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Ports and climate uncertainty: An economic imperative for India

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ABSTRACT

Seaports are an indispensable asset in interconnected and interdependent global supply chains. Their complex infrastructural and operational systems and critical foreland and hinterland networks make ports a vital nodal point in the economic progress of nations at large, and the coastal urban agglomerations in particular. These critical maritime assets are currently under threat from the disruptive impacts of anthropogenic climate change, such as sea-level rise and intensifying extreme weather events. The economic losses from these impacts will span a wide range, from hard infrastructural damages to operational delays in supply chain management. Incorporating climate resilience in existing and new port infrastructure remains a complex challenge that will require port authorities to confront the problem of climate uncertainty and its socio-economic implications. This article focuses on seaports in the Indian context to highlight the complex threats of climate change. It examines the main debates on climate uncertainty and policymaking, path dependencies in port planning, global best practices, knowledge gaps and strategies that will be critical for Indian ports to better confront climate change induced disruptions in the near future.

KEYWORDS

Seaports; climate change; resilience; policymaking; port infrastructure and operations

Introduction

Ports are the critical nodal points in globalised trade and commerce. They act as the threshold space that links the vast hinterlands with critical supply chains of an interconnected and interdependent world market. Further, they act as catalysts for growth and sustenance of nearby industries and communities, and provide an ecosystem for the growth of domestic markets and stakeholders.[1] Historically, port cities have been the epicentre of human economic productivity and socio-cultural exchange; and the port itself, by dint of its geographical location, has acted as the mediating space between the land and the sea.

Ports have played a critical role in shaping the political and economic destinies of nations. Currently, 90 per cent of trade by volume in India docks at its 12 major and nearly 200 minor and intermediate ports.[2] Over the past a few decades, the People's

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Republic of China has witnessed a staggering rise in its port cargo throughput, which, much like the pattern of its overall economic growth, has risen from 0.40 to 8.08 billion tonnes, with coastal provinces like Zhejiang, Fujian, Jiangsu, and Guangdong as the epicentres of this growth.[3] In the case of the United States (U.S.), the total economic impact of port sector exceeds $4.5 trillion dollars annually and the maritime transport sector provides nearly 23 million jobs.[4]

As the port industry undergoes rapid transformational changes, including artificial intelligence, big data analytics, information technology-driven infrastructure, smart grids, changes in trade routes, demographic shifts, and sustainability challenges, the future global port landscape appears to be on a markedly different path.[5] A critical component of this change will include attitudinal and policy shifts on the questions of nature of climate risks, adjustments for future uncertainty, and investments into climate resilience strategies of ports. A 2017 survey by the United Nations Conference on Trade and Development (UNCTAD) reported that 72 per cent of the responding port authorities were impacted by extreme events, which led to delays (60 per cent), operations disruptions (76 per cent), or physical infrastructural damages (45 per cent).[6] Given a port's vital role in the global supply chains and their deep backward linkages, rise in the frequency and scale of port disruptions, such as extreme weather events and pandemics, may prove to be a critical threat to national and international economy (see Figure 1).

Accuracy of predictions and forecasting of trends are a fundamental basis for the planning of ports and port-led development. Future trends in the shipping and port sectors are going to see a complex interplay of technological shifts, hinterland politics, health of oceans, and global competition. Therefore, the tools and techniques of forecasting must be updated to incorporate all new and emerging factors. The climate crisis is one such factor which is rife with uncertainty, and the emerging scientific evidence as well as information gaps and imperfections in the understanding of its interactions with the wider socio-economic systems make it the most complex challenge for vital sectors of economy such as ports and shipping.[7] This article will shed light on the nature of this climate uncertainty and the economic impacts of climate change on the ports sector. The first part of the article will focus on examining climate uncertainty, tipping

