VIEW

Intersecting Tides

Climate Change and Maritime Trade in Indo-Pacific 2040

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Abstract

The article explores the profound impact of climate change on Indo-Pacific maritime trade routes by 2040. It anticipates rising global temperatures and sea levels altering critical maritime pathways, affecting major global powers. Using a forward-looking approach, it integrates future climate projections, geopolitical trends, and economic forecasts. Uniquely, it delves into the intricate interaction between climate-induced changes and geopolitical realities, emphasizing major global powers' strategic interests. The article offers a comprehensive analysis of the complex relationship between climate change and maritime trade, addressing sea-level rise, extreme weather events, and geopolitical shifts. It proposes sustainable solutions and adaptation measures for the maritime sector, highlighting the need for proactive measures, international cooperation, and sustainable solutions. Its significance lies in providing insights for policy makers and operational forces, emphasizing the urgency of addressing climate change in the maritime domain.

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As we cast our gaze into the not-so-distant future of 2040, the Indo-Pacific region stands out as a focal point of significant change, with climate dynamics leading the roster of global challenges. Amid shifting global economic and geopolitical landscapes, the term *Indo-Pacific* has gained prominence, encompassing both the Asia Pacific and the Indian Ocean Region.[1] As temperatures rise, precipitation patterns alter, and environmental uncertainties escalate, this article explores the potential impacts of climate change on maritime trade in the Indo-Pacific. In an era projected to witness intensified anthropogenic climate-change effects, the intricate relationship between environmental shifts and geopolitical realities assumes unprecedented importance. Already crucial for international trade and energy flows, the Indo-Pacific is poised for substantial changes over the next two decades. Maritime trade routes in this vast region serve not only as economic lifelines but also as strategic passages influencing the geopolitical strategies of major global players. With climate change accelerating, bringing new challenges like sea-level changes, ocean current shifts, and

[1] Sam Bateman, Rajni Gamage and Jane Chan, eds., "Introduction," in *ASEAN and the Indian Ocean: The Key Maritime Links* (Singapore: S. Rajaratnam School of International Studies, 2017), 7.

more frequent extreme weather events, the resilience and adaptability of these maritime routes become critically important.

The article delves into potential scenarios for 2040, examining how climate-induced changes might reshape the Indo-Pacific maritime domain. The implications for trade routes, traditionally seen as stable channels of global commerce, are amplified in a world where climate factors evolve rapidly. Additionally, as nations strategically position themselves in the Indo-Pacific, economic and geopolitical interests become intertwined with the need to adapt to and mitigate the effects of climate change. By contextualizing the analysis within the Indo-Pacific of 2040, this article aims to offer a forward-looking perspective that transcends current temporal boundaries. Through synthesizing future climate projections, geopolitical trends, and economic forecasts, this article seeks to enhance understanding of how the intricate interplay between climate change and maritime trade will shape the strategic interests of major global powers in a future marked by both uncertainty and opportunity.

Climate-Change Outlook in the Indo-Pacific Region by 2040

The climate-change scenarios projected for the Indo-Pacific region by 2040 are characterized by rising sea levels (SLR) primarily attributed to global warming. Global temperatures have already exceeded 1.0°C compared to pre-industrial levels and are expected to reach 1.5°C by the 2030s, posing significant risks to coastal developing nations.[2] Concerns loom over the possibility of a 2.0°C temperature increase, deemed a critical threshold for heightened climate-change risks, possibly occurring by the 2050s, depending on future greenhouse gas emissions.[3] Despite sporadic emission reductions during the COVID-19 pandemic and increased climate ambition in select countries, the UN Environment Programme (UNEP) *Emissions Gap Report 2020* indicates a trajectory toward a temperature rise surpassing 3.0°C this century, exceeding the objectives outlined in the Paris Agreement.[4]

The intricate dynamics of global warming contribute to substantial mean sea-level changes in the Indo-Pacific. This phenomenon primarily results from ocean water expansion due to alterations in land water storage, augmented mass from melting glaciers, caps, and continental ice sheets, alongside isostatic adjustment, higher

[2] Valérie Masson-Delmotte et al., eds., *Global Warming of 1.5°C* (Cambridge: Cambridge University Press, 2018), https://www.ipcc.ch/.

[3] Regina Asariotis, "Climate Change Impacts on Seaports: A Growing Threat to Sustainable Trade and Development," United Nations Conference on Trade and Development, 4 June 2021, https://unctad.org/.

