Why Adapting Ports to the Impacts of Climate Change Matters to All

Regina Asariotis

Cities of the future, and the critical infrastructure which supports them, will need to adapt to future environmental conditions. This contribution focuses on the need to adapt ports—vital for cities now and in the future—to the impacts of climate change, a need which is becoming increasingly urgent with global temperatures rising at an alarming rate.[1] Global warming induces several climate hazards, such as rising mean and extreme sea-levels, heatwaves, heavy precipitation/flash floods, and extreme winds. Global warming of 2°C above the pre-industrial level, which may be reached by 2050, has been suggested by the Intergovernmental Panel on Climate Change as the threshold beyond which climate change risks may become unacceptably high.[2] By the end of this century, global warming around 2.7°C is considered "very likely" under an intermediate emissions scenario and could exceed 3.3°C under a high greenhouse gas emissions scenario.[3] Implementation of existing policies and pledges would only limit this global temperature increase to 2.5–2.9°C by 2100.[4]

In this context of a warming world, society needs to prepare for what may be in store. Much of the world's population, economic activities, and

Regina Asariotis, PhD, is Chief of the Policy and Legislation Section of UN Trade and Development (UNCTAD), where she is responsible for work on transport law and policy. This includes extensive research, expert dialogue and technical cooperation on the implications of climate change for maritime transport and trade, with a focus on climate change impacts and adaptation for seaports and other critical transport infrastructure, including in SIDS. Before joining UNCTAD in 2001, Regina was a Senior Lecturer in Maritime Law at the University of Southampton. She holds degrees in maritime law from Universities in the UK and Germany and is a Barrister in England & Wales, Attorney at Law in Greece and Member of the Chartered Institute of Arbitrators (CIArb). The views expressed are those of the author and do not necessarily reflect the views of the United Nations.

critical infrastructure are concentrated near the sea, with nearly 900 million people—10 percent of the global population—already living in coastal zones at low elevations which are under growing threat from the impacts of climate change, such as coastal floods and storms, flash floods, droughts, and extreme heatwaves.[5] This includes many of the world's cities with at least one million inhabitants and mega-cities with more than 10 million inhabitants, which are also home to some of the world's largest ports.[6]

Ports: Critical for Global Cities, Trade and Development, and at the Forefront of Climate Change Impacts

Ports ensure the steady supply of essential raw materials and manufactured goods on which urban population centers across the globe depend.[7] They are key infrastructure assets that serve as catalysts of economic growth and development. They create employment and industrial opportunities, generate wealth, and contribute to national GDP.[8] In addition to being vital for the economies of coastal cities and coastal nations, ports are among the critical infrastructure assets that make global trade and development as we know it possible. They are integral components of international transport networks which provide the physical infrastructure on which our globalized trading system depends. Globalization means societies, industries, and economies are all deeply interconnected and interdependent—so there is no "them" and "us." With over 80 percent of world trade volume carried by sea, ports are key nodes in the network of global supply chains, providing access to global markets for all countries, including those that are landlocked.[9] They are also essential for access to sectors and activities of the ocean or "blue" economy, including fisheries, offshore mineral resources, energy development, and cruise ship tourism.

At the same time, these complex infrastructure assets, often integrated within large urban agglomerations along global coastlines, are on the frontline of climate change.[10] They are exposed to various climate hazards, from heat waves—which can pose a major threat to human health and increase energy needs and cooling costs—to heavy precipitation, flash floods, winds, and waves (e.g., long waves and associated swell) that can jeopardize crane operations and can make access to ports more hazardous.[11] In a warming world, these hazards are set to increase.

