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Draft Study on Port Climate Adaption and Decarbonisation Investment Requirements of Developing Nations

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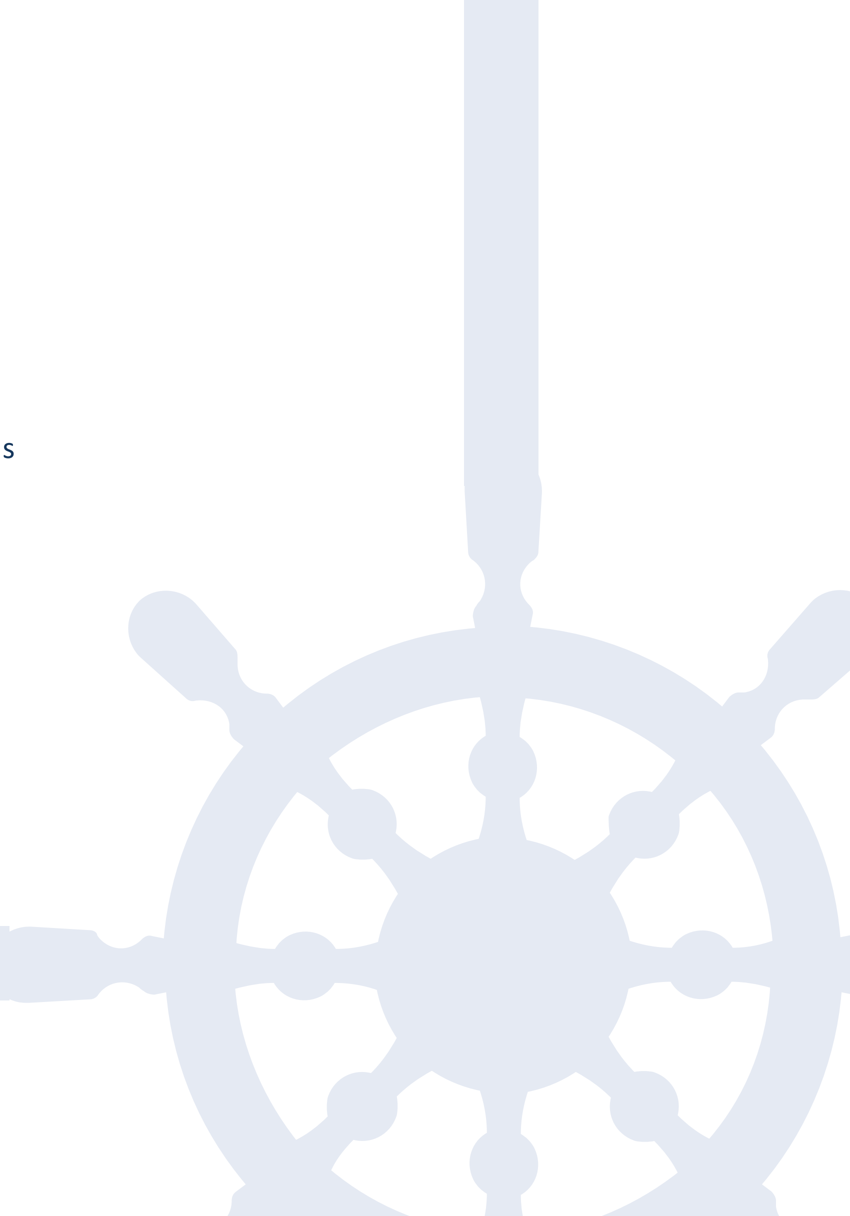


GLOSSARY

CAPEX	Capital Expenditure on port infrastructure
Developing nations	A sovereign state with a less developed industrial base and a lower Human Development Index – in this study the term also encompasses Small Island Developing States, Least Developing countries, a full list of the countries can be found in the annex
Externalities	Negative effects derived from pollutants represent a social cost for port cities and coastal areas close to ports, e.g. noise, dust, smell, etc.
GDP	Gross Domestic Product
GHG	Green House Gas
IMF	International Monetary Fund
IMO	International Maritime Organization "The United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships"
Just transition	Decarbonising the economy in a way that is as fair and inclusive as possible
LCOE	Levelised Cost of Energy in USD/kWh
OPEX	Operational Expenditure on port infrastructure
OPS	Onshore power supply
Port Area	The area that is usually under management of a port management body/port authority in a landlord model. Operations in this area can be outsourced to a private entity depending on the port model in use.
Port industry	All organisations active in a port, including but not limited to, logistics, shipping, blue economy, energy, ship building, industry, cruise, etc.
PPA	Power Purchase Agreement
PPP	Private Public Partnership
SIDS	Small Island Developing States, Group of states that face unique social, economic and environmental vulnerabilities
TEU	Twenty-foot Equivalent Unit