[4] "Emissions Gap Report 2020: Key Messages," United Nations Environment Programme, n.d., https://wedocs.unep.org/.

ocean heat content, and human-induced coastal subsidence. Recent observations indicate a globally averaged mean SLR of approximately 4.0 cm per decade.[5]

Forecasts for sea-level rise are continuously revised, suggesting that a global temperature increase of 2.0°C above pre-industrial levels by 2100 could lead to a 30–93 cm elevation in global sea levels compared to the 1986–2005 average.[6] This heightened mean sea level, coupled with anticipated occurrences such as extreme storm surges, waves, and tides, poses significant risks to seaports in the Indo-Pacific region. The Intergovernmental Panel on Climate Change's (IPCC) 2019 report forecasts a rise in extreme sea levels (ESL) almost universally, with events like the 1-in-100 years ESL becoming more frequent across certain regions. Notable concerns are identified along the macrotidal western European, Northwest and Northeast American, and East Asian coasts, with projections indicating increased future ESLs for ports in all regions as global warming intensifies. In a 1.5°C warmer world, ESL events expected once a century may occur every decade in various ports by the 2030s, escalating to several times a year in a 3°C warmer world.[7] These projections carry significant implications for port adaptation strategies in the Indo-Pacific, impacting decisions regarding infrastructure planning and climate-change adaptation measures.

The urgency for climate action is underscored by the accelerated melting of polar and mountainous glaciers, heightening the potential for future ESLs and elevating the threat of coastal flooding in the Indo-Pacific region by 2040. Research indicates a potential reduction in ice mass ranging from 18 percent to 36 percent by the end of the twenty-first century in mountainous and polar glaciers.[8] The expedited melting of ice sheets in Greenland and Antarctica contributes to additional sea-level rise. The IPCC 2019 report highlights ongoing ice loss in the Greenland Ice Sheet, with projections suggesting a potential significant increase in ice loss after 2060, contributing approximately 0.5 cm/yr to global SLR by 2100.[9] The report also highlights increased melting of the Antarctic Ice Sheet, projecting a potential sudden surge in ice loss after 2060, which could contribute

[5] Asariotis, "Climate Change Impacts on Seaports."

[6] Ove Hoegh-Guldberg, et al., "Impacts of 1.5°C Global Warming on Natural and Human Systems," in *Global Warming of 1.5°C*, ed. Valérie Masson-Delmotte et al. (Cambridge: Cambridge University Press, 2018), 175–312, https://www.ipcc.ch/.

[7] Michael Oppenheimer et al., "Sea Level Rise and Implications for Low-Lying Islands, Coasts, and Communities," in *Special Report on the Ocean and Cryosphere in a Changing Climate*, ed. Hans-Otto Pörtner et al. (Cambridge: Cambridge University Press, 2022), https://www.ipcc.ch/.

[8] Joydeep Gupta and Soumya Sarkar, "As Glaciers disappear, Can We Be Far Behind?," *The Third Pole*, 25 September 2019, https://www.thethirdpole.net/.

[9] Michael Meredith et al., "Polar Regions," in *Special Report on the Ocean and Cryosphere in a Changing Climate*, ed. Hans-Otto Pörtner et al. (Cambridge: Cambridge University Press, 2022), https://www.ipcc.ch/.

approximately 0.5 cm/yr to global sea-level rise by 2100. This acceleration presents a significant risk of coastal flooding, underscoring the critical imperative for immediate climate action.

The World Bank projects that failure to implement measures addressing climate change will compel approximately 49 million people in East Asia and the Pacific to evacuate their homes by 2050 due to climate-related impacts.[10] Among the first regions witnessing these effects are the Pacific Islands, especially low-lying islands, many of which are atolls or just a few feet above sea level. The current unprecedented rate of sea-level rise (SLR) over 5,000 years poses threats of flooding, coastal erosion, and storm surges to these vulnerable island systems. Predictions indicate an average SLR of 25 cm to 58 cm by the mid-twenty–first century, a disastrous scenario for islands positioned at or slightly above sea level.[11] With a 2-degree Celsius increase in global temperatures from preindustrial levels becoming more probable, it is anticipated that 90 percent of coral reefs in much of the Pacific Island region could suffer severe degradation, negatively impacting marine species reliant on these ecosystems.[12] Researchers have found that, under various climate-change scenarios, all studied island systems face threats throughout the twenty-first century. In the most likely scenario, the rate of SLR would triple, resulting in the permanent loss of groundwater sources in the coming decades, rendering islands unstable in the latter half of this century. In a more pessimistic climate-change scenario, a one-meter SLR would destabilize the islands within the next 20 to 40 years, exposing many communities to intolerable levels of risk by 2060.[13] Furthermore, according to the ASEAN State of Climate Change Report, the Association of Southeast Asian Nations (ASEAN) region is expected to experience detrimental effects on priority sectors such as agriculture, water resources, coastal zones, and human health.[14] For instance, projected SLR by 2050 shows an average increase ranging significantly across nations: from as little as 7 cm for Brunei Darussalam to a striking 378 cm for Vietnam. Concurrently, heat stress projections under Representative

[10] "Climate Change could force 216 million people to migrate within their own countries by 2050," World Bank, 13 September 2021, https://www.worldbank.org/.