Due to the location of ports at the land-sea interface, average sea-level rise and associated extreme sea-levels (ESLs) are especially concerning, with potential devastating impacts on port infrastructure and operations, and important knock-on effects throughout global supply chains.[12]

Increases in the mean and extreme sea levels can cause coastal flooding and port inundation, with the northwestern European, northwestern American, and southeastern Asian coasts, as well as those of Small Island Developing States (SIDS), projected to be particularly affected.[13] Recurring port inundation from extreme events can render transportation systems unusable, and can cause damages to terminals, freight villages, storage areas, cargo and vessels, as well as prolonged disruptions to supply chains.[14] Damages and operational disruptions from extreme waves that can cause coastal erosion, wave overtopping, quay flooding and in-port wave agitation that can constrain access, vessel handling, and berthing, could also increase under climate change.[15] Extreme tropical winds can also be very damaging, as they can cause infrastructure failures and operational disruptions from channel changes/silting, wind-generated debris, inability to operate cranes, vehicle blow-overs, and damages to connecting rail tracks and roads. They can also endanger berthing operations.[16]

Importantly, rising mean sea levels, combined with future extreme storm surges, waves, and tides, can generate devastating extreme sea level (ESLs), which especially pose a threat to seaports across the globe. Extreme sea levels are set to increase almost everywhere, which means that history no longer serves to predict future exposure.[17] Port defenses are designed to withstand extreme sea levels with a certain return period (i.e. recurrence frequency), commonly the 1-in-100 years extreme sea-level (ESL100) estimated at the time of design or construction. However, extreme sea levels of a magnitude previously expected to occur only once a century will occur much more often under climate change, significantly increasing the flood hazard for global ports, including for some of the top 100 container ports.[18]

As shown by projections under different climatic scenarios and timelines covering 3,630 ports across global coastlines, the future "once a century" extreme sea level (ESL100), which ports will need to cope with in a few decades' time, is going to be significantly higher. By 2050, depending on the climate scenario, 55 percent to 60 percent of these ports could face ESL100s that exceed two meters above the baseline mean sea levels of the 1980–2014 period.[19] By 2100, between 71 percent and 83 percent of ports could face ESLs of this same magnitude.

As concerns extreme heat, with 2°C global warming, ports in most tropical or sub-tropical settings will also face the baseline (mean of the

1976–2005 period) 1-in-100 year extreme heat event every one to five years, whereas with 3°C global warming, most global ports, except some at higher latitudes, could experience the baseline 1-in-100 years extreme heat event every one to two years.[20]

The Cost of Inaction

Climate risks directly translate into business risks for individual ports, but they also pose a threat to the integrity of transport systems and networks on which global society relies.[21] Climate change impacts on ports can result in significant infrastructure damage, as well as costly disruption and delay across supply chains, with potentially far-reaching consequences for international trade and sustainable development prospects, particularly of the most vulnerable nations. [22]

Hanson et al. (2011) estimated the total value of assets exposed to coastal flooding in 136 port megacities with over one million inhabitants at about 9 percent of the global GDP by the 2070s. Lenton et al. (2009), who additionally considered tipping points (global sea level rise of 0.5 meters), estimated that asset exposure to flooding in the same 136 port megacities could reach $28 trillion by 2050.[23] For the Tokyo Bay port areas alone, Hoshino et al. (2016) estimated the potential flooding costs from combined mean sea level rise and typhoon-induced storm surges as up to $690 billion (2016 values).[24] A more recent estimation of the value of assets exposed to coastal flooding has suggested that, in the absence of adaptation measures, by 2100, damage could amount to 12 to 20 percent of the global GDP.[25]

Economic losses can be extensive, not only in terms of infrastructure damage, but also—and maybe more importantly—in terms of operational disruptions and delays which have important knock-on effects throughout global supply chains.