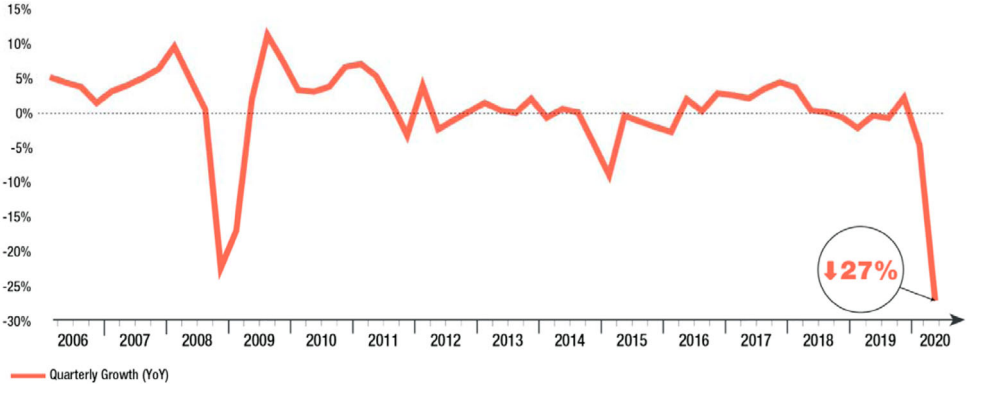

Figure 1. Trends in global trade (percentage change). Source: UNCTAD, "COVID-19 and Maritime Transport Impact and Responses", Transport and Trade Facilitation Series No. 15, 2021, https://unctad.org/system/files/official-document/dtltlb2021d1_en.pdf (accessed 15 December 2021).

points, and social cost of carbon (SCC), which are critical part of the current economic thinking and debates on climate change. The second part will focus on port economics and the rising threat of climate change to port infrastructure, supply chains, and future business prospects. The main argument presented in the article is that there is a strong economic case for India to err on the side of pre-emptive planning and climate-resilient port development in order to secure against future uncertainty.

Ports and climate disruption

Natural disasters and anthropogenic climate change, which are accelerating the frequency and scale of such disasters, are affecting the ports in multiple ways. Given the critical role that port infrastructure, operations, and supply chains play in the interconnected global markets, the heightened vulnerability to future changes to water, oceanic, and atmospheric conditions will be an important point of concern. A port disruption can lead to severe economic and infrastructural losses, as has been the case with multiple cyclones hitting the shorelines of tropical nations. For instance, India's busiest port, Jawaharlal Nehru Port in Mumbai, which handles almost 52 per cent of all cargo traffic in India (see Figure 2), had to suspend vessel berthing operations for almost two days due to the landfall of Cyclone Tauktae in May, which resulted in delays at Nhava Sheva;[8] and this upward trend is further expected to result in higher instances of port disruptions and blank sailings. The delays also led to greater congestion at the

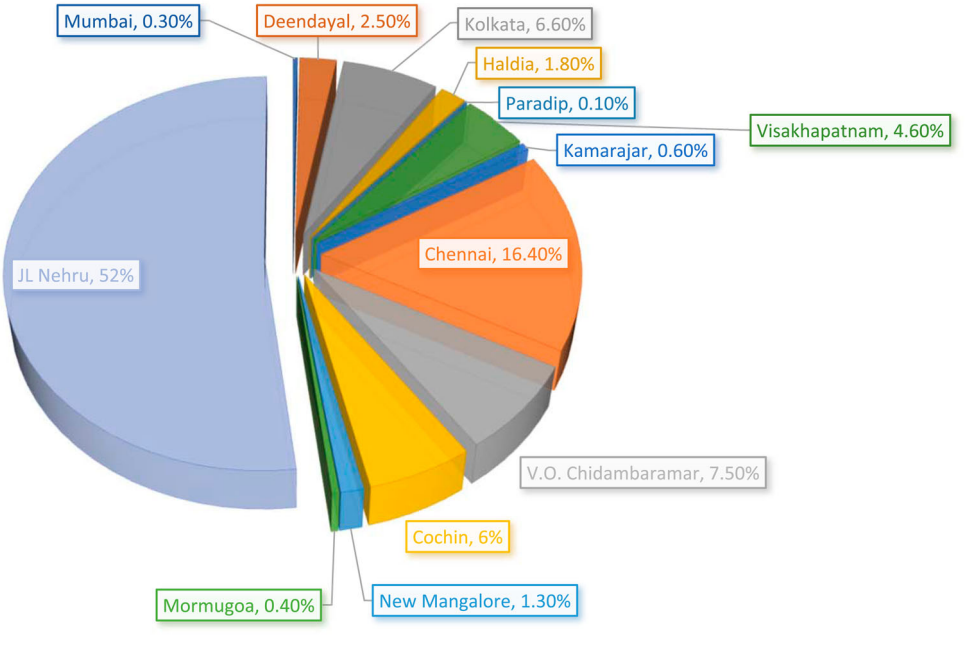

Figure 2. Share of major port container traffic in 2018–2019. Source: *Basic Port Statistics of India (2018–19)*, Ministry of Shipping, GoI, 2020, https://shipmin.gov.in/transport-reseach/basic-port-statistics (accessed 15 December 2021).

port, which directly impacted the importers who had to pay higher rates for demurrage – a cost that will finally have a cascading impact on the customers.