[11] "Pacific Climate Change" (fact sheet, Secretariat of the Pacific Regional Environment Programme, August 2008), https://www.sprep.org/.

[12] "Climate Change increasing threats in southwest Pacific: WMO report," *UN News*, 10 November 2021, https://news.un.org/.

[13] Chris Parsons, "The Pacific Islands: The front line in the battle against climate change," *Science Matters* (blog), 23 May 2022, https://new.nsf.gov/.

[14] *ASEAN State of Climate Change Report: Current status and outlook of the ASEAN region Toward the ASEAN climate vision 2050* (Jakarta: ASEAN Secretariat, October 2021), https://asean.org/.

Concentration Pathways (RCP)[15] scenarios indicate that ASEAN countries will face an increase in average heat mortality (number of deaths per 1,000 km2), with the Philippines expecting an average of 5.50 to 5.67 and Vietnam expecting an average of 7.82 to 7.85 under RCP 4.5 and RCP 8.5 scenarios by 2050.[16]

Moreover, in the Indo-Pacific region, the El Niño–Southern Oscillation (ENSO) continues to exert significant influence, notably affecting the natural variability of tropical cyclones (TC). Projections for the region suggest an increased frequency of TCs, estimated to be approximately 20 to 40 percent more frequent in the entire central Pacific during future El Niño periods compared to the present.[17] Climate model experiments indicate a heightened likelihood of more severe TCs and increased global rainfall as the climate warms, with the Pacific anticipating elevated TCs-induced extreme wind gusts and rainfall. The region is expected to experience ongoing warming, with temperatures projected to rise by around 0.7°C by 2030 and further increases of approximately 0.8°C by 2050 for a low emission scenario and up to 1.5°C for a high emission scenario. SLR is foreseen, with estimates ranging from 0.09 to 0.18 meters by 2030 and further increases up to 0.63 meters by 2070, depending on emission scenarios. Despite a projected decrease in the number of TCs, their average intensity may change by -5 to +10 percent for a 2°C global warming scenario.[18] This anticipated rise in average cyclone intensity, combined with SLR and increased heavy rainfall, underscores the heightened risk of intensified cyclone impacts in the Indo-Pacific region in 2040.

These climate-change projections for the Indo-Pacific region carry significant implications for maritime trade. The more frequent and intense occurrence of TCs, coupled with SLR and extreme weather events, poses notable challenges for coastal infrastructure and navigation in the area. Climate change can disrupt global trade by altering trade costs, shifting comparative advantages, and disturbing global value chains. Research indicates that a temperature rise of 1°C is associated with a reduction in the yearly export growth rate of developing nations by approximately 2.0

[15] A Representative Concentration Pathway (RCP) is a trajectory of greenhouse gas concentrations (not emissions) adopted by the IPCC. Four pathways were utilized for climate modeling and research for the IPCC Fifth Assessment Report (AR5) in 2014. These pathways delineate various climate change scenarios, all of which are deemed possible depending on the quantity of greenhouse gases (GHG) emitted in the future. Rajendra K. Pachauri et al., Fifth Assessment Report (Cambridge: Cambridge University Press, 2015), https://unfccc.int/.

[16] *ASEAN State of Climate Change Report*.

[17] Kate Morioka, "Tropical cyclones and climate change: implications for the Western Tropical Pacific," Regional Climate Consortium for Asia and the Pacific, 2022, https://www.rccap.org/.

[18] "Climate Change Update for the Pacific," Regional Climate Consortium for Asia and the Pacific, n.d., https://www.rccap.org/

to 5.7 percentage points.[19] The IPCC warns that if current practices persist, we could reach the critical warming threshold of 1.5˚C to 2.0˚C within the next decade, by 2030.[20] Our planet, already experiencing heightened temperatures, could witness a staggering global average temperature increase of up to 5.5˚C. Even with immediate intervention, it is anticipated to take 20 to 30 years, equivalent to a full generation, to stabilize the current negative trends. Consequently, the outlook for the Indo-Pacific region by 2040 appears bleak, with further adverse impacts on maritime trade due to the changing climate. As maritime trade heavily relies on stable and accessible ports, the heightened risk of cyclone impacts and SLR necessitates strategic adaptations and resilience measures in the maritime sector. Furthermore, the potential disruption of global value chains due to climate-induced events underscores the need for a comprehensive understanding of how these climatic shifts may impact the future landscape of maritime trade in the Indo-Pacific.