INTRODUCTION

Introduction

Developing nations face significant investment gaps in transitioning to energy-efficient and climate-resilient port infrastructures. This study, commissioned by the International Association of Ports and Harbors (IAPH), seeks to comprehensively analyse these investment gaps, focusing on infrastructure aimed at reducing emissions and bolstering resilience against climate impacts.

The global push towards a sustainable future has placed unprecedented pressure on maritime seaport infrastructure, particularly in developing nations. The ports in these nations serve as vital nodes in the international trade network, facilitating the movement of goods and services that drive economic growth and sometimes also as the only lifeline for the local economy. However, they are increasingly challenged by the dual imperatives of reducing emissions (mitigating strategies) and enhancing resilience (adaptation strategies) to climate change.

This study is largely based on a combination of desk research and in-depth interviews with local maritime industry experts, including but not limited to government representatives, port managers, infrastructure developers, and operational experts.

This study explores the current state of port infrastructure in developing nations, identifies key areas where investment is most needed, and proposes actionable recommendations for bridging these investment gaps. By leveraging data-driven analysis and insights from industry experts, we aim to provide a clear roadmap for stakeholders, including policymakers, financial institutions, and port authorities, to support the energy transition and climate resilience of maritime seaports.

Objectives

Provide insight into the size of the climate change problem for ports in developing nations

Provide insight into the port investment needs and sourcing of developing nations

Provide insights in potential ways forward to support a just transition for developing ports

Framing the challenge

Study on Port Climate Adaption and Decarbonisation Investment Requirements of Developing Nations

FRAMING THE CHALLENGE

The problem of climate mitigation and adaptation of ports in developing nations

With maritime transport being the **cornerstone of global trade**, it generated both incredible wealth but also high externalities for coastal regions across the globe. Developing countries have significantly contributed to global maritime trade with around 55% of exports and 61% of imports.[2]

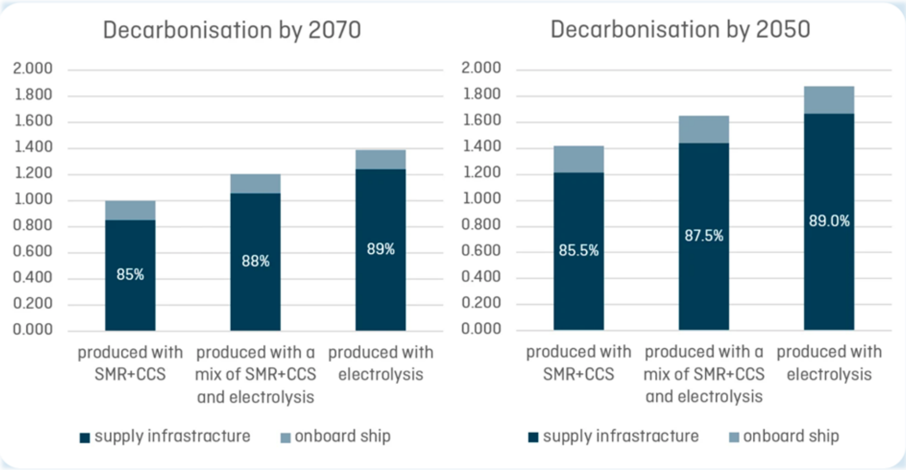
Over the past years we have seen large fluctuations in maritime transport costs. Events like geopolitical disruptions, container shortages, port congestion, the blockage of the Suez Canal and, most of all, the COVID outbreak, led to exceptionally high container freight rates. In addition, the requirements for climate adaptation (resilience) and climate mitigation (sustainability) investments have pushed ports towards ever higher levels of investments.