A similar story unfolded at the port of Pipavav in Gujarat, run by a private enterprise, where the port authorities declared force majeure due to the disruption in critical infrastructure of power supply and communication that led to operational delays and diversion of cargo traffic.[9] Further, disruptive events like cyclones and flooding have caused damages to the breakwater, and also led to other construction-related delays, at the upcoming international multipurpose deep-water seaport project at Vizhinjam in Kerala, which is expected to compete with Sri Lankan port as the preferred port of call for transhipment. Currently, the ports in Colombo, Singapore, and Jebel Ali (Dubai) handle 62 per cent of India's transhipment cargo, which adds to both the costs as well as transit time of the cargo.[10]

The first-ever regional climate assessment report published by the Ministry of Earth Sciences, Government of India, notes:

> There has been a significant reduction in the annual frequency of tropical cyclones over the NIO basin since the middle of the twentieth century (1951–2018). In contrast, the frequency of very severe cyclonic storms (VSCSs) during the post-monsoon season has increased significantly (+1 event per decade) during the last two decades (2000–2018).[11]

In recent decades, rainfall occurrences of unprecedented intensity have also been witnessed during the Indian summer monsoon season, which has brought major coastal cities – Mumbai (2005, 2014, 2017), Chennai (2002, 2004, 2005, 2006, 2007, 2015), and Kolkata (2007, 2017) – to a crippling standstill.[12]

The right time for climate action?

Today, how should ports weigh the value of costs and benefits that will accrue in future? The cost–benefit analysis of climate action has been a long-standing debate which can be understood through the concept of SCC, which, essentially, "tries to add up all the quantifiable costs and benefits of emitting one additional tonne of CO_2, in monetary terms. This value can then be used to weigh the benefits of reduced warming against the costs of cutting emissions".[13]

This vexing question of SCC has been traditionally addressed by the economists through the method of discounting.[14] Social discount rates (SDRs) are used to assign a present value on costs and benefits that will occur in future. The debate between Lord Nicholas Stern, the author of the *Stern Review: The Economics of Climate Change*,[15] and William Nordhaus, the 2018 winner of Nobel Prize in Economics, essentially dealt with this broad question: whether we should act on climate incrementally or should one opt for immediate precautionary efforts to avoid catastrophic and irredeemable losses in the future? The *Stern Review* assumed: "a dollar of economic damage prevented a century from now (adjusted for inflation) is roughly as valuable as a dollar spent reducing emissions today".[16] Nordhaus challenged this assumption, arguing that the burdens of climate change can be discounted in the present as it will only have a marginal impact on the global gross domestic product (GDP) and the future generations will be richer and better equipped to handle the crisis. Nordhaus developed the integrated assessment models (IAMs), particularly the Dynamic Integrated Climate Economy (DICE) model,

which allowed scientists to assess divergent economic pathways and their implication for climate change and well-being of future generations.[17] The smooth relationship that Nordhaus predicts between the economic impacts and increasing temperatures has been critiqued extensively. Also, the underlying assumptions within the DICE model, particularly its choice of high discount rate, which is a critical element in determining the pace of decarbonisation, have raised concerns in recent years.[18]