Maritime Trade Dynamics Amid Indo-Pacific Climate Challenges

The Indo-Pacific region holds strategic importance for three primary reasons. Firstly, it hosts three of the world's largest economies—the United States, China, and Japan—collectively contributing to 60 percent of global gross domestic product (GDP). Secondly, a significant portion of global maritime trade, totaling 60 percent, flows through the waters of this region.[21] Additionally, the Indo-Pacific hosts the fastest-growing emerging economies, such as Cambodia, India, and the Philippines. Key economies in the area, such as China, India, and Japan, heavily rely on sea routes in the Indo-Pacific for their trade and energy supply, solidifying the region as a pivotal nexus in global trade and energy networks. Notably, 80 percent by volume and 70 percent by value of global trade is conducted via maritime routes, and 60 percent of this maritime trade traverses the Indo-Pacific.[22] The economic significance underscores the strategic value of the Indo-Pacific region. Stability in the Indo-Pacific is essential for global trade prosperity, given the presence of critical maritime chokepoints like the Bab al Mandeb and the Malacca Strait. Moreover, the economic importance of the Indo-Pacific region is highlighted by the presence of ten of the busiest container ports worldwide along the Pacific

[19] Marc Bacchetta et al., "The Role of Trade in Adapting to Climate Change," in *World Trade Report 2022: Climate Change and International Trade* (Geneva: WTO, 2022), 33, https://www.wto.org/.

[20] Kim Atkinson and Suki Dixon, eds., *Asia-Pacific Futures in 2040: Raising Ambitions for a Healthy Environment* (Bangkok: United Nations, 2021), https://www.unescap.org/.

[21] Françoise Nicolas, "The Regional Economic Order: Four Scenarios," *National Security College Futures Hub*, May 28, 2021, https://futureshub.anu.edu.au/.

[22] Deniz Barki and John Rogers, eds., *Review of Maritime Transport 2015* (Geneva: UN Conference on Trade and Development, 2015), https://unctad.org/.

and Indian Ocean coasts. Additionally, more than half of the global maritime trade in petroleum passes through the Indian Ocean alone.[23] As the region continues to play a pivotal role in global trade and economic growth, addressing the impacts of climate change on maritime trade becomes imperative for sustaining the prosperity and stability of the Indo-Pacific.

Maritime transport, encompassing the conveyance of goods and passengers by seafaring vessels on journeys conducted wholly or partially at sea, stands as a cornerstone of the global economy. Despite its pivotal role, the maritime sector is implicated in contributing to global warming through its carbon emissions, accounting for approximately 3 percent of the world's CO_2-equivalent emissions.[24] Nonetheless, when juxtaposed with land and air transport, maritime transport emerges as the most economically efficient method for the global distribution of goods. More than 90 percent of globally traded goods are transported by sea, and maritime trade volumes are projected to triple by 2050, as reported by the Organisation for Economic Co-operation and Development.[25] However, this vital trade sector faces increasing challenges due to the escalating impacts of extreme weather events, exacerbated by climate change. The frequency of Category 3 to 5 cyclones has risen by approximately 5 percent per decade since 1979, with storms causing significant disruptions, such as the loss of 80 ships out of 400 between 2015 and 2019.[26] In 2019, bad weather accounted for one in five ship losses, indicating the severity of the problem.[27] The consequences of extreme weather are far-reaching, causing missed port calls, delayed arrivals, and financial losses, with an estimated USD 54.5 million lost in the first four months of 2021 alone due to containers falling overboard.[28]

Seaports are susceptible to significant disruptions from extreme weather, facing vulnerabilities such as flooding, waves, and winds due to their geographical locations. The occurrence of storm surges and "flood" tides can adversely affect the loading and unloading of cargo, causing delays and longer journey times. Extensive

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[23] Michael J. Green, "China's Maritime Silk Road: Strategic and Economic Implications for the Indo-Pacific Region," *CSIS*, 2 April 2018, https://www.csis.org/.

[24] George Zittis et al., "Maritime Transport and Regional Climate Change Impacts in Large EU Islands and Archipelagos," *Euro-Mediterranean Journal for Environmental Integration* 8 (May 2023): 441–54, https://doi.org/.

[25] "Ocean Shipping and Shipbuilding," *The Ocean* (blog), n.d., https://www.oecd.org/.