Some developing countries may require assistance to address rising maritime costs and infrastructure investments linked to climate change. Despite increased participation in global seaborne trade, many developing countries face challenges such as low maritime connectivity and inefficient port services; this is even more prevalent in the small island developing state (SIDS) subgroup of the developing countries. Obstacles, including being landlocked or distant from major economic centres, coupled with low trade volumes and imbalances, contribute to increased transportation expenses. In addition, **these countries are often more vulnerable than their developed counterparts to environmental shocks and disruptions caused by climate change.**

As we will see throughout this document, many developing countries experience significant trade imbalances, relying heavily on imports while exports are often limited.

The adoption of the 2023 IMO GHG Strategy aims, as a matter of urgency, to phase shipping GHG emissions out as soon as possible, while promoting, in the context of this strategy, a just transition, focusing on reaching net zero GHG emissions by 2050. **The costs of implementing this decarbonisation strategy are estimated to be between 1-2 trillion USD.** It is assumed that developing nations carry a disproportionate amount of the financial burden linked to climate change mitigation efforts, as well as the consequences of climate change.

Estimated cost of shipping decarbonization[1]



Note: Total investments needed to achieve IMO decarbonization targets and investments needed to fully decarbonise by 2050

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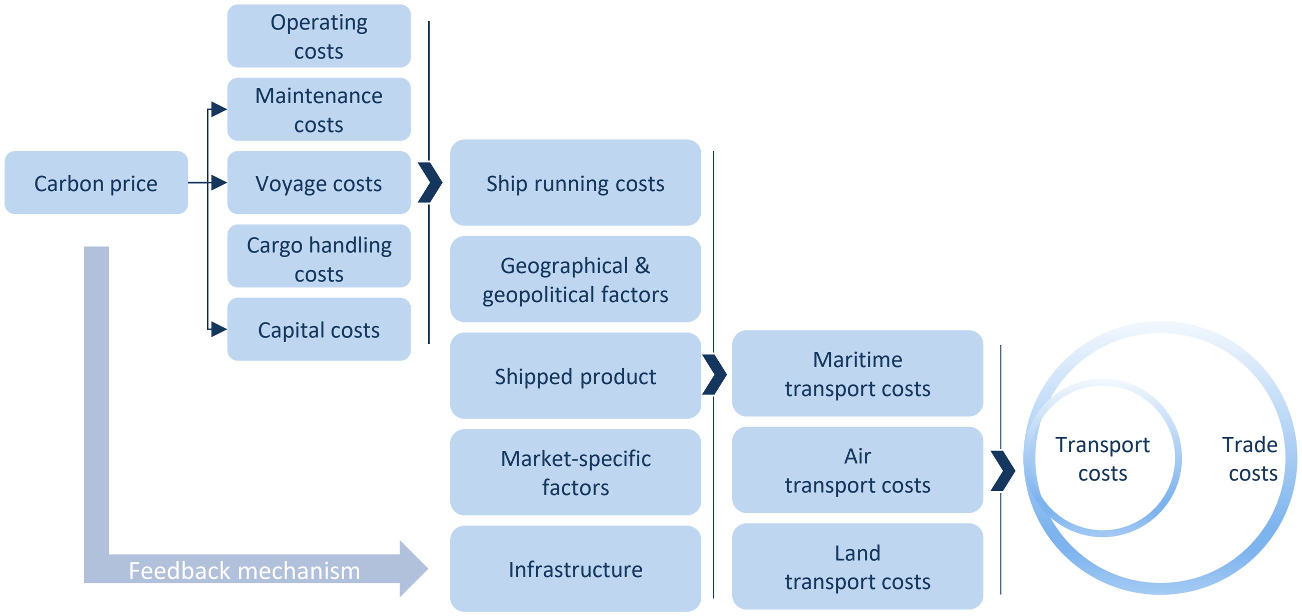
Mitigation investments (e.g. green bunkering, renewables/electrification for terminal operations, fully decarbonised ports) and adaptation investments (heightening, dredging, storm walls, etc.) are estimated to run into the hundreds of billions- to trillions of dollars between now and 2050. both types of investments increase transport costs without necessarily increasing port revenue/quality of service. Without targeted actions and investments, **the more vulnerable developing states could consequently encounter a double shock of climate change impacts (disruptions) in addition to the increasing shipping costs**.

