refineries)
Sea level rise	☐	☐	☐	☐	☐	☐
Low/high river flow	☐	☐	☐	☐	☐	☐
Storm surges	☐	☐	☐	☐	☐	☐
Wave penetration	☐	☐	☐	☐	☐	☐
Winds	☐	☐	☐	☐	☐	☐
Precipitation	☐	☐	☐	☐	☐	☐
Fog	☐	☐	☐	☐	☐	☐
High temperatures	☐	☐	☐	☐	☐	☐
Low temperatures	☐	☐	☐	☐	☐	☐

33. Do you expect impacts on your port/terminal due to weather or climate-induced changes to the following? (Check all that apply)

- ☐ Migration trends and population settlement patterns
- ☐ Demand for energy
- ☐ Agricultural production
- ☐ Industrial production
- ☐ Investment
- ☐ Modal shift
- ☐ Competition issues or trade diversion to other ports
- ☐ Supply-chain disruption
- ☐ Labour shortage
- ☐ Other (please specify)

34. Has your port/terminal mainstreamed weather or climate-related considerations in planning, design and construction of infrastructure?

- ○ Yes
- ○ No

35. Has your port/terminal carried out any work, including research, to identify and evaluate possible adaptation measures?

- ○ Yes
- ○ No

36. Has your port/terminal developed, or is it planning to develop, a corporate adaptation strategy?

- ○ Yes
- ○ No

37. As applicable, please indicate whether implemented or planned adaptation measures cover any of the following (check all that apply):

- ☐ Port planning
- ☐ Port investment
- ☐ Port design, construction and engineering
- ☐ Material used for construction
- ☐ Equipment (e.g. cranes and vehicles)
- ☐ Operations (e.g. working hours)
- ☐ Maintenance (e.g. frequency of inspections)
- ☐ Management
- ☐ Emergency management plans and processes
- ☐ Insurance
- ☐ Other (please specify)

38. As applicable, please indicate the estimated or projected total expenditure for adaptation measures in your port/terminal (in US$):

39. Has financial or other assistance (government/non-government) been received or is it expected in the implementation of adaptation measures?

- ○ Yes
- ○ No

40. Which adaptation measures (hard or soft) taken in your port/terminal do you consider effective, good value for money and an example of best practices?

41. Are there any other comments or information you would like to submit regarding this part?

42. Please enter your contact details (these will be treated confidentially):

Name:

Company:

Address 1:

Address 2:

City/town:

State/province:

ZIP/postal Code:

Country:

E-mail address:

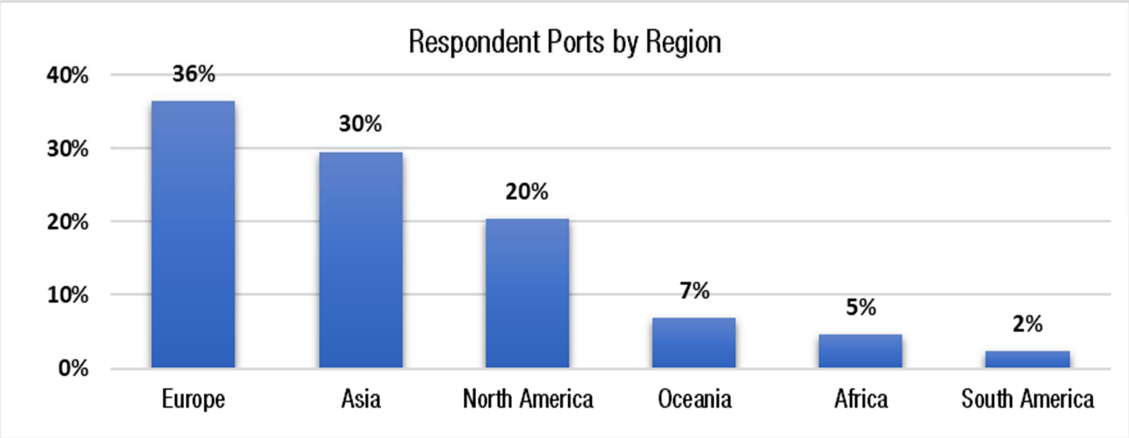
Telephone:

Appendix B - Results of the Questionnaire Survey[32]

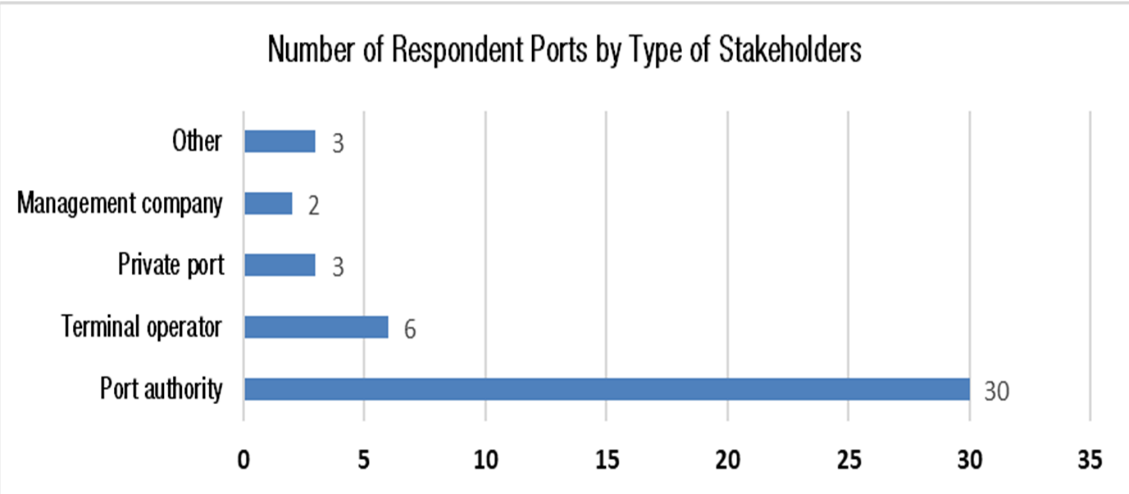
1. Profile and General Information

QUESTION 1 Name

QUESTION 2 Country (Fig. B2)

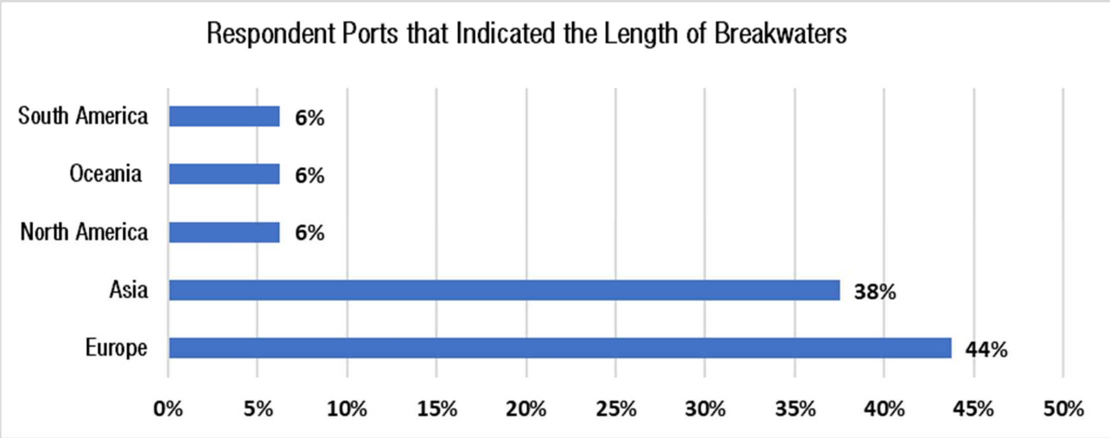


QUESTION 3 Which stakeholder category do you belong to? (Fig. B3)



[32] The survey was carried out in 2014.

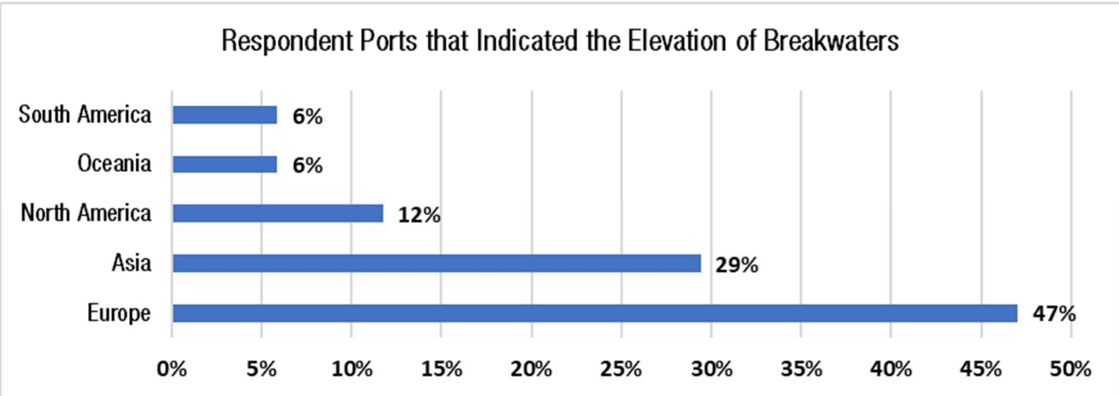
QUESTION 4 Please specify the following regarding breakwater(s) if any in your port/terminal: (Fig B4 a)



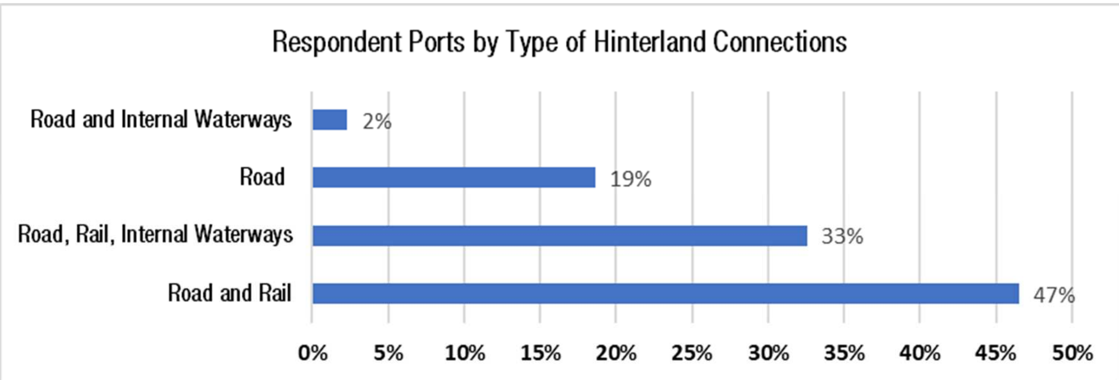
(Fig. B4 b)