Stern, on the other hand, suggests a lower discount rate, which makes it easier to rationalise a higher investment in costly technological changes in the present. Unlike Nordhaus, Stern rests greater faith in bottom-up technological progress which, he argues, can cut down costs of climate mitigation drastically by the year 2050 for an abatement level up to 75 per cent.[19] Nordhaus critiqued the *Stern Review* as "political in nature", which essentially has "advocacy" at its main purpose.[20] The ideas such as SCC and discount rates remain hotly debated and there may be a temptation on the part of non-economists to dismiss their practical utility, but it is clear that IAMs, such as the DICE model, are now an integral part of decision making.[21] In the case of ports and port-led development models, the economic question is of paramount concern. Much like in the case of shipping sector – which was excluded from the 2015 Paris Agreement on account of the international nature of the activity, which is difficult to address through a framework of national commitments alone – the ports sector too has paid little attention to the climate question. The performance of ports is heavily reliant on the health of oceans and port authorities will find themselves increasingly under pressure to wrestle with the question of climate uncertainty and its impact on economic performance of ports and resilience of port infrastructure and operations. However, the task of incorporating elements of climate uncertainty into decision-making processes, such as the future of port development, remains an uphill challenge.

Understanding climate uncertainty: Risks and tipping points

Martin Weitzman, an economist, describes the most striking characteristic of climate economics to be its extreme downside, which, he argues, remains non-negligible. He notes, "Deep structural uncertainty about the unknown unknowns of what might go very wrong is coupled with essentially unlimited downside liability on possible planetary damages".[22]

The lexicon of climate change economics has always carried the weight of risk, uncertainty, and liability as its core concern; and this is reflected in the United Nations Climate Change Conference of the Parties negotiations, which are currently stalled on the outcomes of Article 6 that deals with carbon markets.[23] Within the specific context of climate change economics, the notion of uncertainty is not limited to the classical understanding of risk, where the probability of a certain event occurrence is known. It has to take into account the notion of future risk, which is largely unknown and uncertain. It further lacks any clear consensus on the assignment of probability due to a lack of information or vastly different predictions and opinions derived from different scientific models and data sets.[24] The scientific models serve as an important and incisive tool to organise knowledge, predict outcomes, and map out the relationship between multiple variables.[25] In the environmental economics

domain, models can be categorised into scientific and economic models. The former concentrate on the ecological and biophysical impacts and long-term consequences of rising greenhouse gas (GHG) concentrations and emissions, while the latter concentrate on cost–benefit analysis and assessment of alternative strategies, such as renewable transition.[26] The IAMs, a hybrid form of these two models, are commonly used to assess the SCC, as discussed in the previous section.[27]

These models provide a map of different pathways to the future, which can guide policy changes. However, they lack the precision that can entirely overcome uncertainty, which, for example, in the case of scientific models of temperature projections may "differ by the lead time of the prediction, and even by geographical region".[28] Similarly, in economic models, the objective probability remains a crucial hurdle, along with the difficult task of assigning economic value to indicators, such as health of the future generations, reducing health of ecosystems, biodiversity, and cost–benefit analysis. The 2007 Intergovernmental Panel on Climate Change (IPCC) report notes:

> Where we cannot measure risks and consequences precisely, we cannot simply maximize net benefits mechanically. This does not mean that we should abandon the usefulness of cost-benefit analysis, but it should be used as an input, among others in climate change policy decisions.[29]

The IPCC had introduced the idea of tipping points two decades ago, which has gained greater traction among policymakers in recent years. The idea was largely mooted as a precautionary approach against a low-probability scenario, rather than a definite threshold. At the time of its conception, the scientific predictions regarding large-scale discontinuities in the climate system were limited to future scenario where global warming would exceed 5°C above pre-industrial levels. This prediction has sharply changed in the recent years, especially with the publication of IPCC special reports, which suggest that erring on the side of inaction would be inadvisable as tipping points could now be exceeded between 1°C and 2°C of global warming.[30]

While the future uncertainty and SCC are important ways to understand climate change economic risks, it is also equally important to observe the recent historical trends to understand the business risks of climate change. A rating agency's recent paper highlights the credit implications of physical climate change:

> While our sovereign bond rating methodology does not account separately or explicitly for the credit risks posed by climate change, climate risks are already broadly captured in the four key risk factors we use in our analysis – economic strength, fiscal strength, institutional strength and susceptibility to event risk – either directly or indirectly through a variety of indicators.[31]

Ports and climate change: Impacts and strategies

The rate of increase in synoptic-scale weather disturbances, like tropical cyclones and coastal flooding, that last for a few days and rising trends for sea surface temperatures and sea level rise in the Indian Ocean Region carry severe consequences for port operations and supply chain management. These relate to the chain of external systems and internal assets and activities on which a port's commercial success relies.