[26] Hans Vermij, "Is Climate Change Altering Trade Routes around the World?," *International Trade Magazine*, 19 January 2023, https://intrademagazine.com/.

[27] "Shipping Losses at Record Low, but Covid-19 Impact and Political Tensions Cloud the Horizon," *Allianz*, 15 July 2020, https://commercial.allianz.com/.

[28] Natalie Marchant, "How Climate Change is Impacting Shipping and Maritime Trade," *Wärtsilä*, 16 March 2022, https://www.wartsila.com/.

economic harm arises from direct damage to infrastructure and disruptions in interconnected global supply chains, particularly in regions affected by TCs and associated storm surges and waves. An illustrative case is Hurricane Sandy in 2012, where losses exceeded USD 62 billion in New Jersey, New York, and Connecticut.[29] This event led to significant damage and a week-long closure of the container port in and around New York and New Jersey. Additionally, these conditions contribute to heightened bunker consumption, adding further strain to the maritime sector. Heightened vulnerability to coastal flooding will assess the robustness of port infrastructure and operations, potentially disrupting the loading, unloading, and movement of goods. This impact extends to transportation and communication networks, industrial areas, housing, and sanitation systems. Alexander Eslava Sarmiento outlines the risks associated with climate change on infrastructures and details the resulting side effects. These include the degradation of materials, foundations, and structures due to shifts in groundwater, increased temperatures, or intensified rains and winds. Heatwaves may necessitate increased energy use to cool cargo stored in ports. He also emphasizes limitations in vessel maneuverability, docking, loading, and unloading operations during strong winds, challenges for port personnel working outdoors on hot days, reduced visibility due to rainfall (especially during storms), leading to delays in berthing and cargo handling operations. Additionally, limitations in approach maneuvers due to wave height and constraints on port operations due to flooding are highlighted. Sarmiento underscores that since seaports operate as part of intricate transportation, logistics, and supply-chain systems, any weather-related disruptions to them have broader implications for the resilience of the global economy.[30] Furthermore, as the Paris Agreement's 1.5^0C ceiling appears challenging to achieve, the maritime sector faces potential disruptions and the need to adapt to new trade routes. Ports, numbering over 3,700 globally, must grapple with the dual challenge of SLR and storm threats, necessitating resilient designs and reinforced weather monitoring systems. The interconnected nature of these challenges was evident in the 2003 Typhoon Maemi's impact on Busan, South Korea, illustrating the cascading effects of climate change on both ports and inland infrastructure.[31]

Climate-related risks present increased vulnerability for maritime transport, particularly as rising sea levels directly jeopardize port operations. Moreover, alterations in precipitation patterns affect the sustainability of vital shipping hubs

[29] Asariotis, "Climate Change Impacts on Seaports."

[30] Alexander Eslava Sarmiento, "El Cambio Climático Global y Su Impacto en los Puertos Marítimos," *Pórticolive*, August 2022, https://www.puertocartagena.com/.

[31] Vermij, "Is Climate Change Altering Trade."

and passages. A noteworthy instance is the Panama Canal, facilitating about 6 percent of worldwide maritime trade.[32] Its reliance on freshwater availability for operational purposes makes it highly prone to fluctuations in precipitation and periods of drought. Approximately 1,000 vessels navigate through the Panama Canal every month, transporting more than 40 million tons of goods, constituting roughly 5 percent of the total global maritime trade volumes.[33] However, due to the most severe drought in the canal's 143-year history, water levels in this crucial link between the Atlantic and Pacific oceans have declined to precarious lows. Furthermore, rising sea levels, a consequential outcome of climate change, can have multifaceted impacts on trade. Elevated sea levels may render certain ports inaccessible, necessitating substantial investments in infrastructure for adaptation. Conversely, it could unveil new routes previously too shallow for sizable cargo ships, potentially reshaping global trade networks and carrying significant economic implications.[34]

The interconnectivity of global value chains shaping the current international trade system amplifies the impact of disruptions in key locations on the global economy. This poses a particular challenge when disasters impact regions that manufacture unique and difficult-to-replace goods, as exemplified by the disruption of electronics parts production during the Thailand floods in 2011.[35] These factors significantly affect the trade of food products and manufacturing sectors, especially those relying on climate-sensitive agricultural inputs. Moreover, economies in sub-Saharan Africa and South Asia, heavily dependent on agricultural exports with a substantial workforce in this sector, face a disproportionate level of vulnerability. Concerns about food insecurity, intensified by climate change, might prompt countries to limit crop exports during stressful periods, as demonstrated by India's decision to ban wheat exports in May 2022 to secure national food security during a heatwave.[36] Furthermore, the impact of climate change, leading to acidification and ocean warming, is negatively affecting fisheries. This has consequences for the trade of ocean-related products and food security, particularly impacting the lives

[32] Danae Kyriakopoulou, Georgina Kyriacou, and Natalie Pearson "How Does Climate Change Impact on International Trade?," Grantham Research Institute on Climate Change and the Environment, 12 June 2023, https://www.lse.ac.uk/.