Longest	126 km	Large port in Europe
Shortest	0.9 km	Medium port in South America

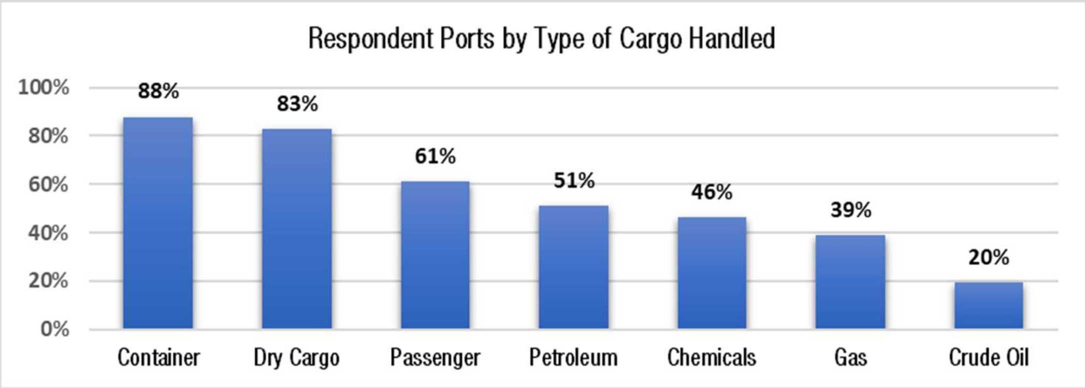
(Fig. B4 c)



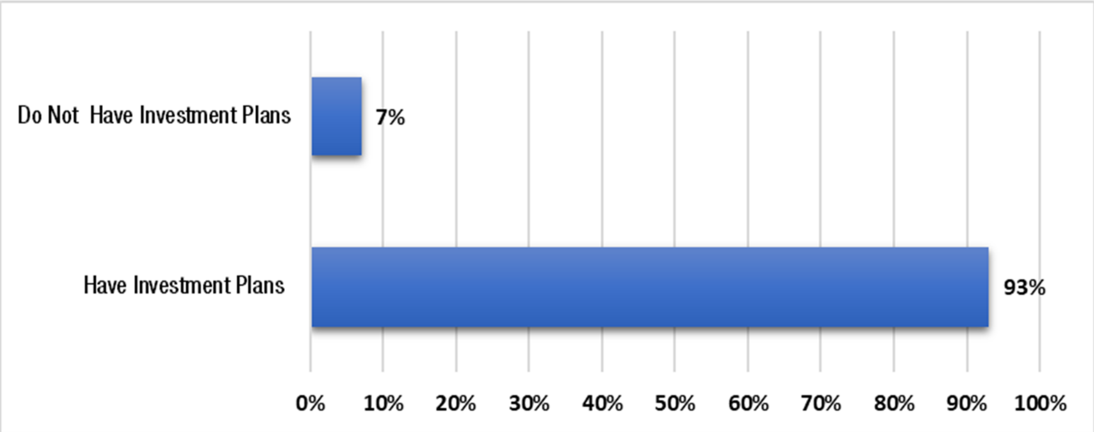
QUESTION 5 Please indicate the access routes or hinterland connections to your port/terminal (check all that apply): (Fig. B5)



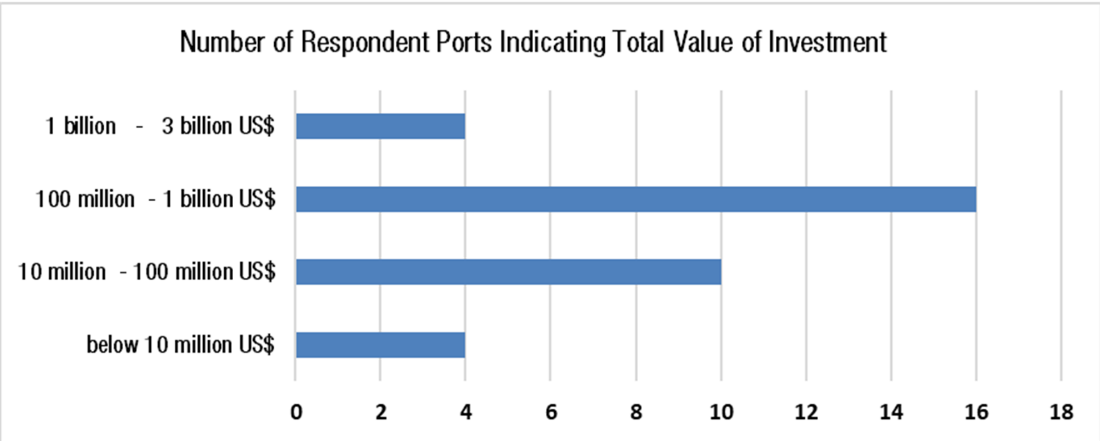
QUESTION 6 Please complete the following with the latest annual data available: (Fig. B6)



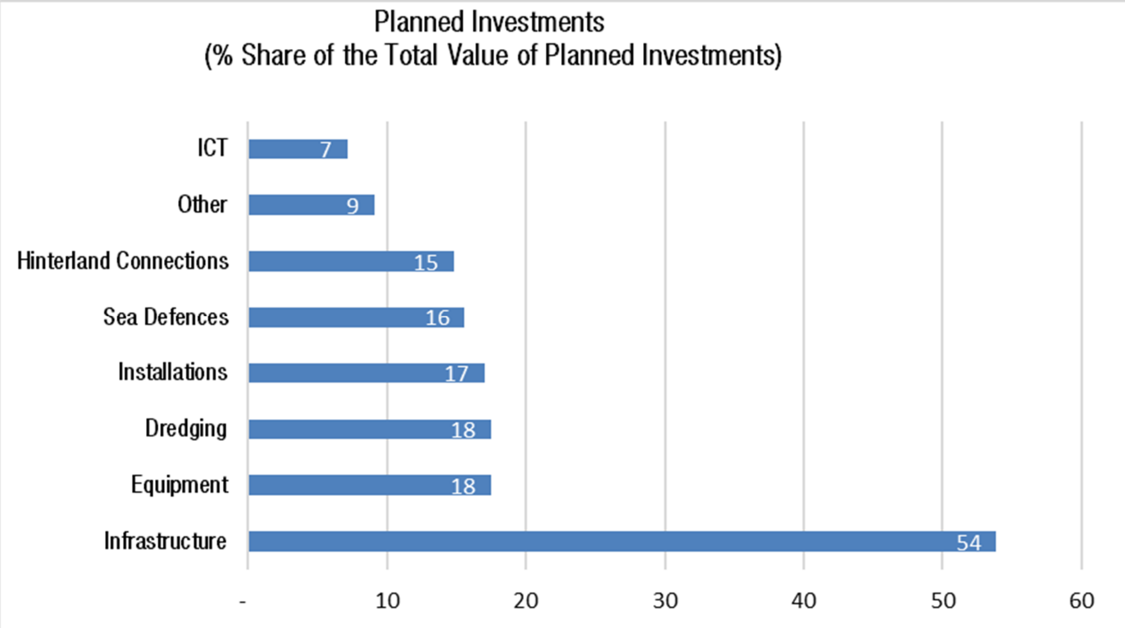
QUESTION 7 Is your port/terminal planning any investments in the next 5 years? (Fig. B7)



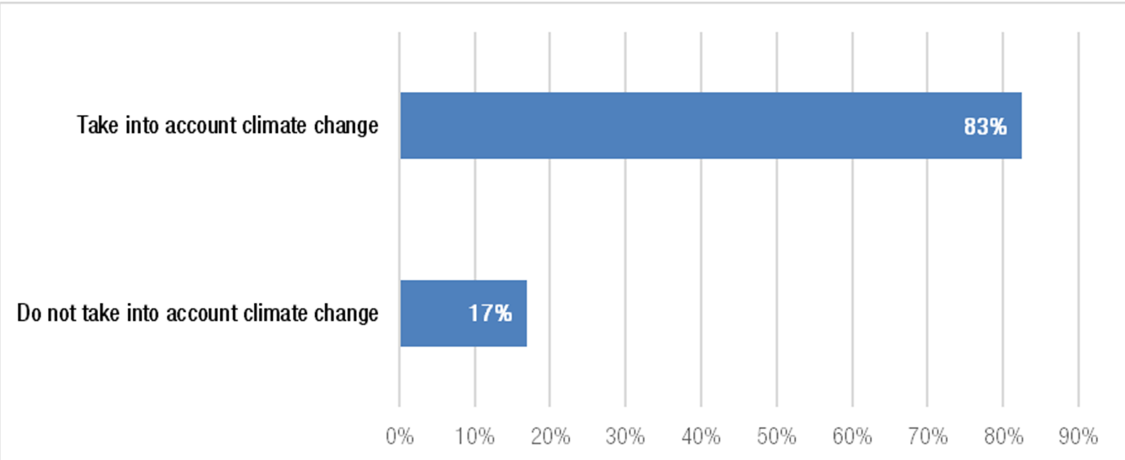
QUESTION 8 If Yes, please indicate the total value (in million US$): (Fig. B8)



QUESTION 9 As applicable, please indicate the share of each of the following in terms of % of total investment value: (Fig. B9)



QUESTION 10 Do planned investments in your port/terminal take into account weather or climate-related factors? (Fig. B10)