Trade patterns and demand

(1) Climate change is a planetary-scale phenomenon that is increasingly shaping the geophysical and geopolitical state of the world. Its impact on the global economy will be disruptive and, in most cases, damaging. Commercial ports are dependent on the vitality of the shipping sector and the overall GDP of the country. The *Stern Review* estimated that the average costs of climate change could be up to 1.25 per cent of global per capita consumption by the 2050s, which will mean heavy annual revenue losses for the ports. The high-risk, low-probability events, the *unknown unknowns*, will also affect the port sector heavily, as has been the experience during the COVID-19 pandemic and the 2008 economic downturn. Economic losses, which includes direct loss in the form of critical infrastructure and operational disruptions/delays, will affect the tropical countries the most due to high instances of cyclones, storm surges, and waves.

(2) The Northern Sea Route, which runs from the Barents Sea to the Bering Strait between Siberia and Alaska, is increasingly becoming accessible due to the melting of ice in the region. The new sea route, which will be 4000 nautical miles shorter compared to the Suez Canal, will carry severe ecological implications: for instance, black carbon from ships could lead to loss of reflective capacity of the earth, which would be "equivalent to adding one trillion tons of CO_2 to the atmosphere, on top of the 2.4 trillion tons emitted since the Industrial Age".[32] Apart from contributing to the global sea level rise and acceleration of global warming, this new sea route will lead to "remarkable shifts in trade flows between Asia and Europe, diversion of trade within Europe, heavy shipping traffic in the Arctic and a substantial drop in Suez traffic".[33]

(3) Climate disruption may also lead to supply-side disruptions. The supply of raw material, especially agricultural products, is highly vulnerable to changes in climatic patterns and will directly impact the supply flows to the ports where the agricultural items of trade are a critical source of revenue. Changes in the pattern of economic development may have an impact on the location of economic clusters, which will further affect the port–hinterland connections. Notteboom et al., in a comparative study of the impact of the 2008 recession and COVID-19 on shipping, note:Changes (declines) in consumption patterns (demand) are related to the type of goods and related services. … Basic goods (also labeled essential goods such as food and household items) and luxury goods (fashion items) tend to be the most resilient. … However, recessionary forces can have significant impact on the demand for durable goods (e.g. cars, appliances, computers), discretionary goods (e.g. electronics, apparel), and capital equipment (e.g. ships, trucks, machinery, and port infrastructure).[34]

(4) Rick Bosman et al. define transition as a radical, structural change of a societal (sub)-system that is the result of the co-evolution of economic, cultural, technological, ecological, and institutional developments at different scale levels. It comes about through the simultaneous build-up of sustainable alternatives and the breakdown of existing unsustainable practices.[35]

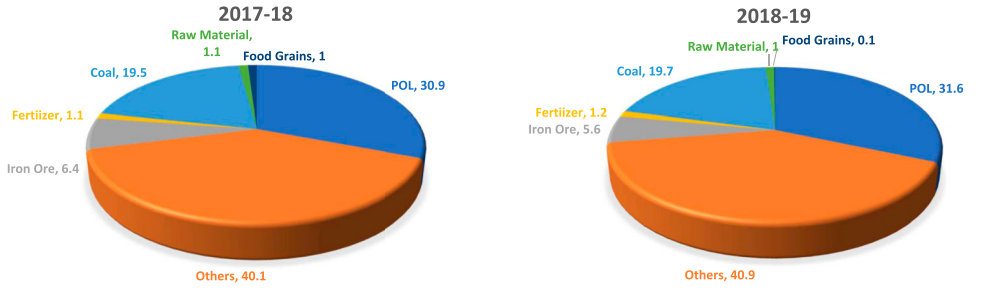

Figure 3. Percentage share of commodity-wise traffic handled at major ports of India (2017–2018 and 2018–2019). Source: Ministry of Shipping, *Basic Ports Statistics of India (2018–19)*.
Note: POL: petroleum, oil, lubricant.