Current global annual storm damages to ports have been estimated at roughly $3 billion, on average.[26] Additionally, global port-specific risk from natural hazards is estimated at $7.5 billion per year, with 32 percent of the risk attributed to tropical cyclone impacts, and an additional $63.1 billion in trade estimated to be at risk.[27] Annual systemic risk to global maritime transport, trade, and supply-chain networks is estimated at $81 billion, with at least $122 billion of economic activity on average also at risk.[28] These estimates do not, however, account for the expected increase of hazards under climate change.[29] These may also be considered conservative, given that a single extreme event can lead to major losses in affected regions. This was illustrated by Hurricane Sandy (2012) which caused over $60 billion in losses, including extensive damage and a week-long shutdown of the U.S. New York/New Jersey container port.[30] Hurricanes Irma and Maria (2017), Dorian (2019), and Beryl (2024) caused devastating impacts in many Caribbean nations, with overall losses in some of countries amounting to a significant fraction or multiple of their annual GDP.[31] Most recently, in the United States, Hurricane Beryl shut down ports and curtailed refinery operations in Texas; within a two-week period in September and October 2024, Hurricanes Helene and Milton hit Florida, leading a number of major ports to suspend operations.[32] In addition to hundreds of fatalities, early estimates indicate that the 2024 Atlantic hurricane season has caused overall losses of $500 billion.[33]

Climate-related damage, delay, and operational disruption also affects the performance of commercial contracts, with repercussions for the obligations and liabilities of contracting parties engaged in international transport and trade. These issues could hold potential for further economic losses and costly legal proceedings.[34] In addition, they may have important implications for insurance coverage, premiums, and, ultimately, insurability of losses. These implications deserve further attention and need to be both better understood and addressed to reduce disruptions and related economic losses, avoid costly litigation, and ensure that insurance remains available and affordable.

Given the critical role of ports in the global trading system and their potential exposure to climate related damage, disruptions, and delays, enhancing their climate resilience is a matter of strategic socio-economic importance for the global economy and society as a whole.[35] It is also key to enabling SIDS and other vulnerable coastal and island nations to harness the full potential of the blue economy for sustainable development.[36] SIDS and other island nations depend on seaports as lifelines for external trade, food and energy security, and tourism—which is often a major driver of economic growth and development—as well as in the context of disaster response and recovery.[37] Ports also provide vital socio-economic linkages and are key to regional and inter-island connectivity. However, in many SIDS, these critical assets are at high and growing

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risk of climate change impacts such as coastal flooding, beginning as early as the 2030s.[38]

Are Ports Prepared for a Future under Climate Change?

The risk of climate change impacts can be understood as a function of three parameters—hazard, exposure, and vulnerability (the capacity to respond). Exposure to growing hazards will result in increasing risks, unless effective adaptation measures are taken to reduce vulnerability.[39] Given that ports are infrastructure assets with long lifespans and planning horizons, reducing their vulnerability through timely adaptation measures is a matter of increasing urgency.

However, at the global level, progress in implementing fit-for-purpose measures on the ground remains slow, both in coastal cities and in ports. Recent research on climate change adaptation in 199 coastal cities worldwide suggests that overall progress is "rather slow, of narrow scope and not transformative," albeit with differences across regions, sizes, and economic capacities.[40] Industry surveys conducted by UNCTAD—encompassing ports collectively responsible for over 16 percent of global seaborne trade—and by industry organizations suggest that ports and their engineers are not yet adequately prepared.[41] Many global ports are increasingly impacted by "exceptional, unprecedented or otherwise out-of-the ordinary" climate and weather-related extremes and events, often causing "significant" or "critical" delays and disruptions.[42] At the same time, there are still important knowledge gaps regarding the specific nature and extent of exposure to climate hazards that individual port facilities of all sizes and across regions may be facing, with important repercussions for levels of preparedness. For example, the majority (76 percent) of respondent ports to the UNCTAD port industry survey stated that they had mainstreamed weather/climate related considerations in planning, design, and construction of infrastructure. However, a significant proportion (41 percent) had not yet carried out any work or research to identify and evaluate possible adaptation measures. 40 percent of respondent ports had neither carried out nor planned relevant vulnerability assessments. Only 29 percent of respondents to an online survey of 85 U.S. port and maritime infrastructure engineers indicated that their organization had an internal sea level change (SLC) policy, design, or planning document.[43] Survey results also show that the lack of regulatory design standards in this area leads to engineers and their clients disregarding SLC more frequently.

What Needs to be Done?