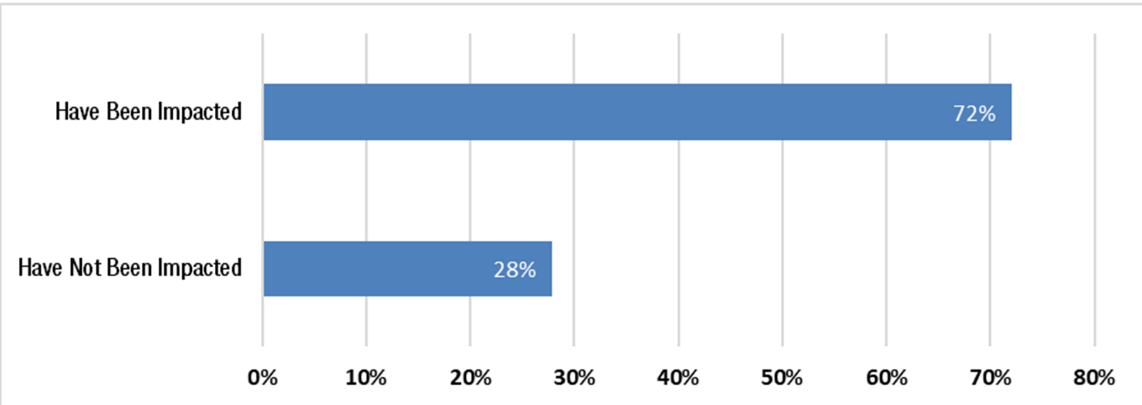


Port	Comment
Large European port	Making plans to build a protection zone for storage of solid bulks.
Port management company in Europe	Climate related factors are considered during their conduct of environmental review of projects.
Average sized Asian port	Investments catering for E-Gate; Green and Clean Port as well as Electric Forklift Truck. These investments are focusing on mitigation but are indicative of efforts at the port level to be sustainable.
Small South American port	When making their investment plans, they take into account tides, waves, current, wind and pollution
Averaged-sized North American port	They take into account the impact of wind on equipment, tie down and mooring facilities.
Large European port	The planned investment includes a protection against rising water levels

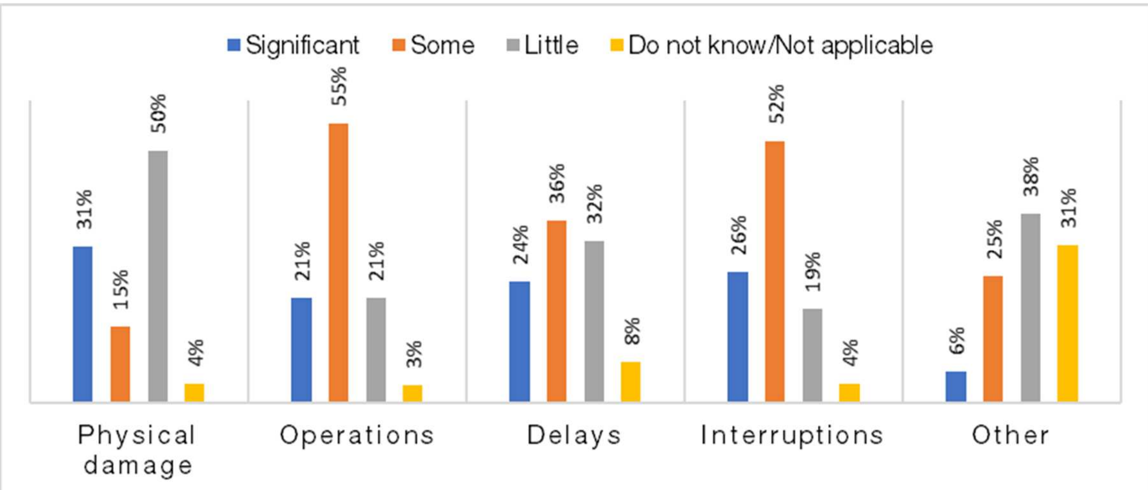
Large North American port	All projects consider weather and climate related factors, as applicable.
Small sized North American port	Investment plans incorporate the expected Service life of infrastructure and equipment, susceptibility to sea level rise as well as environmental protection considerations
Large European Port	All investments are planned according to ROM (Estate Recommendations on Port Infrastructures)
Small island port in an African country	Sea level rise, cyclone, tsunami, abnormal swells are factored in their investment plans
Large European port (low-lying area, therefore prone to sea level rise problems)	Investments do factor in wind- and visibility information and forecasting systems North Sea Canal.
Very small North American port	Environmental reviews at the port and permit applications take climate and weather factors into account.
An averaged sized European	The infrastructure design considers IPCC estimates for sea level rise, and other factor such as wave height and storm surge elevation
Very large North American Port	The design of facilities takes into account rain and wind events
Small sized North American port	Investments aim to ensure shoreline protection, storm water rehabilitation, up-grade facilities to existing (…) Building Code standards.

2. History of Weather or Climate-related Impacts

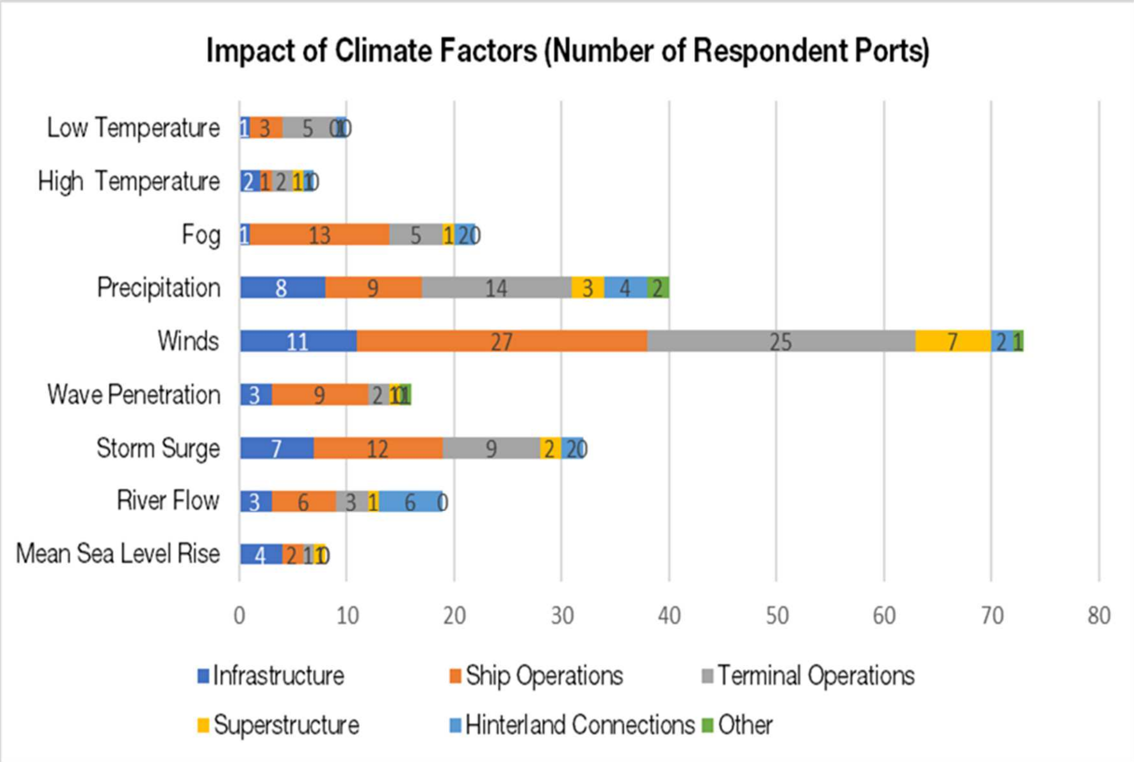
QUESTION 11 Has your port/terminal ever been impacted by weather or climate-related events including by extremes? (Fig. B11)



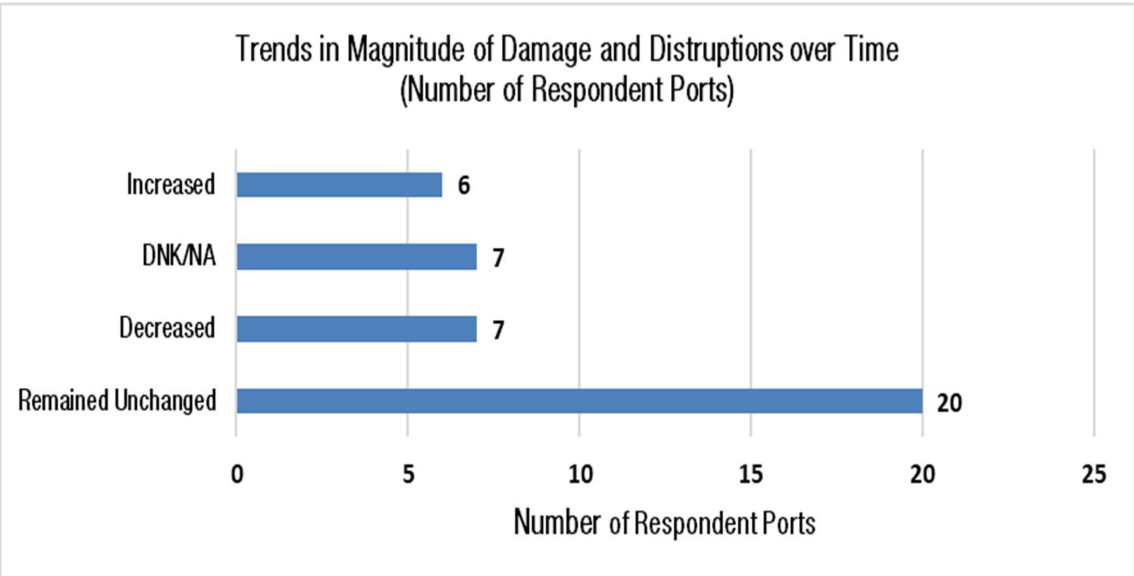
QUESTION 12 If yes, indicate the type and extent of impact (check all that apply): (Fig. B12)