A blue–green transition will require weaning off the fossil fuels, which are the major commodities of trade at ports in India (see Figure 3). Port authorities will have to take into consideration such transformative changes in the global economy to stay relevant and ahead of the curve. Trade will be the major concern for ports from the perspective of climate change and, therefore, it merits further research.[36]

Port infrastructure and operations

(1) Biophysical changes, such as the average sea level rise, will affect port operations and infrastructural demands in the long term.[37] The rise in sea levels can prove useful in some cases: for example, the dredging requirements at the port would go down, thereby lowering the marine traffic congestion and reducing operational expenditure on maintenance of navigable waterways.[38] However, longer and frequent spells of precipitation, drought, and tropical cyclones will reduce the capacity of ports to function without disruption and delays. Damages to the cargo and port infrastructure from such incremental and abrupt high-impact events will cause changes to the coastline, such as inundation and wave regime changes. Franco-Ochoa et al. Note: Currently, the global mean sea level and wave energy are increasing at rates of 3.26 mm and 0.4 per cent per year, respectively. However, a precise quantification of regional rates is much harder and depends on factors such as the local wind energy, the sea water temperature and tectonic uplift/subsidence motions, among others.[39]

Consequently, it is critical that each port carries out its regional climate risk assessments, and also invest in technologies and infrastructure for downscaling of climate data to make effective operational forecasting at local scales.[40] This will facilitate ports to counter incremental and abrupt changes, as well as anticipate high-impact, low-probability events more effectively.

(2) A container terminal can be described as: "open systems of material flow with two external interfaces. These interfaces are the quayside, with loading and unloading of ships, and the landside, where containers are loaded and unloaded on/off trucks and trains".[41] High winds, droughts, and high waves pose a direct risk to port terminal

operations and safety, especially navigability and berthability of ships. This is likely to increase maintenance costs, dredging expenditures, risks of spoilage of cargo, demurrage, operational delays, along with reducing port access and operability range of equipment like quay cranes, which cannot be used above certain wind speeds and precipitation levels. The port is also heavily dependent on its hinterland connections through roads, railways, and inland waterways networks, which are critically exposed to extreme weather events. Therefore, the catchment area of concern for port operations falls well beyond its location and must take into account the emerging climate risks in both the foreland as well as the hinterland.[42]

(3) The critical infrastructure of ports, that includes its power supply, transport, data communication network, and marine traffic service towers, is increasingly at risk due to disruptive events. Such disruption leads to terminal closure and heavy revenue losses. Climate resilience and adaptation measures, therefore, acquire a critical importance in maintaining operability of ports and enhancing their capacity to bounce back from extreme conditions. The COVID-19 experience has catapulted adaptative management strategies to the forefront as the "new normal" sets in the global trade and shipping. There are multiple examples of such approaches that were taken up during the pandemic. In the ports of Rotterdam and Hamburg, a submission of Maritime Declaration of Health (MDoH) was made mandatory before arrival or exit from the port. The Hamburg Port Authority also decided to defer rents and charges for operations at the port. The Northern Corridor and the East Africa Community (EAC) created an online platform for exchange of information, practices, and experiences during COVID-19 to enhance the resilience of supply chains and minimise losses.[43] Future adaptation strategies must include investments in climate-resilient infrastructures, such as allowances for sea level rise;[44] upgradation and regular review of dredging programmes and drainage systems; redesigning flood response plans taking into account the latest scientific data; development of closed systems for handling goods; investments in wind speed monitoring and prediction systems; and development of guidelines and protocols for extreme weather events which will improve and safeguard the safety and security of staff and labour.[45]

(4) Apart from trading operations, ports are also knowledge hubs which facilitate several economic activities and influence lives and livelihoods of people who live in their vicinity. Initiatives such as port-led development models of growth are going to be central to the development of blue economy. The harbours are critical source of employment generation for local fishing communities, labour, and mechanics who depend on port facilities. A resilient port strategy must ensure that the health and safety of its workforce is enhanced to maintain productivity and community participation.[46]

(5) Apart from the capacity-led arguments in favour of climate-resilient ports, which includes grey and green infrastructures as well as operational and adaptation strategies, there is also a need to acknowledge the critical distinction between ports in developed and developing countries and the higher vulnerability of states, particularly small island states, to climate extremes. The simple comparison of statistics regarding countries experiencing highest number of climate-related disasters (see Figure 4) and the countries with maximum economic damages as a percentage of