[33] Serkan Arslanalp et al., "Climate Change is Disrupting Global Trade," *IMF Blog*, 15 November 2023, https://www.imf.org/.

[34] George Zittis et al., "Maritime Transport and Regional Climate Change Impacts."

[35] Shamika Sirimanne and Jerry Velasquez, eds., *Reducing Vulnerability and Exposure to Disasters: The Asia-Pacific Disaster Report 2012* (Bangkok: UN Economic and Social Commission for Asia and the Pacific, 19 October 2012), https://www.unisdr.org/.

[36] Santosh K. Singh, "India Bans Wheat Exports Due to Domestic Supply Concerns" (attaché report, US Department of Agriculture, 19 May 2022), https://apps.fas.usda.gov/.

of rural, small-scale fishermen and individuals engaged in food supply chains. Moreover, rising temperatures contribute to increased trade costs by elevating cooling expenses in storage facilities.

The heightened frequency of flood tides is anticipated to have a substantial impact on the processes of loading and unloading cargo. This phenomenon is expected to bring about challenges attributed to both elevated tide levels and increased instances of flooding. As these occurrences become more frequent, the difficulties in cargo handling are likely to escalate, introducing notable impediments in maritime operations. In certain instances, adjustments to port infrastructure may be necessary to accommodate higher water levels. On the other side, the diminishing sea ice is opening fresh opportunities for trade routes in certain regions and seasons that were previously impassable. The feasibility of the Northern Sea Route is growing, significantly cutting down the time and fuel needed for transportation from the Canadian Maritimes and/or northern Europe to the Far East, thereby influencing conventional maritime routes.[37] Additionally, with the evolution of weather patterns, ice melting, and temperature increases, these alterations have consequences for ocean currents. Although local winds mainly propel most surface ocean currents, the strengthening and more frequent occurrence of storms lead to more robust yet potentially more unpredictable surface ocean currents. The deep-water currents, guided by variations in density, are similarly impacted as the influx of melted ice introduces more fresh water into the ocean, inducing density shifts that influence worldwide current patterns. These alterations in ocean currents can subsequently induce further changes in weather patterns, which adversely affect maritime trade. While it may not be the primary concern for those navigating the seas, shifts in marine life induced by climate change could eventually influence decisions on maritime routes. This is because certain regions might be identified and designated as restricted areas to safeguard delicate ecosystems. As climate-driven alterations in marine ecosystems continue, considerations about preserving biodiversity and mitigating environmental impact may increasingly factor into the planning and selection of optimal sea routes. The evolving dynamics of marine life due to climate change could introduce a new layer of complexity in route planning, prompting a balance between economic interests and environmental conservation efforts. Additionally, the gradual rise in drought and desertification may contribute to an upsurge in sand and dust storms, posing challenges for navigation. Further, by 2050, extreme heat events reaching 45°C are projected to double, and by 2100,

[37] Keith Wagner, "Climate Change and Shipping," *Maritime Executive*, 15 March 2021, https://maritime-executive.com/.

they could increase sevenfold.[38] The repercussions of high temperatures encompass alterations in sea salinity and density, impacting engine cooling on ships. Simultaneously, drier soil conditions may heighten the likelihood of sandstorms, posing a potential threat to visibility.

Beyond the physical repercussions of weather and climate hazards, anticipated socioeconomic effects are expected to ensue. These effects may include heightened risk perceptions among users, leading to reduced rates of moorings and turnover, elevated costs for the maintenance of nautical installations and equipment, increased expenses for new investments and insurance, the influence of carbon taxes on fossil fuel prices, diminished turnover from maritime transport activities, and escalated disruption costs.[39] A recent report underscores the vulnerability of the global shipping and port industry to substantial infrastructure damage and trade disruptions from climate-change impacts. RTI International crafted the report *Act Now or Pay Later: The Costs of Climate Inaction for Ports and Shipping* for the Environmental Defense Fund, analyzing climate-related disasters and forecasting potential industry damages and its financial impact. Absent ambitious emissions reduction measures, climate-change impacts could impose annual costs of up to USD 25 billion on the shipping industry by the century's end. Based on historical consequences and predicted climate-change scenarios, the report projects that extra annual costs to port infrastructure could reach almost USD 18 billion by 2100.[40] Additionally, storm-related disturbances may contribute an extra USD 7.5 billion annually. These numbers represent the financial setbacks encountered by shippers, shipping clients' carriers, and ports due to closures.