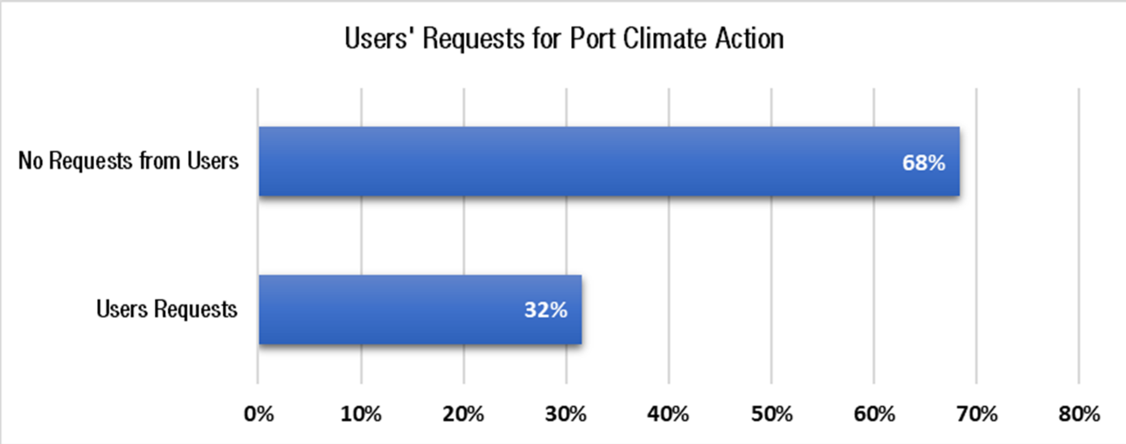
QUESTION 13 Which of the following weather or climate-related factors have impacted your port/terminal (check all that apply) (Fig. B13)



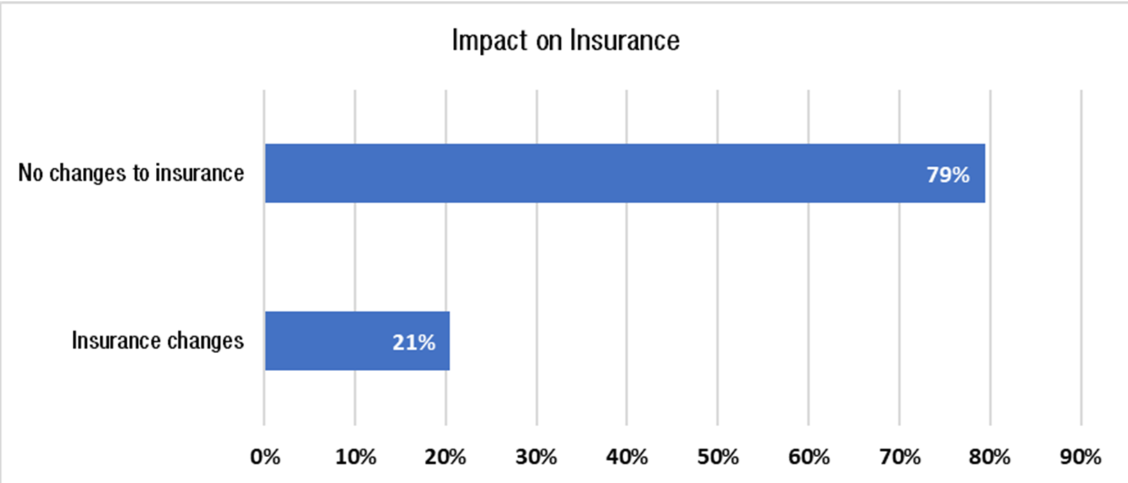
QUESTION 14 Over time, has the magnitude of damage and/or disruption caused by weather or climate-related events (Fig. B14)



QUESTION 15 Have users of your port/terminal (e.g. shippers) requested that effective response measures be taken? (Fig. B15)



QUESTION 16 Has your port/terminal experienced changes in insurance level of premiums, terms or coverage as a result of weather or climate-related events? (Fig. B16)



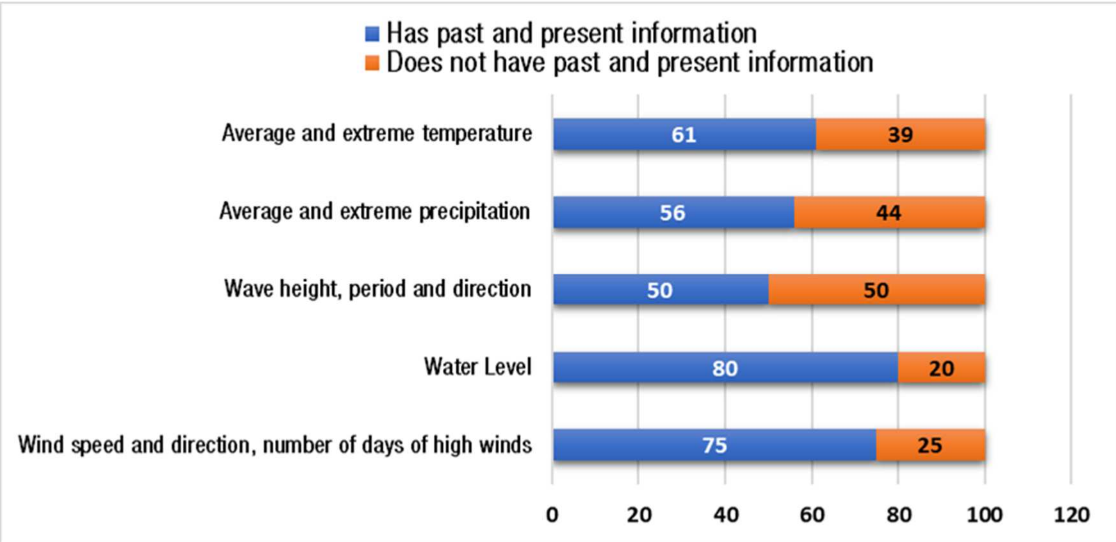
QUESTION 17 Are there any other comments or information you would like to submit regarding this part?

Port	Comment
Small European Port	Wind impact delayed ship's berthing for few hours.
Large US Port	Port Administration developed an independent Vulnerability Assessment of our terminals and operations that considers likely future impacts and incorporates the findings into design for future terminals.
Small North American port	Rising sea level has the potential to significantly impact port superstructure including underground utilities, vaults, wharves, etc. Additionally, significant storm events (tropical storms/wave energy) have potential to significantly impact infrastructure, shipping, and operations due to lack of breakwater/protective infrastructure.
Large European Port	A high river flow happened in the 50's, and as a result the whole city, and thus, the port of (…) was covered by water. After this event, the river basin was deviated, and we did not have such experience so far.
Average North American Port	The port is in the process of performing a Resiliency & Infrastructure Planning Study to determine potential climate change impacts for the Port.
Large Asian Port in developing region	Undertook an infrastructure Expansion Project. Project of 6.8 km of breakwater completed in 2012. Considered all adverse factors during the planning & construction time.

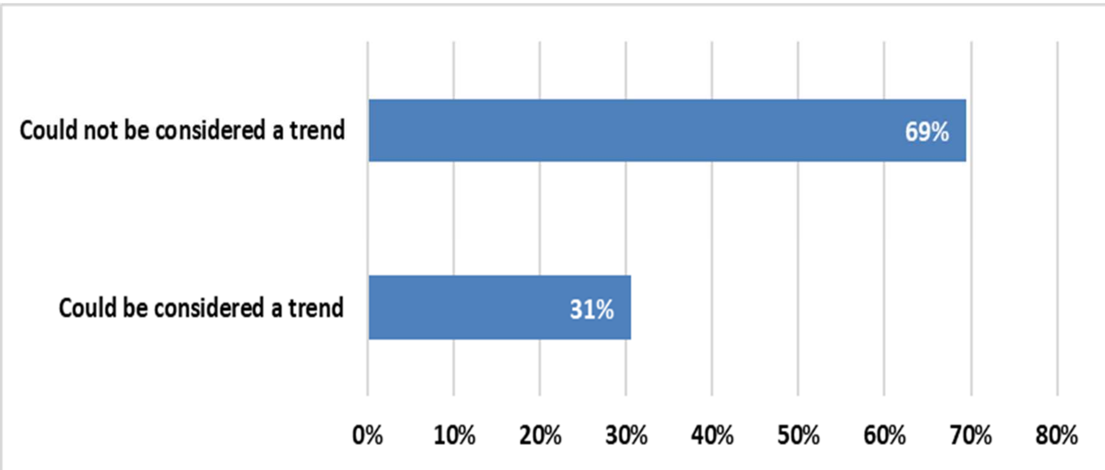
A small North American Port	Climate-related events have helped spur the development of new response plans and/or revise already existing plans. This effort was recognized and spurred on internally
North American Port	The port is self-insured.
Average size Asian port	Except more for some unpredictable changes in the climate such as rain, storm occurrences, we have not yet experienced changes which caused serious impacts on port operations.

3. Availability of Data and Information Needs

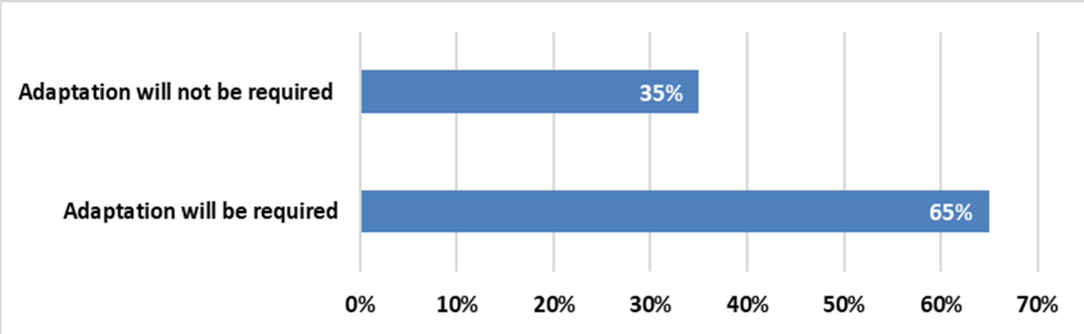
QUESTION 18 Does your port/terminal have past and present information on the following? (Fig. B18)



QUESTION 19 Does relevant data (see previous question) show changes over time which could be considered a trend? (Fig. B19)