As mentioned before, smaller economies generally incur higher maritime transport costs. These countries –already today- often require an enhancement of their port facilities to facilitate improved shipping services, enable the accommodation of larger vessels and reduce waiting times before port entry. Introducing a carbon pricing mechanism requires a pricing instrument that is directly related to the carbon or GHG emissions of the charged product or serivce. A carbon pricing mechanism will have a direct effect on the trade costs. The effect of an increase in maritime logistics costs can be marginal on global trade flows and GDP, projection show increases up to 1% of the GDP of individual countries and an impact less than 0.1% impact on the global GDP.

SIDS may bear greater negative impacts due to their comparatively higher transport costs. For instance, SIDS face potential export reductions of 8% to 18% for every 10% rise in transport costs[3].

It is therefore of extreme importance that the money generated by the pricing mechanism is re-invested to facilitate a just transition, supporting ports in developing nations to reach net-zero (mitigation) and protect vulnerable communities against the on onslaught of climate change (adaptation).

Impact of carbon pricing mechanisms on trade costs[3]



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Ports and port infrastructure

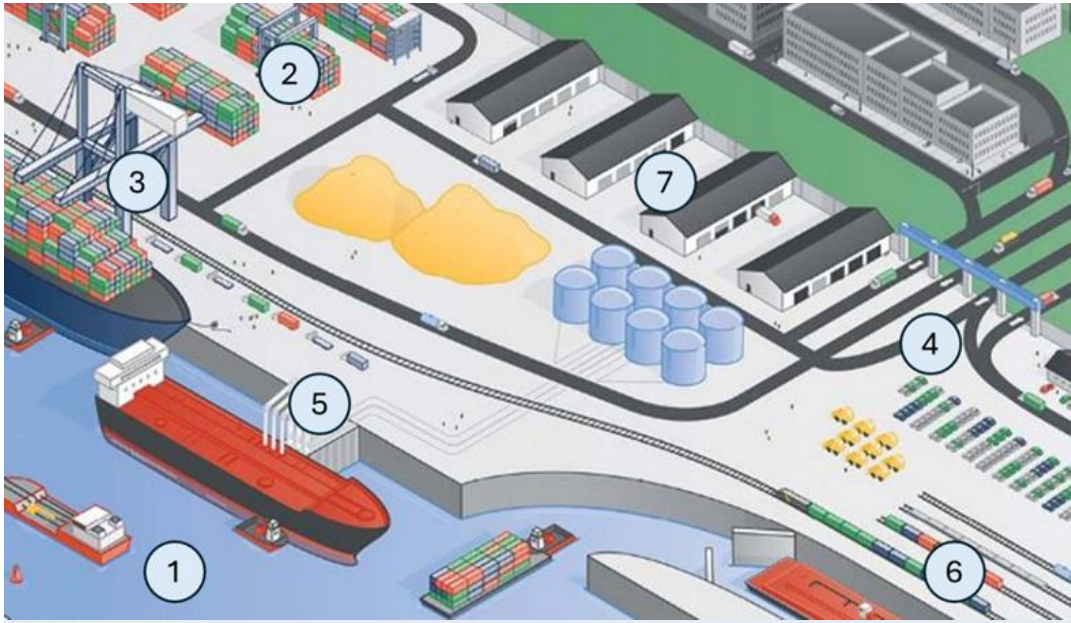
There is no uniform definition of a “port.” According to different sources, different activities and infrastructure can be included in a port setting. Some commonalities between the definitions include intermodal interfaces, land adjacent to water, centers for industrial activities, logistics nodes, and many others.

Whereas ports in developed nations are often seen as mature, developed transport and industrial clusters, in developing nations they are often seen as literal life nodes for the survival of the local communities. This high variation in types of ports across the world also translates into the type of infrastructure that is present in ports.

Berths, docks, terminals, energy infrastructure, maritime access channels, locks, and aids to navigation, roads, rail networks, and inland navigation channels might all be present or not. This renders the overall comparison of ports, and the quantification of investment needs, a very complex matter.

It is important to note that **this study focuses on ports in developing nations.** Where in developed nations ports have evolved from the classic role of being predominantly responsible for the reception of ships (import, export, storage) to a more comprehensive cluster of industrial and blue economy activity, ports in developing nations often offer a more “basic” direct benefit to the economy and community. The upcoming decarbonized energy industry offers ports the opportunity to become energy producers and expand the contribution to the economy in developing countries.