Furthermore, climate change has the capacity to shape the dynamics of great-power competition in the Indo-Pacific. Major players like China, the United States, and others are engaged in a struggle for regional influence, focusing on trade, military prowess, and political sway. The competition becomes more intricate with the impact of climate change, introducing an additional dimension as nations vie to control resources and exert influence over vulnerable communities, some of which may be exploited. This competitive environment also hampers collective efforts to tackle climate change, as certain countries prioritize economic development over environmental conservation. Recognizing this, all countries in the region and

[38] "Key Shipping Routes at Risk from Climate Change Disruption, Report Finds," *Maritime Gateway*, 16 November 2022, https://www.maritimegateway.com/.

[39] Carmelo J. Léon et al., *Downscaling climate change impacts, socio-economic implications and alternative adaptation pathways for islands and outermost regions* (Madrid: McGrawHill, 2021).

[40] George Van Houtven et al., *Act Now or Pay Later: The Costs of Climate Inaction for Ports and Shipping* (Research Triangle Park, NC: RTI international, March 2022) https://www.edf.org/.

beyond have a role to play in ensuring the stability and sanctity of the region. Additionally, climate change is expected to compel approximately 45 percent of fish stocks traversing multiple exclusive economic zones to significantly shift their historical habitats and migration paths by 2100, potentially escalating into international conflicts.[41] This displacement of fish due to climate change may drive fishers, who traditionally relied on these stocks, toward engaging in illegal, unreported, and unregulated (IUU) activities for sustenance and income, potentially leading to an uptick in the scale and sophistication of organized crime related to fishing.[42] Alterations in ocean temperatures, currents, and sea levels from climate change affect fish distribution and abundance, intensifying resource competition and fostering illegal fishing practices, ultimately contributing to overfishing. Vulnerable communities displaced by climate change become more susceptible to exploitation by transnational criminal organizations (TCO) engaged in IUU fishing. Both TCOs and China play significant roles in IUU fishing, leading to the depletion of fish stocks, environmental harm, and economic impacts across the Indo-Pacific and globally.[43] China's involvement in the global fishing industry, including IUU fishing through its domestic and distant water fleets, further underscores the importance of addressing IUU fishing to mitigate the broader impacts of climate change in the Indo-Pacific region.

Sustainable Solutions for Indo-Pacific Maritime Trade

Given the current climate-change scenario, a less optimistic outlook emerges for the Indo-Pacific region by 2040. As previously discussed, the repercussions of climate change on maritime trade are poised to indiscriminately impact the strategic and economic interests of both developed and developing nations. Considering the significant relevance of the Indo-Pacific region for the economic stability and prosperity of countries within and beyond, it becomes imperative to proactively implement measures to mitigate the adverse effects of climate change. This proactive approach is crucial for shaping a more favorable future for international trade in the Indo-Pacific by 2040.

To address the challenges posed by climate change on maritime trade, a multifaceted approach is essential. Firstly, governments should play a pivotal role by

[41] "Nearly half of countries' shared fish stocks are on the move due to climate change, prompting dispute concerns," *ScienceDaily*, 18 January 2022, https://www.sciencedaily.com/.

[42] Kevin He and Gina Fiore, "New report predicts how climate change and illegal fishing could threaten global ocean," *Pew*, 10 April 2023, https://www.pewtrusts.org/.

[43] Joseph Green et al., *Indo-Pacific 2050 climate change impact analysis: anticipating climate change impacts to enhance climate security across the region* (Kihei, HI: Pacific Disaster Center, 2023), https://www.cfe-dmha.org/.

setting regulatory standards and offering financial incentives to encourage the adoption of greener technologies in shipping, such as cleaner fuels, electric or hybrid engines, and energy-efficient measures. The development and deployment of new technologies aiming to enhance fuel efficiency, explore alternative, less carbon-intensive fuels, integrate renewable energy sources such as wind or solar power, and implement operational procedures to minimize fuel consumption and carbon emissions is highly significant.

Further, investing in climate-resilient maritime infrastructure is equally crucial to mitigate disruptions caused by extreme weather events. This includes modifying port infrastructure to manage rising sea levels, altering routes to avoid adverse weather conditions, and enhancing equipment resilience to withstand extreme weather events. Emission reduction strategies, such as enforcing caps on emissions and supporting research into cleaner propulsion technologies, are imperative. Additionally, policies should facilitate the shipping industry's transition to low-carbon alternative fuels, such as hydrogen or ammonia. Encouraging "green ports" through policies promoting renewable energy use and waste recycling further contributes to sustainability.