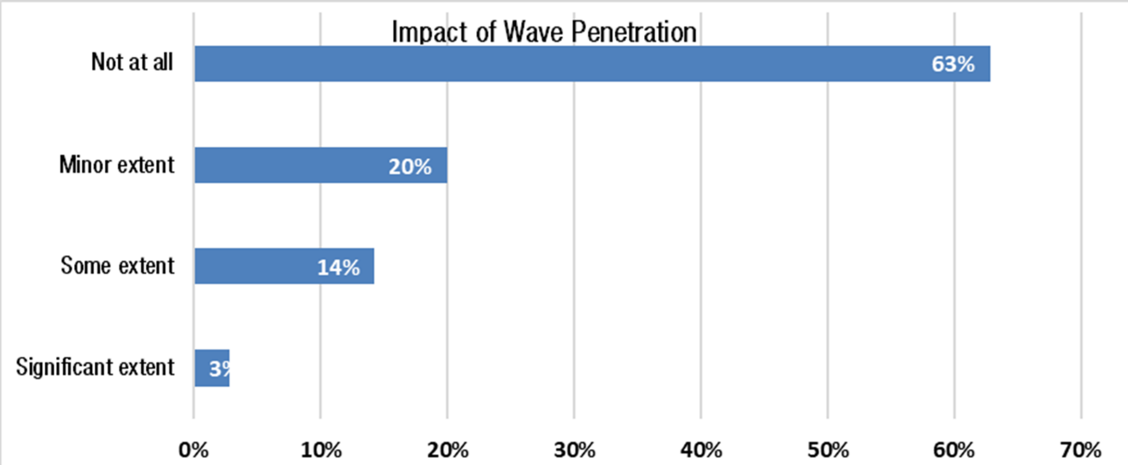
QUESTION 20 If Yes, have or will observed trends necessitate adaptation responses (e.g. in the design of breakwaters, port entrances)? (Fig. B20)



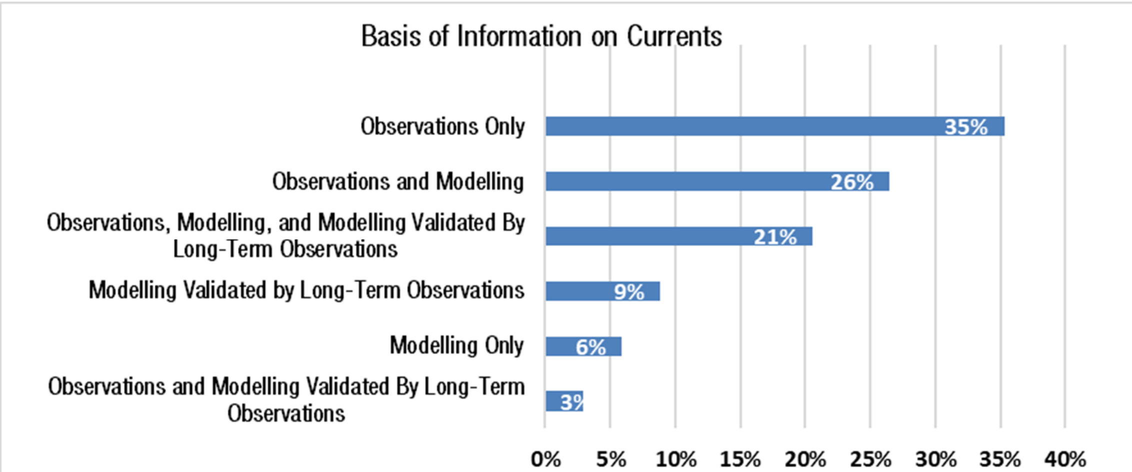
QUESTION 21 As applicable, please provide further information:

Port	Comment
Large European port	New calculations of high water protection
Middle East port	New port development designs factors in changes in mean water levels and storm surge levels.
Large North American port	Future terminal improvements should be developed in consideration of mean sea level rise and consider options to reduce impacts of potential temporary flooding.
Small North American port	Trend data and modeled predictions present significant impacts to the port of Hueneme from flood plains, sea level rise, winds, etc.
Small island port in an African country	Breakwaters will be needed
North American port	Increase in Flood Construction levels, and height of dikes.
A large European port	In the design of the new locks (2016), which also serves as a protection against water rises, the height above HWS has been taken into account with an extra safety-margin.
Small North American port	The Port is working with the U.S. Army Corps of Engineers to realignment their Federal Navigation Channel lower settling basin in the (…) River. The realigned settling basin will capture a greater percentage of sediment travelling down the (…) River, lessening the impact it has on Port infrastructure
European port	Information on precipitation and temperature is available from the national meteorological entities.
Very large North American port	We have not analysed our information to detect any trends. We will be monitoring predicted SLR and adapt our designs as required.
Average size Asian port	Since we are operating river terminals deep inland, the impacts from sea level and waves are not so significant.

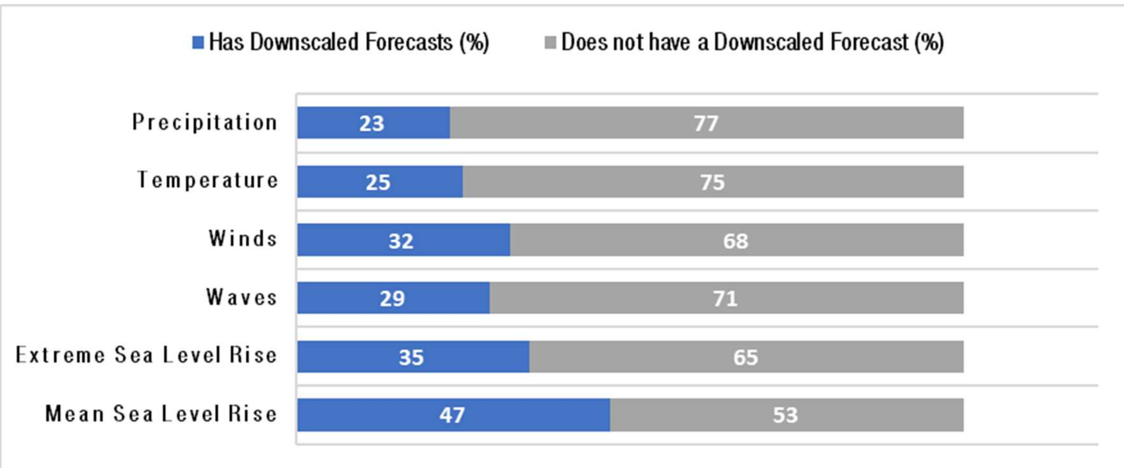
QUESTION 22 To which extent does longwave penetration present problems for your port/terminal? (Fig. B22)



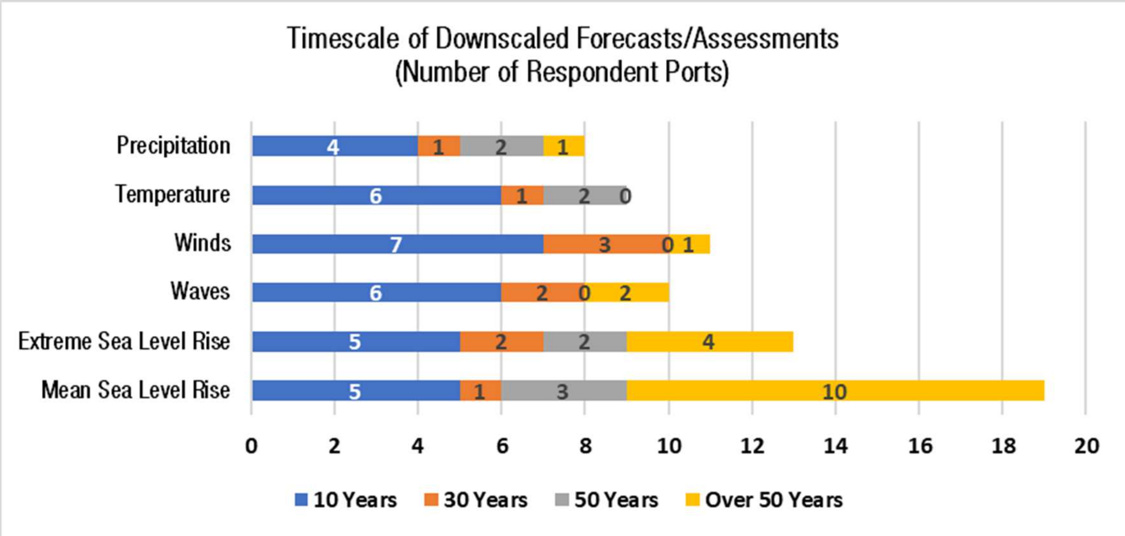
QUESTION 23 Please indicate the basis for information on currents in your port/terminal (check all that apply) (Fig. B23)



QUESTION 24 Are downscaled forecasts or assessments about the following climate forcings and factors available for your port/terminal, and if so, at which timescale? (Check all that apply) (Fig. B24 a)



(Fig. B24 b)



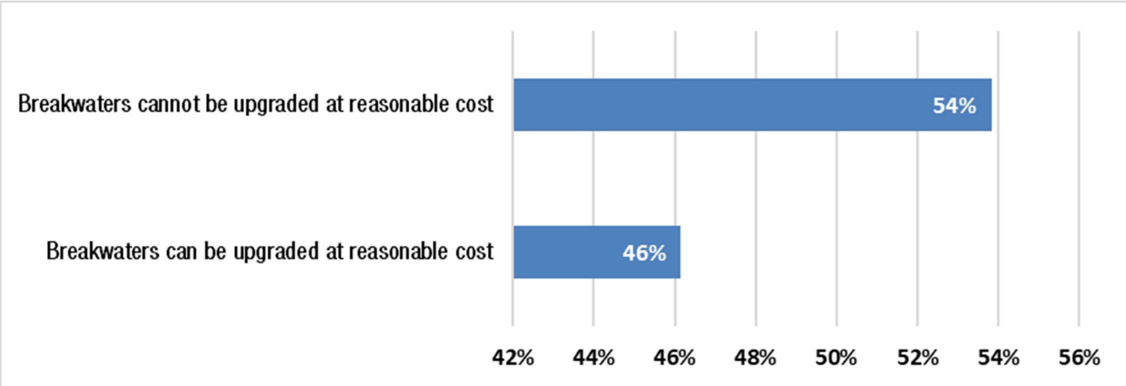
QUESTION 25 Are there any other comments or information you would like to submit regarding this part?