With maritime trade expected to triple by 2050 and climate-driven hazards expected to increase, significant acceleration of climate change adaptation and resilience-building for ports is needed to avert, minimize, and mitigate costly damages and economic losses and safeguard the integrity of supply chains on which global cities and society depend.[44]

In light of long infrastructure planning horizons and lifespans, timely adaptation action in a systemic manner must be an urgent priority for all public and private entities with a stake in international transport and trade. Thus, all stakeholders involved in the planning, development, and operation of ports and other coastal transport infrastructure need to mainstream considerations related to climate risks and impacts as part of their decision-making processes.[45]

Ports do not exist in isolation, but rather are closely connected to the cities they inhabit and inland transport links like road and rail. Collaboration and the participation of a broad range of public and private sector actors, including transport operators, regulators, municipal planners, port tenants, shippers, and coastal managers, as well as scientists, engineers, and other technical experts, will be particularly important. These actors will be crucial both in relation to the assessment of risks and impacts and the planning, development, and implementation of effective adaptation measures at the facility level and across transport networks and systems.[46]

Policy and legal frameworks, while typically not sector specific, have a particularly vital role to play in strengthening risk management and increasing levels of resilience on the ground.[47] They can facilitate, support, and accelerate climate-risk assessments and the development of effective action on adaptation.

Policies, strategies, and plans establish agreed objectives, priorities, and commitments which guide the allocation and use of resources and institutional frameworks and can provide important incentives to advance port resilience. *Legal frameworks* are both powerful and vital tools to facilitate and advance implementation. They also help create a level playing field and establish accountability. To be fit for purpose and avoid maladaptation, both policies and laws need to consider the latest available scientific information and facilitate risk-informed decision making under uncertainty.

A range of policy and legal instruments reflecting related commitments and objectives and fostering their implementation have been agreed upon internationally, including the 2015 Paris Agreement (195 Parties), the Sendai Framework on Disaster Risk Reduction (SFDRR) 2015–2030, and the 2030 Agenda for Sustainable Development, along with regional and national frameworks.[48] Relevant legal obligations and normative technical guidance aimed at ensuring the "climate proofing" of new infrastructure, in line with agreed policy commitments on resilience-building, adaptation, and disaster risk reduction, are already in place as a matter of supranational law, applicable in the 27 Member States of the European Union (EU).[49] These could significantly enhance levels of climate-resilience and preparedness for European ports, as well as for EU-funded port projects in other countries, and may serve as useful examples of good practices for policymakers in other regions.

In order to ensure the integrity of closely connected global supply chains and reduce, minimize, and avert extensive economic losses arising in the future, much more needs to be done. Effective adaptation requires multifaceted approaches: "soft" and "hard" measures, including innovative and effective technical measures; bridging of potential data and knowledge gaps; and the development of appropriate management solutions that reduce vulnerability and allow for decision-making under uncertainty.[50] In the light of the long service life of ports (and other key transport infrastructure), and the potentially major consequences of inaction, effective adaptation and resilience building requires rethinking established approaches and practices early.[51]

Moreover, to avoid overengineering and maladaptation and to increase levels of preparedness on the ground, a good understanding of climate risks in all their dimensions is critical. With climate hazards growing at an alarming rate, past experiences can no longer be relied on to predict future exposure and risks. Relevant risks need to be both assessed and effectively addressed before any major impacts materialize. High-quality technical risk assessments at local and facility levels, using the best available science and facility specific information and involving collaboration with relevant stakeholders, are therefore urgently required.[52] On the basis of such risk assessments, the probability and severity of impacts can be determined together with the urgency of specific adaptation responses; this can be defined as the ratio of the time needed to plan and implement an effective response to the time available.[53] Relevant information is needed to support on-the-ground decision-making and inform the prioritization of resources and the design of the required adaptation measures. However, as noted already, recent industry surveys suggest that many global ports have not yet carried out risk assessments and therefore still lack relevant information to prioritize and appropriately target effective adaptation measures.