Moreover, financing and investment play a pivotal role in realizing these changes, particularly in resource-constrained developing countries. This entails a global commitment to investment through mechanisms like public sector funding, private investment, and financial instruments such as carbon pricing or green bonds to incentivize capital flows toward low-carbon maritime solutions.

Further, in addressing the evolving challenges in the Indo-Pacific region by 2040 due to climate change, the military plays a pivotal role. A critical aspect of this role involves providing essential support during natural disasters, encompassing the evacuation of affected populations, delivery of emergency supplies, and the reconstruction of vital infrastructure. Given that climate-induced resource scarcity may escalate tensions, military engagement extends to peacekeeping and stability operations aimed at preserving or restoring peace in vulnerable areas.[44]

Additionally, militaries contribute to infrastructure adaptation initiatives, safeguarding crucial services and assets against climate-related damages, such as fortifying structures against extreme weather events. Beyond reactive measures, the military plays a proactive role in building the resilience of local communities and strengthening institutions, thereby enhancing their capacity to withstand environmental disruptions. Furthermore, military involvement in environmental peace-

[44] Shirley V. Scott and Shahedul Khan, "The implications of climate change for the military and for conflict prevention, including through peace missions," *ASPJ Africa & Francophonie* 7, no. 3 (2016): 82–94, https://www.airuniversity.af.edu/.

building endeavors helps mitigate conflicts over resources, fostering sustainable management and cooperative utilization of natural assets.

Moreover, given the global nature of the issue, collaborative international efforts, facilitated through organizations like the United Nations, are essential to enact policies at an international level. Cross-sector collaboration and cooperation emerge as essential components in this collective effort. Engaging stakeholders from the maritime industry, governments, research institutes, and international communities fosters the identification and implementation of effective climate-change adaptation and mitigation measures. This collaborative approach ensures a holistic and impactful response to the challenges posed by climate change in the maritime sector. It is crucial to develop parallel strategies, focusing on emission reduction and adaptation measures in coastal territories and port areas, involving substantial investments in technology and infrastructure to navigate the challenges posed by climate change.

Conclusion

In conclusion, the envisioned landscape of the Indo-Pacific region in 2040 presents a complex tapestry of challenges and opportunities shaped by the intricate interplay of climate change and maritime trade dynamics. As global temperatures rise and sea levels follow suit, the ramifications for the critical maritime arteries threading through this vast region are profound. The climate-induced transformations forecasted for 2040 carry significant implications for the strategic interests of major global powers, echoing the urgent need for comprehensive analysis and proactive measures. The projections for SLR, extreme weather events, and the shifting patterns of ocean currents in the Indo-Pacific portend a future where the resilience and adaptability of maritime trade routes become paramount.

The anticipated increase in the frequency and intensity of TCs, coupled with rising sea levels, poses substantial challenges to coastal infrastructure and navigation. These challenges, in turn, reverberate through the global trade network, impacting the stability and efficiency of maritime trade, which constitutes a lifeline for economies across the globe.

The economic significance of the Indo-Pacific region, hosting major players like the United States, China, and Japan, further amplifies the need for strategic foresight and proactive adaptation. As the maritime sector faces heightened exposure to climate-related risks, it is imperative to prioritize sustainable practices, green technologies, and climate-resilient infrastructure. Governments, in collaboration with international organizations, must spearhead efforts to enforce regulatory standards, incentivize the adoption of eco-friendly technologies, and invest in the resilience of maritime infrastructure.

Moreover, the interconnected nature of global value chains emphasizes the cascading effects of disruptions, underscoring the importance of a comprehensive understanding of how climate-induced shifts may impact the future landscape of maritime trade. The projected socioeconomic effects, ranging from increased costs to reduced turnover and heightened risk perceptions, necessitate a multifaceted approach that spans regulatory, technological, and international cooperation fronts.

In the face of this climatic uncertainty, the imperative for immediate and sustained climate action cannot be overstated. The envisioned challenges are formidable, and their repercussions extend far beyond the confines of the Indo-Pacific. The window of opportunity to mitigate these challenges and adapt to the evolving climate reality is narrowing. The choices made today will resonate through the maritime trade routes of tomorrow, shaping the trajectory of global economic interdependence.

The call to action is clear—a collaborative and forward-looking approach is essential to navigate the stormy seas of climate change and secure a sustainable and resilient future for maritime trade in the Indo-Pacific and beyond. ✪

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