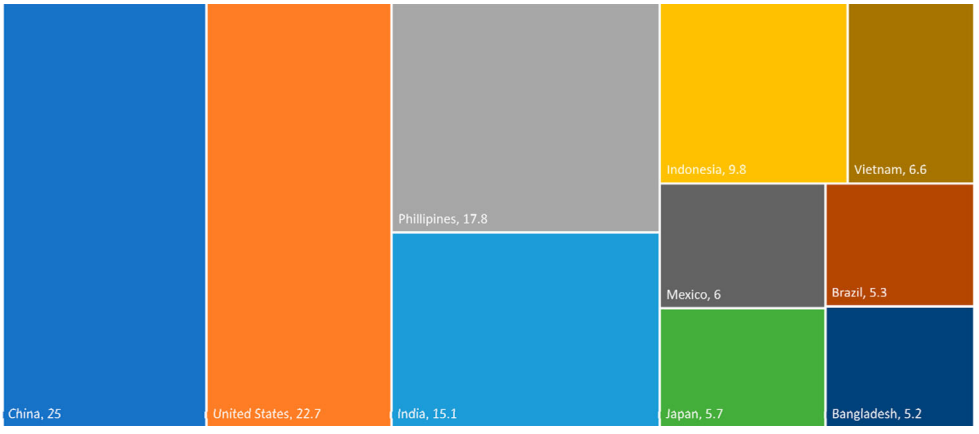

Figure 4. Number of climate-related disasters (average 10 years). Source: Compiled by author from "How Moody's Assesses the Physical Effects of Climate Change on Sovereign Issuers", *Moody's Investors Service*, 7 November 2016, https://www.eticanews.it/wp-content/uploads/2017/01/Moodys-climate-change-and-sovereigns-November-7.pdf (accessed 7 July 2021).

GDP (see Figure 5) brings out the contrasts between nations to the fore. Countries like the U.S., India, and China face a higher percentage of climate-related disasters, but it is the countries with lesser capabilities and capacities, such as the Maldives, which are the least economically resilient to face such disasters.

Conclusion

The following paragraphs address some of the major strategies that Indian ports must adopt in order to counter the threats of climate change. Future proofing port infrastructure, as has been outlined earlier in the article, is a complex interplay of range of factors

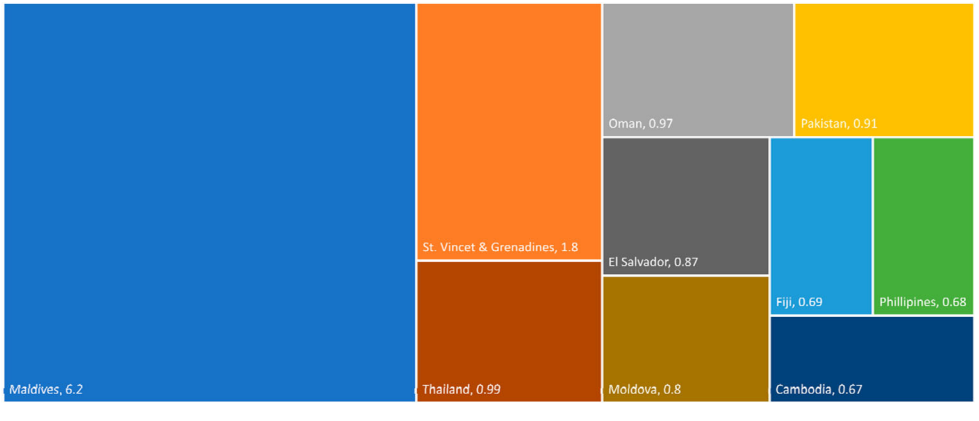

Figure 5. Economic damage (percentage of GDP; average 10 years). Source: Compiled by author from "How Moody's Assesses the Physical Effects of Climate Change on Sovereign Issuers". *Moody's Investors Service*, 7 November 2016, https://www.eticanews.it/wp-content/uploads/2017/01/Moodys-climate-change-and-sovereigns-November-7.pdf (accessed 7 July 2021).

including assessment of future risks, political and economic feasibility of interventions, and potential negative effects of climate interventions. Some key strategies to counter these impacts are discussed below.