In this context, industry guidance, standards, and methodological tools to assist stakeholders have an important role to play. Some important progress has been made in this respect over the past few years. For example, the Marrakech Partnership for Global Climate Action has developed a number of recommendations for different groups of stakeholders, together with milestones towards 2050.[54] Similarly, the International Standardization Organization (ISO) has developed two standards to assist in adaptation and related vulnerability and risk-assessments.[55] PIANC, the World Association of Waterborne Transport Infrastructure, has produced detailed technical guidance on adaptation planning for ports, as well as on selecting, designing, and evaluating options for resilient infrastructure. [56] In addition, a range of cross-sectoral and port-specific methodological frameworks and tools have been developed.[57]

However, a number of other issues are also important for the development of effective adaptation measures at the facility level and deserve increasing focus and attention. This includes the generation and dissemination of more tailored data, such as infrastructure inventories, higher resolution data, including better digital elevation models and research to improve the understanding of coastal processes under climate change, as well as ecosystem approaches to adaptation that can play a significant role in reducing risks.[58][59] Drawing on synergies with energy efficiency, decarbonization, and renewables can also provide important co-benefits for adaptation (including in response to extreme heat), reduce related energy needs and costs, and increase energy security.[60] Increased investment in human resources and skills, in particular skilled coastal scientists and engineers, at regional, national, and local levels, will be critical for successful adaptation and resilience-building in the future, as will be the mainstreaming of climate change-related considerations for critical infrastructures into nationally determined contributions and national adaptation plans under the Paris Agreement.

Targeted capacity-building—human, technological, and financial—is urgently needed, particularly in the most vulnerable developing countries which are often at the frontline of impacts but have low adaptive capacity and face a worsening debt crisis.[61] The major financial scaling of affordable infrastructure adaptation finance, including in the form of grants rather than loans, will be critical for these countries, particularly vulnerable SIDS that are sea-locked and thus heavily dependent on their ports (and coastal airports).[62] With the gap between adaptation costs in developing countries and available public adaptation finance flows estimated as US$187-359 billion per year, scaling up financing for adaptation will require a major collaborative effort by policymakers and development partners.[63]

According to the Organization for Economic Co-operation and Development (OECD), in 2022, total climate finance provided and mobilized for developing economies amounted to $115.9 billion, exceeding the annual $100 billion goal for the first time. However, of this total, only $32.4 billion (28 percent) was for adaptation, and only a fraction of this amount will have targeted climate change adaptation for ports and other critical coastal infrastructure.[64] While a New Collective Quantified Goal on Climate Finance (NCQG) was negotiated at the 29th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP29), its successful implementation will depend on a number of factors, including political will and private sector contributions.[65] With extreme weather events, such as hurricanes and tropical storms, heatwaves, and extreme precipitation causing flash floods, projected to increase in frequency or severity under climate change, effective disaster risk reduction, management, and response will be an increasingly important imperative for coastal cities across the globe. To increase preparedness and mitigate impacts, there is a need to upscale support for multi-hazard Early Warning Systems (EWS), including through the Early Warnings For All (EW4All) initiative and national and regional efforts to develop EWS.[66]

In light of the cost of inaction, policymakers should consider resilience-building, adaptation, and disaster risk reduction for ports and other critical transport infrastructure assets a particularly valuable investment for a sustainable future. According to World Bank estimates, each dollar invested in resilient infrastructure in developing economies generates a four dollar return, amounting to up to $4.2 trillion in benefits.[67] Above all, resilience helps prevent and mitigate economic, environmental, and human losses and ensures that future

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generations in cities and communities across the globe have a liveable future.

As noted from the outset, ports are vital for all cities—not only coastal cities—both now and in the future, and they need to adapt to changing environmental conditions. There is no one-size-fits-all approach to adaptation and there are no quick fixes. However, the key message for policymakers, industry actors, international organizations, and development partners is that there is no time to lose and "all hands on deck" are needed. A world of interconnected cities, communities, trading networks, and supply chains depends on well-functioning transportation links. Failure to adapt is not an option, and time is of the essence.