Port	Comment
Large European port	There are forecasts available for temperature and precipitation for the region
Small sized North American port	The port participates in the (…) Green-Print Program which is currently in the process of: a. Tracking local and regional climate change indicators and trends (i.e. seal level rise, temperature, precipitation, and tropical storms; and b. Developing local and regional climate change scenarios depicting various impacts (i.e. changes in sea level rise, temperature, precipitation, and tropical storms).
European port	The port is located in a large estuary with very good shelter conditions. Thus, long wave penetration is not a significant issue in the operational areas. Nevertheless, the access channel is exposed to long wave penetration.
Large European port	The port Authority has not needed to carry out assessments on currents as there is no significant current at this area at present.
Large Asian port	No climate impacts, except during the monsoon period, there is little swell. Even that swell is no more due to the (…) Expansion Project breakwater construction completed in 2012.
Very large North American port	There are no known downscaled forecasts for the port. Natural Geological Sea conditions / coastal canyon have presented naturally protective conditions; however, these natural features did not protect the port in 1939 when a tropical storm impacted the district.
A small island port in an African country	The national Meteorological Services keep track and records at national level but not specific to the port.
Large North American port	The port coordinates closely with the National Weather Service, State Environmental and Natural Resource Agencies, as well as several academic and State and federal emergency response agencies to consider current and future conditions of concern. The port is also currently coordinating with the City of (…) on their implementation of a new Climate Resiliency plan. The port also participates in use of NOAA's Physical Oceanographic Real-Time Systems (PORTS).
North American port	Regarding SLR thresholds on infrastructure: as the port is located outside of a storm belt, rise in mean sea level is the only natural hazard. The port in partnership with other Municipalities within their jurisdiction has engaged consultants to investigate the impact that Climate Change will have on sea level rise, and how that change may affect the current system of dikes and flood control measures. Equipment in the terminals are owned and maintained by the terminal operators.

Asian port	Regarding infrastructure-related thresholds noted that in our port/terminal will be impaired by wind and precipitation, but it has little impact for our services. The value in km/hr or mm/day is not known.

4. Resilience, Level of Preparedness and Adaptation Planning

QUESTION 26 Can breakwater(s) be upgraded at manageable costs if sea level and/or wave regime change in your port/terminal? (Fig. B26)

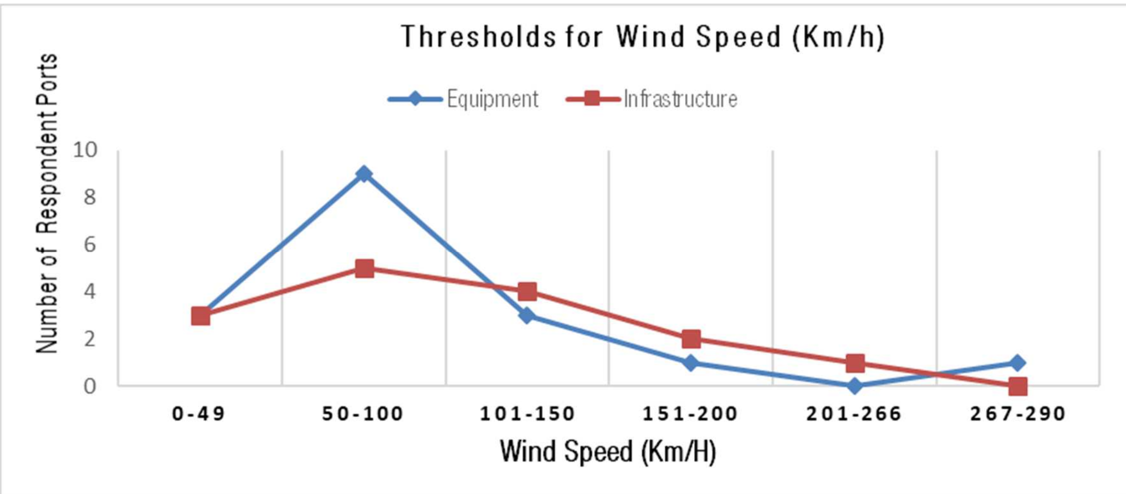


QUESTION 27 If new breakwater(s) will be required, please indicate the approximate costs in US$:(Fig. B27)

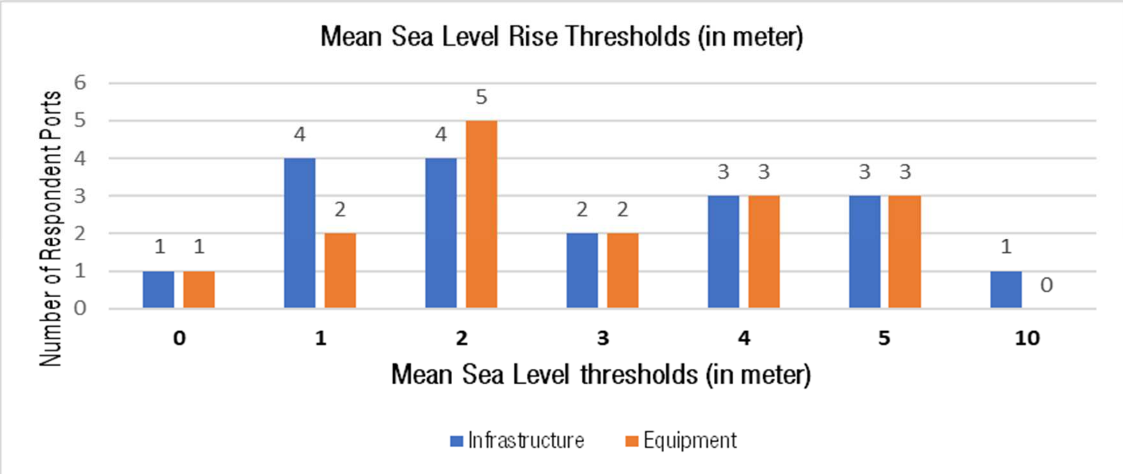
US$	Region
30.000.000	Europe
15.000.000	Europe
118.000.000	Asia

QUESTION 28 At which thresholds do you anticipate that integrity and functionality of infrastructure in your port/terminal will be significantly impaired?

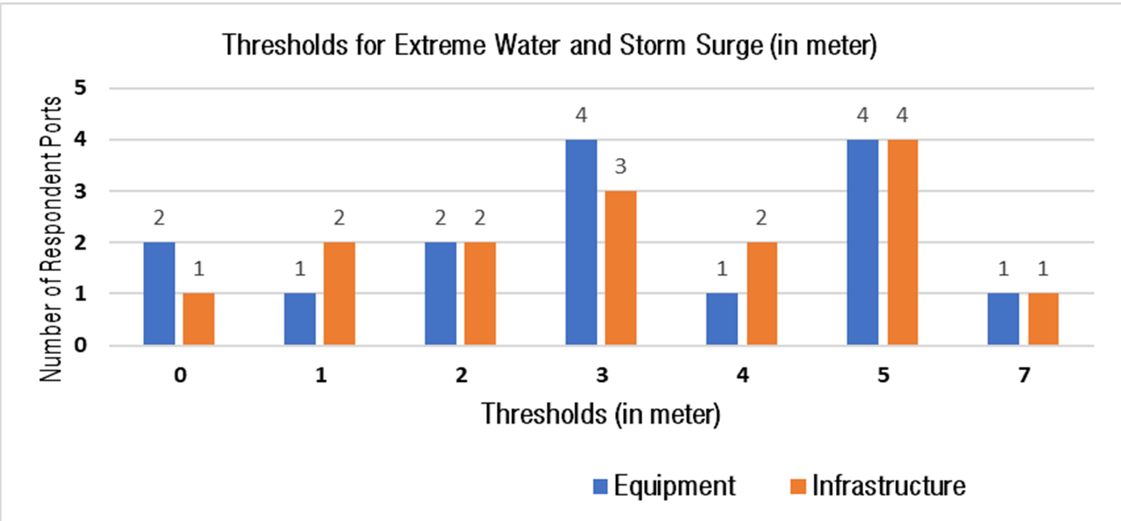
QUESTION 29 At which thresholds do you anticipate that integrity and functionality of equipment in your port/terminal will be significantly impaired? (Fig. B28-29 a)



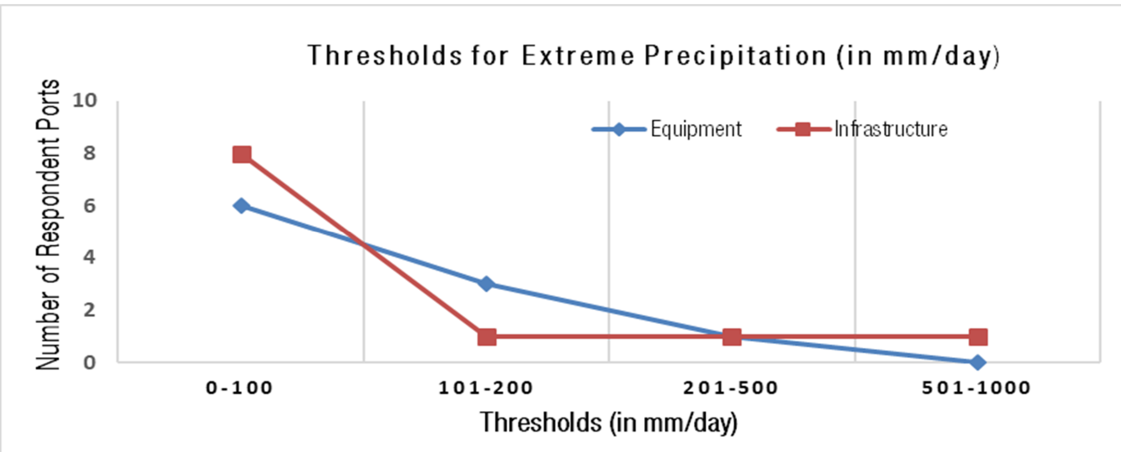
(Fig. B28-29 b)