Climate proofing of ports

The initial sections of the article have highlighted the critical importance of understanding climate uncertainty. Scientific and economic models facilitate a road map to the future. Foresight has been a key characteristic of global trade, and accurate forecasts have managed to improve the functioning of ports, save lives, mitigate the impacts of extreme weather events, and prevent economic losses. Therefore, it is critical that port authorities and governments invest in new approaches to tackle climate uncertainty.[47] There are a number of approaches and policy experiments that have been employed to tackle uncertainty, such as dynamic strategic planning approach,[48] multi-criteria analysis,[49] adaptive port planning,[50] assumption-based planning,[51] and what-if analysis and scenario analysis.[52] The ports in India are highly vulnerable to extreme weather events in short, medium, and long term. While the short-term planning, where the climate risk is determinable, can be based on predictive models of forecasting, the long-term risks remain uncertain and unknown and require adaptative planning as well as multiple scenarios planning to develop alternatives. Climate proofing the port infrastructure will require a holistic risk-based approach to planning, which entails:

> identifying risks to a development project, or any other specified natural or human asset, as a consequence of both current and future climate variability and extremes, and ensuring that those risks are reduced to acceptable levels through long-lasting and environmentally sound, economically viable, and socially acceptable changes implemented at one or more of the following stages in the project cycle: planning, design, construction, operation, and decommissioning.[53]

While the precautionary principle remains central to dealing with the *unknown unknowns*, it is equally important for stakeholders to invest in building resilience, that is, the ability to bounce back, and adaptive robustness, which implies that states must be prepared to change their plans and strategies in case the conditions change.[54]

Mainstreaming of blue–green solutions

The process of mainstreaming green solutions as part of long-term adaptive strategy remains a pipeline dream. One key way of mainstreaming adaptative measures is to treat ports as liminal spaces rather than fixed infrastructural assets. This requires greater synergies between the specific port development models, subnational level governance and planning, and national-level strategic vision. Therefore, in the case of India, initiatives such as the Sagarmala and Maritime India Vision 2030 must align with other key goals, such as the Security and Growth for All in the Region (SAGAR), blue economy, Sendai Framework for Disaster Risk Reduction 2015–2030, Sustainable Development Goals, and nationally determined commitments under the Paris Agreement.

A contextual approach

Dupuis and Biesbroek made an important intervention in adaptation studies by highlighting the "dependent variable problem", which they define as:

> the indistinctness of the phenomenon that is being measured and the fuzziness of its scope and boundaries, which leads to contradictory results and difficult comparisons between studies … if comparative research on adaptation policy is to evolve toward more explanatory ambitions, the dependent variable problem should be considered and addressed.[55]

They critique the comparative methods utilised to study adaptation policies at a national level for its conceptual indistinctness, inadequate research design, and unclear indicators. Adaptation is predominantly understood as a context-dependent problem. Its operationalisation on the ground has been idiosyncratic, which tends to fluctuate from one country to another, one state to another, and one port to another. Therefore, a holistic approach to climate adaptation of ports cannot merely be adoption of best practices from another country. It must meet two critical parameters. The first parameter is "intentionality", which implies that port authorities in India must treat climate change policy as a distinct problem, both as a mitigation as well as adaptation challenge, preempt and prepare for its future implications, and adopt decision-making approaches that allows for the incorporation of the phenomenon of climate change in their short- to long-term planning. The second key parameter is "substantiality", which implies that adaptation measures taken up by ports must directly contribute towards a reduction in vulnerability of ports.[56] This requires the Indian port authorities to carry out substantial climate risk assessments, which can provide a more substantial view of climate risks and facilitate the transition of Indian ports to a new climate regime.

Framing the climate change crisis

While sustainability and environmental monitoring measures at India's major ports have increased in recent years, particularly pollution control, ambient air monitoring, marine water quality, and plastic management, there is a conspicuous absence of adaptation framing of the issue, which relates to the threats that climate change impacts pose to the port infrastructure, workforce, and operations. Therefore, the challenge of climate change uncertainty for the Indian port authorities is a question of framing of the issue itself, which will give equal weightage to both mitigation and adaptation outcomes. The climate resilience of ports is intricately linked with economic viability of sustainability measures and regulations, and the government's willingness and effectiveness in making the process of blue and green transitions just and economically viable for all the stakeholders who are involved in this industry.

Notes

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