Notes

1. The year 2023 was the warmest year on record, with the global average near-surface temperature at 1.45 °C (± 0.12°C) above the 1850–1900 pre-industrial average. This figure is projected to reach 1.5 °C in the 2030s. See: World Meteorological Organization, *The State of Global Climate 2023*, WMO No. 1347, March 19, 2024, https://library.wmo.int/idurl/4/68835; Intergovernmental Panel on Climate Change, Climate Change 2023: Synthesis Report, 35–115, https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf.

2. Intergovernmental Panel on Climate Change, *Global Warming of 1.5 ºC*, 2018, https://www.ipcc.ch/sr15/. See only Summary for Policymakers at B.2. This is also reflected in Art. 2.2 of the Paris Agreement, which aims to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels."

3. Intergovernmental Panel on Climate Change, *Climate Change 2023: Synthesis Report*, 35–115, https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf.

4. United Nations Environment Programme, *Emissions Gap Report 2024* (Nairobi: United Nations, 2024), https://www.unep.org/resources/emissions-gap-report-2024; "Warming Projections Global Update," Climate Action Tracker, November 2024, https://climateactiontracker.org/documents/1277/CAT_2024-11-14_GlobalUpdate_COP29.pdf.

5. Intergovernmental Panel on Climate Change, *6th Assessment Report Fact sheet - Cities and Settlements by the Sea*, November 2022, https://www.ipcc.ch/report/ar6/wg2/downloads/outreach/IPCC_AR6_WGII_FactSheet_CitiesSettlementsBtS.pdf. As noted by the IPCC, "[t]he population potentially exposed to a 100-year coastal flood is projected to increase by about 20% if global mean sea level rises by 0.15 m relative to 2020 levels; this exposed population doubles at a 0.75 m rise in mean sea level and triples at 1.4 m without population change and additional adaptation (medium confidence). By 2100 the value of global assets within the future 1-in-100 year coastal floodplains is projected to be between US$7.9 and US$12.7 trillion (2011 value) under RCP4.5 [medium emissions scenario], rising to between US$8.8 and US$14.2 trillion under RCP8.5 [high emissions scenario] (medium confidence)." Extreme heatwaves are estimated to kill almost half a million people a year (about 30 times more than tropical cyclones), particularly in developing countries, see United Nations Secretary General, "Following Three Hottest Days on Record, Secretary-General Launches Global Action Call to Care for Most Vulnerable, Protect Workers, Boost Resilience Using Data, Science," *United Nations Secretary General Press Release*, July 25, 2024, https://press.un.org/en/2024/sgsm22319.doc.htm. See also: Jonathan Watts and Kate Kaminski, "Heat Inequality 'causing thousands of unreported deaths in poor countries,'" *The Guardian*, August 16, 2020, https://www.theguardian.com/environment/article/2024/aug/16/heat-inequality-causing-thousands-of-unreported-deaths-in-poor-countries.

6. "One Hundred Container Ports 2023," Lloyd's List, https://www.lloydslist.com/one-hundred-container-ports-2023; United Nations Department of Economic and Social Affairs, *The World's Cities in 2018*, https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/documents/2020/Jan/un_2018_worldcities_databooklet.pdf.

7. In 2023, with the volume of seaborne trade accounting for 12.3 billion tons (United Nations Conference on Trade and Development, *Review of Maritime Transport 2024*, UNCTAD/RMT/2024, https://unctad.org/publication/review-maritime-transport-2024) and an estimated world population in excess of 8 billion ("Day of 8 Billion," United Nations, https://www.un.org/en/dayof8billion), around 1.5 tons of goods per global citizen were shipped—from port to port.

8. See for instance key facts and figures for the Port of Rotterdam—the 10th largest container port by throughput in 2023—which generates over 500,000 jobs and provides an added value of over €60 billion for the Netherlands, see: "Facts and figures: The port

of Rotterdam in numbers," Port of Rotterdam, https://www.portofrotterdam.com/en/experience-online/facts-and-figures. U.S. ports' contribution to the U.S. GDP totals almost $311 billion, see: American Association of Port Authorities, *2024 Port and Maritime Industry Economic Impact Report*, https://aapa.cms-plus.com/files/2024-Economic-Impact-Study.pdf.