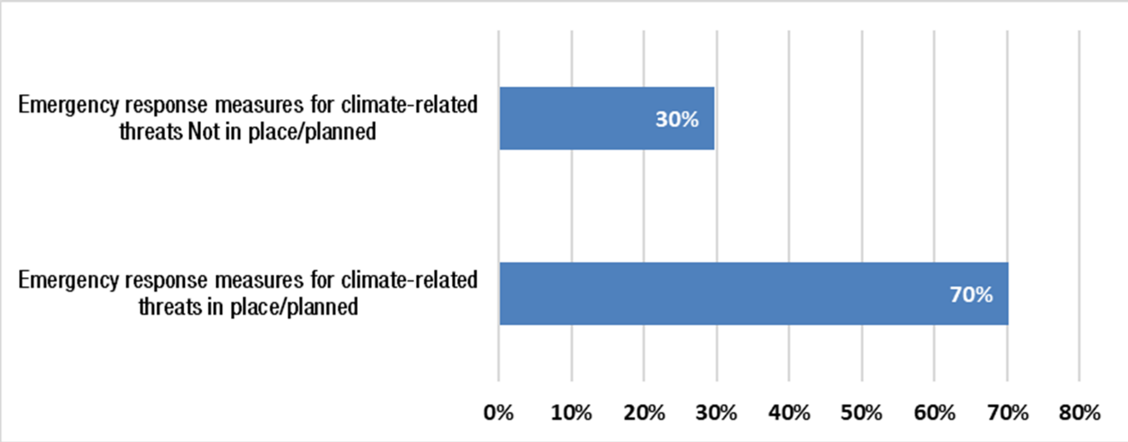
(Fig. B28-29 c)



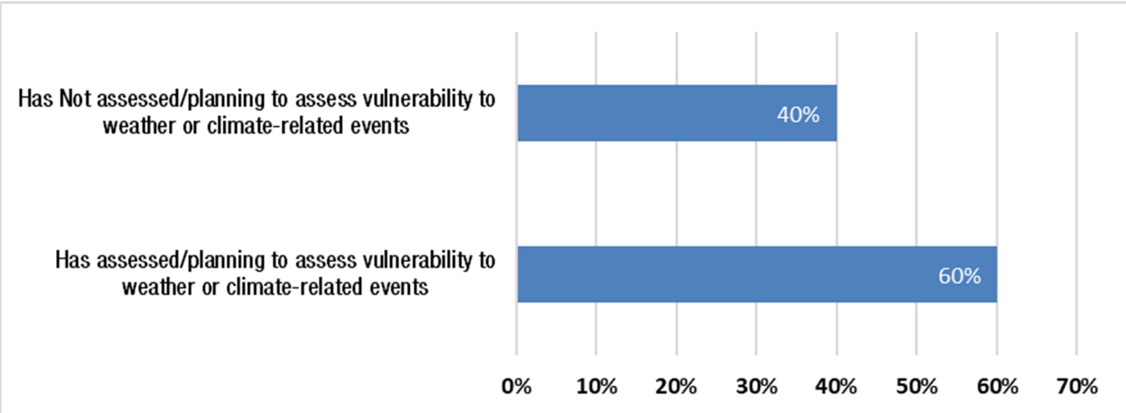
(Fig. B28-29 d)



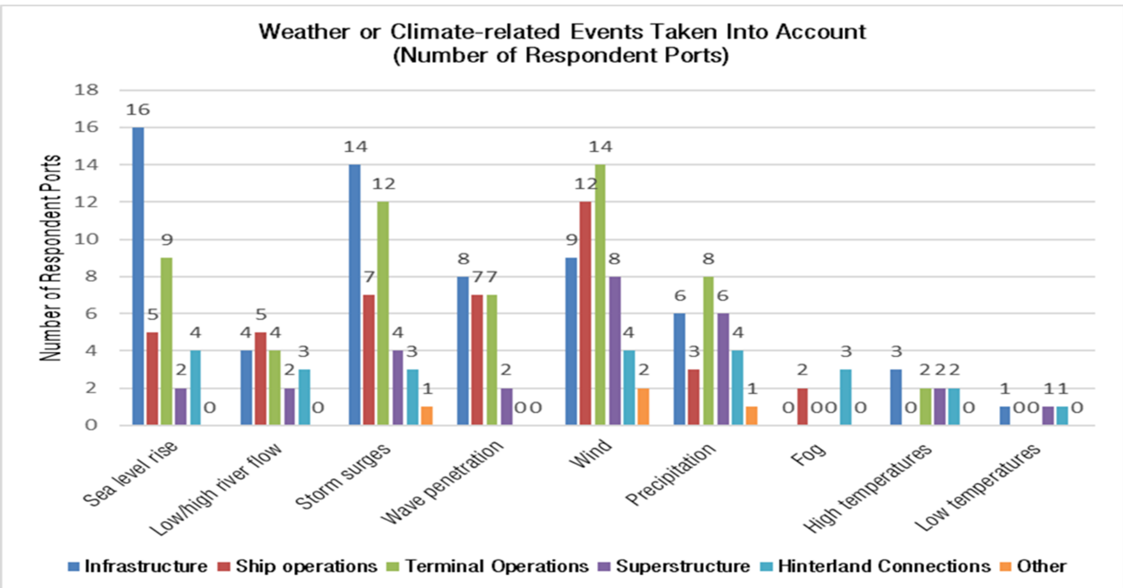
QUESTION 30 Are emergency response measures for climate-related threats in place or planned in your port/terminal? (Fig. B30)



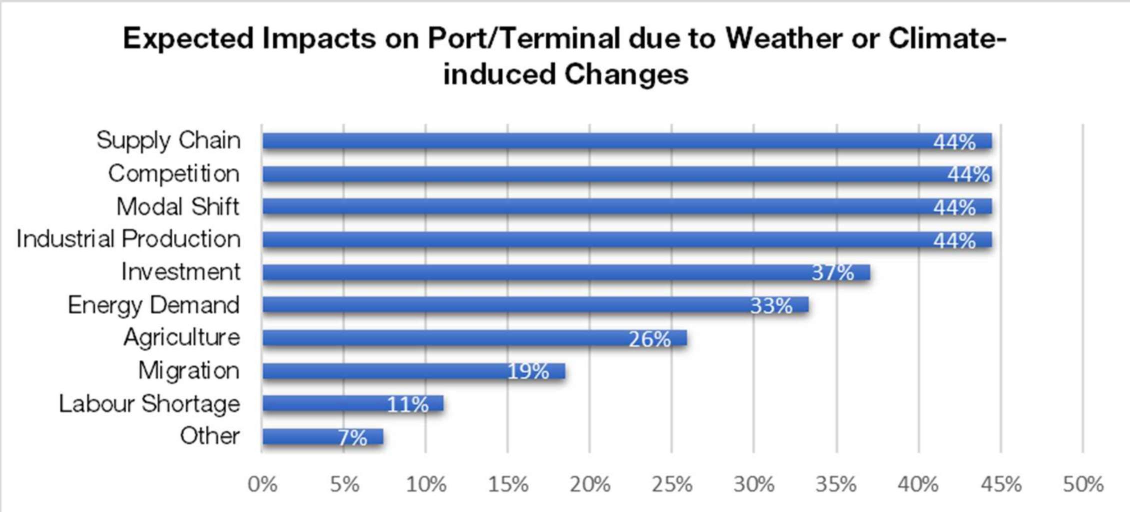
QUESTION 31 Has your port/terminal assessed or is it planning to assess its vulnerability to weather or climate-related events? (Fig. B31)



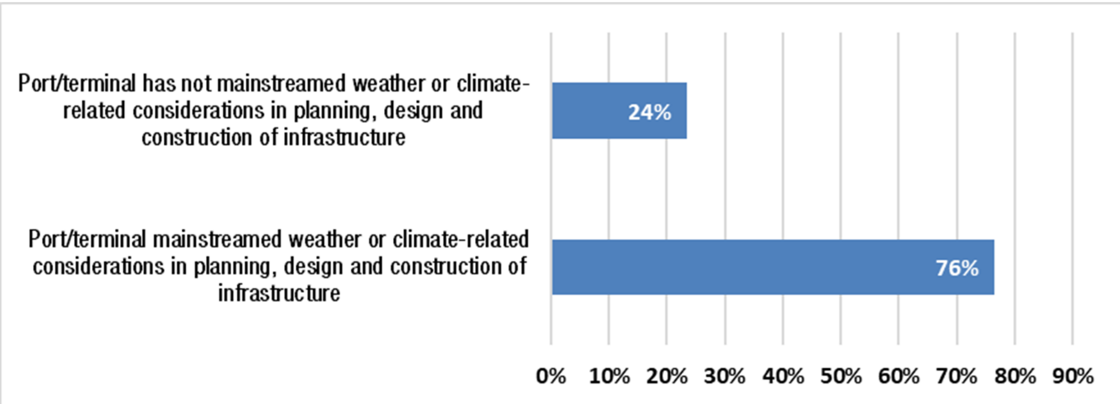
QUESTION 32 If Yes, which of the following have been considered when assessing vulnerability and impacts? (Check all that apply) (Fig. B32)



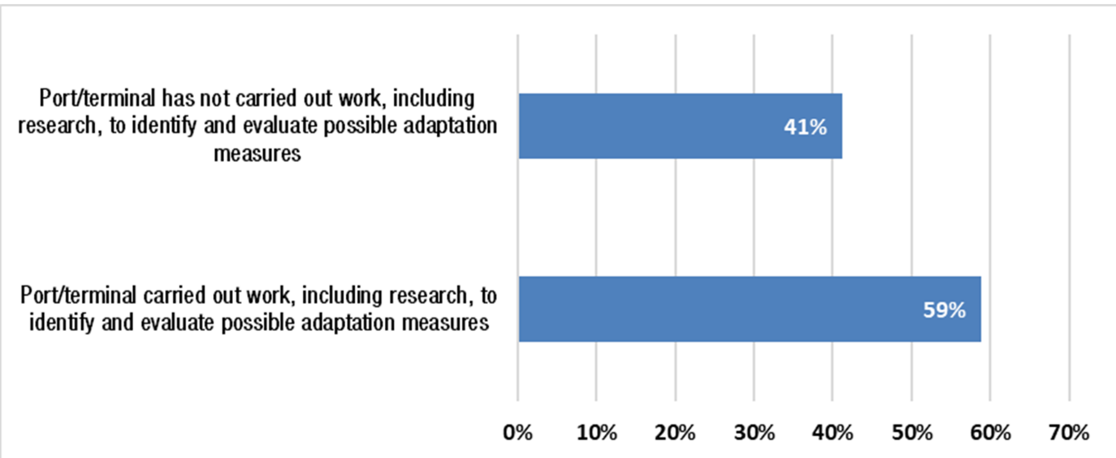
QUESTION 33 Do you expect impacts on your port/terminal due to weather or climate-induced changes to the following? (Check all that apply) (Fig. B33)