9. United Nations Conference on Trade and Development, *Review of Maritime Transport 2022*, UNCTAD/RMT/2022, available from https://unctad.org/publication/review-maritime-transport-2022; Jasper Verschuur, Elco Koks, and Jim Hall, "Ports' criticality in international trade and global supply-chains," *Nature Communications* 13, no. 4351 (2022). Lack of access to the sea is the defining disadvantage of Landlocked Developing Countries (LLDCs), a recognized group of geographically disadvantaged vulnerable countries, who rely on the cooperation of transit countries to exercise their right of access to and from the sea and freedom of transit under the UN Convention on the Law of the Sea, 1982 (Part X).

10. C. Izaguirre et al., "Climate change risk to global port operations," *Nature Climate Change* 11 (2021): 14–20.

11. Isavela Monioudi et al., "Climate change impacts on critical international transportation assets of Caribbean Small Island Developing States (SIDS): the case of Jamaica and Saint Lucia," *Regional Environmental Change* 18 (2018): 2211–2225; Austin Becker et al., "A note on climate change adaptation for seaports: a challenge for global ports, a challenge for global society," *Climate Change* 120 (2013): 683–95.

12. Izaguirre et al., "Climate change risk." In a fictitious scenario, it has been suggested that under average global sea levels rise of at least 40 cm by 2050, some of the world's largest container ports could no longer be in operation, see: Economist Impact, *Global Maritime Trends 2050*, https://impact.economist.com/ocean/global-maritime-trends-2050/downloads/Global%20Maritime%20Trends%202050%20Report.pdf.

13. S. Hanson and R.J. Nicholls, "Extreme flood events and port cities through the twenty-first century," in *Maritime Transport and the Climate Change Challenge*, ed. Regina Asariotis and Hassiba Benamara (London and New York: Earthscan/Routledge), 243–265; Izaguirre et al., "Climate change risk." Michalis Vousdoukas et al., Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard," *Nature Communications* 9, no. 2360 (2018); Alessio Giardino, Kees Nederhoff, and Michalis Vousdoukas, "Coastal hazard risk assessment for small islands: assessing the impact of climate change and disaster reduction measures on Ebeye (Marshall Islands)," *Regional Environmental Change* 18 (2018): 2237–48.

14. United Nations Economic Commission for Europe, *Climate Change Impacts and Adaptation for International Transport Networks* (New York and Geneva: United Nations, 2013), www.unece.org/fileadmin/DAM/trans/main/wp5/publications/climate_change_2014.pdf.

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16. Dylan Folkman et al., "Port resiliency and the effects of hurricanes on port operations," *International Journal of Advanced Operations Management* 13 (2022): 409–30; United Nations Economic Commission for Europe, *Transport for Sustainable Development: The case of Inland Transport, ECE/TRANS/251* (New York and Geneva: United Nations, 2015), https://unece.org/fileadmin/DAM/trans/main/wp5/publications/climate_change_2014.pdf; United Nations Economic Commission for Europe, *Climate Change Impacts and Adaptation for International Transport Networks* (New York and Geneva: United Nations, 2014), www.unece.org/fileadmin/DAM/trans/main/wp5/publications/climate_change_2014.pdf.

17. *Intergovernmental Panel on Climate Change, IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, https://www.ipcc.ch/srocc/.

18. United Nations Trade and Development SDG PULSE, *Disruptions Persist in Maritime*

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19. Regina Asariotis et al., "Climate change and seaports: hazards, impacts and policies and legislation for adaptation," *Anthropocene Coasts* 7, no. 14 (2024), https://link.springer.com/article/10.1007/s44218-024-00047-9.

20. Ibid.

21. PIANC, *Climate Change Costs to Ports and Waterways: Scoping the Business Case Assessment for Investment in Adaptation* (2024), https://www.pianc.org/publication/climate-change-costs-to-ports-and-waterways-scoping-the-business-case-assessment-for-investment-in-adaptation.

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