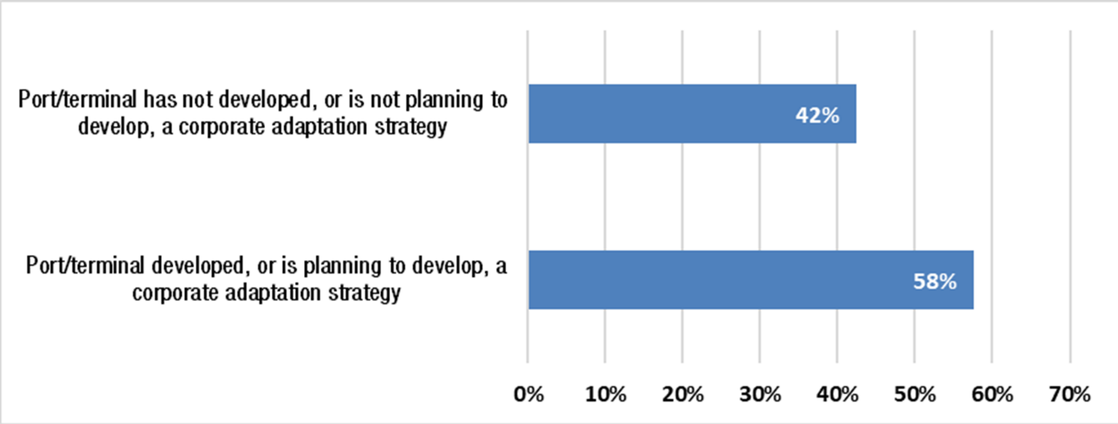
QUESTION 34 Has your port/terminal mainstreamed weather or climate-related considerations in planning, design and construction of infrastructure? (Fig. B34)



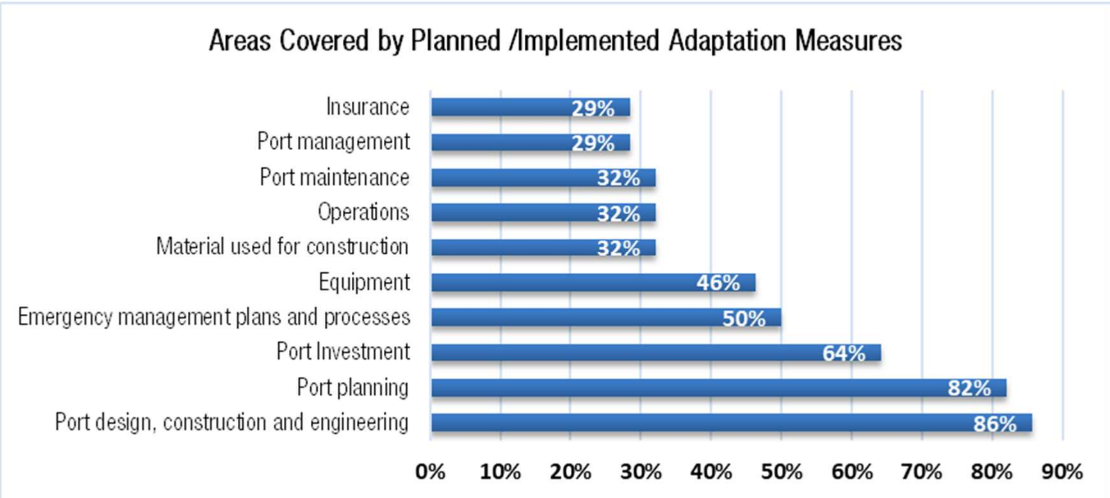
QUESTION 35 Has your port/terminal carried out any work, including research, to identify and evaluate possible adaptation measures? (Fig. B35)



QUESTION 36 Has your port/terminal developed, or is it planning to develop, a corporate adaptation strategy? (Fig. B36)



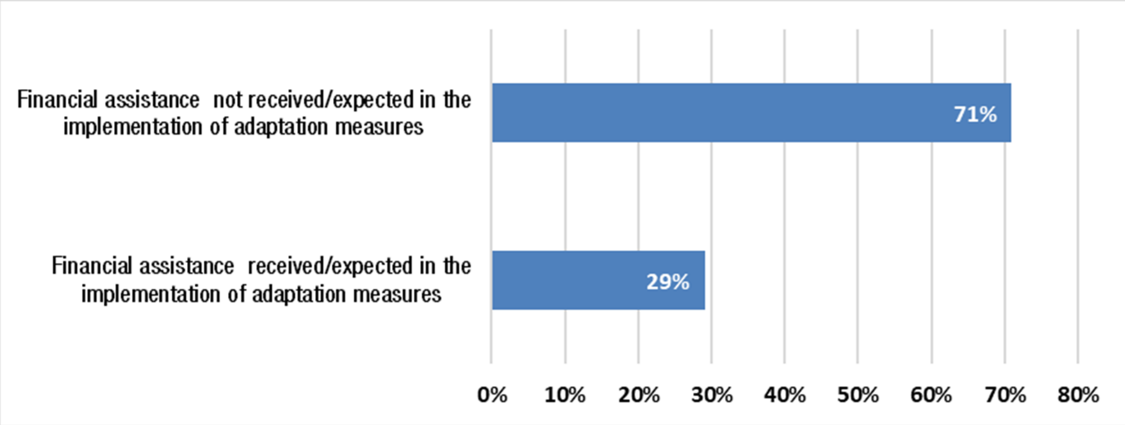
QUESTION 37 As applicable, please indicate whether implemented or planned adaptation measures cover any of the following (check all that apply): (Fig. B37)



QUESTION 38 As applicable, please indicate the estimated or projected total expenditure for adaptation measures in your port/terminal (in US$): (Fig. B38)

Total expenditure (US$)	Region
50.000.000	Middle East
20.000.000	Europe
150.000.000	Latin America
5.000.000	North America
n/a	North America
500.000	North America
not applicable	Europe
to be determined	North America
500.000.000	Asia
N/A	North America
165.763.000	North America
Not Known	Asia-Pacific

QUESTION 39 Has financial or other assistance (government/nongovernment) been received or is it expected in the implementation of adaptation measures? (Fig. B39)



QUESTION 40 Which adaptation measures (hard or soft) taken in your port/terminal do you consider effective, good value for money and an example of best practices?

Port	Adaptation measures
Small South American port	Working to measure and account the carbon footprint of port activities. Renewable energies are being sponsored and studied at the port by private companies and universities. First port in the country that will publish a sustainability report as part of our commitment to the city and industry.
Asian port	We cannot judge if the measures were effective or meet the cost that we invested
Asian port	No particular measures have been implemented
Large European port	Real time monitoring of waves and tides.
Small North American port	A retaining was erected to prevent flooding due to storm surges, swells and waves.
Large Asian port in a developing region	We follow good practices
Large North American port	We are currently only monitoring for changes. No adaptation is currently planned for implementation.
North American port	Better forecasting tools for water levels; Dynamic under keel clearance management tools; Improved bathymetric surveying tools and data. All are good value and good practices
Asian port	Conduct Enterprise Risk Management. To minimize the effect of weather and climate, we built enterprise risk management and Business continuity management. For example, if there is tilde time when container fall because of wind (very low, maybe once a year), our management ready to solve the step to improve or cover this event so that the business is going as well as usually.
Average size Asian port	Awareness: although climate change and the rise of sea level etc. issues are receiving more attention but not yet by all stakeholders and not yet fully in depth in respect of causes, consequences, remedial measures, preparedness etc. By better awareness of all the above, there would be more, quicker and effective actions in port development planning, management and operations. Insurance: both as spending item for management decision for better protection against potential risks to the port (stronger storms mean higher risks to port assets, ships, cargoes, container…) and also cost item for customers' consideration in choosing and using the port services. Port design criteria: s port's life span could be more than 50 years. So, there is a trade-off between higher investment cost by building the facilities on higher elevation (than required under the current construction code/master plan) to sustain higher level/frequency of sea level/tide/wave, and the property damage/business opportunity losses potentially caused by climate change in the future.
Asia-Pacific port	Development of Robust Planning Codes and Guidelines that incorporate sustainability and climate change related resilience and adaption measures

QUESTION 41 Are there any other comments or information you would like to submit regarding this part?

Port	Comment
Asian port	The Port Terminal Co, Ltd is operating the International Container Terminal as a joint venture between (…) city government (Port Authority) and private sectors. We are taking actions regarding global warming by introducing eco-friendly cargo handling equipments under the experiment study together with MLIT, (…) City, as following. For example, we acquired 17 Electric RTG; 5 of Hibrid Straddle Carriers. These experiments are showing a remarkable result so far by reducing the CO2 emissions by about 70% in the whole terminal. Prior to that equipment was operated using light oil gas.
North American port	It is recognized that Climate Change will impact the Port's future. Anticipated impacts include more intense and frequent wind, rain storms and sea level rise. Adaption to these Climate Changes will require a combination of Policy, Planning and Engineering responses. Prior to identifying preferred mitigation strategies, it will be necessary for the Port to gain a comprehensive understanding of the consequences of the hazard posed by sea level rise and changes to sea state by conducting detailed studies. Through the studies, the Port hopes to acquire a broad base of technical, policy and planning knowledge to be used to develop a robust and defensible approach to coastal flood and erosion risk.
European port	The areas covered by planned adaptation measures refer to prerequisites for planning, design and project of infrastructures and to the operational limits of terminal equipment, which should be considered in the public and private planned investments.
Asian port	In implementing enterprise risk management, should analyse the things listed on question no.32 (weather or climate-related events)
Asian port	More information and support from world port community on the issues.