The relevant types of infrastructure in ports



① **Maritime access**

② **Basic port infrastructure**

③ **Superstructure**

④ **Port terminal and hinterland transport infrastructure**

⑤ **Energy related infrastructure**

⑥ **ICT/digital infrastructure**

⑦ **Industrial and logistics terminals**

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① Maritime access

The seaside infrastructure allowing (large) vessels to enter the port. Infrastructure includes access channels (dredging), breakwaters, sea locks to protect from tidal differences.

Impact on climate change

Badly maintained access infrastructure slows down vessels and increases congestion increasing the carbon emissions of a port.

Impact from climate change

Changing currents and water levels can lead to siltation of channels or submergence of water linked infrastructure.

② Basic port infrastructure

Basic port infrastructure starts where maritime access infrastructure ends and covers infrastructure providing (ship) transport-related port services. The focus here is not on access but on ship-shore and terminal operations. This type includes berths/ quay walls, jetties and floating pontoon ramps in tidal areas, internal basins, backfills and land reclamation.

Impact on climate change

Badly maintained infrastructure increases congestion increasing the carbon emissions of a port.

Impact from climate change

Increased weather events can lead to damage of the base infrastructure.

FRAMING THE CHALLENGE

③ Superstructure

Investments made on top of basic port infrastructure focused on trade management and terminal operations examples include storage, warehouses and mobile equipment (quay cranes).

Impact on climate change

Older equipment generates CO2, badly maintained equipment increases congestion increasing the carbon emissions of a port.

Impact from climate change

Increased weather events can lead to damage of the superstructure.

④ Port terminal and hinterland transport infrastructure

Transport infrastructure in the port area, covers inland waterway, road, and rail. All such infrastructure is required for smooth transport flows between maritime terminals and ultimately connects to the hinterland networks. Linking to the Intra-terminal network, Rail-road-barge transport infrastructure links maritime terminals in ports to the main networks. Such infrastructure, should enable direct (or easy) transfer from Rail-road-barge to ships and vice versa and facilitate operations to/from the hinterland.

Impact on climate change

Badly maintained equipment increases congestion increasing the carbon emissions of a port. Bad or lacking infrastructure impacts the modal split of a port.

Impact from climate change

Increased weather events can lead to damage of the transport network, siltation and low water levels of channels are possible.

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⑤ Energy related infrastructure

Seaports provide a strategic role for storage and production of energy (ranging from fossil fuels to source of renewable electricity through for e.g. wind or solar). This infrastructure category includes pipelines for fuel, LNG, heat, steam, CO2 as well as (smart) electricity grids, infrastructure for the provision of transport fuels (including LNG) to ships and infrastructure for onshore power supply (cold ironing) to ships.

Impact on climate change

Substantial impact on climate change, air quality and water quality through direct CO2 emissions, can be either positive or negative depending on the investments.

Impact from climate change

Increased weather events can lead to damage, over or underutilisation of renewable networks/energy grids.

⑥ ICT / Digital infrastructure

Within the category of ICT/digital infrastructure, both the hardware, such as fibre cables in the port area, as well as a digital port community platform are considered as ‘infrastructure’ in the sense that they enable information flows in the same way that transport infrastructure enables flows of physical goods.

Impact on climate change

Potential positive impact through increase of trade facilitation

Impact from climate change

None

⑦ Industrial and logistics terminals

Ports often develop industrial and logistic zones in direct proximity to transport terminals.

Impact on climate change

Large impact through direct CO2 emissions

Impact from climate change

Increased weather events can lead to damage of the buildings and infrastructure.

Important remarks port infrastructure

In addition to these seven categories there are two important points to be made:

1. **Port operations, but also new port development plans relating to both land and sea activities, may have negative impacts on the environment** (direct emission, biodiversity, water quality, air quality and climate change). New infrastructure may mitigate these effects, for instance by increasing coastal protection, curbing water and air emissions (onshore power supply, LNG refuelling points, wind on land, wind at sea), investments in optimization of activities, or reducing other negative effects for local communities such as noise or waste (recycling activities, natural walls).

2. In addition, these **categories of investment are strongly interrelated**. For instance, improving maritime access may only be possible, admissible, or valuable if it goes hand in hand with an investment in basic port infrastructure and better connections to road, rail, and inland waterway networks. In addition, due to the scale economies in construction, investment decisions often concern various infrastructure types. This renders the effect and impact analysis of mitigation and adaption investments to be very complex.

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Drivers in port infrastructure

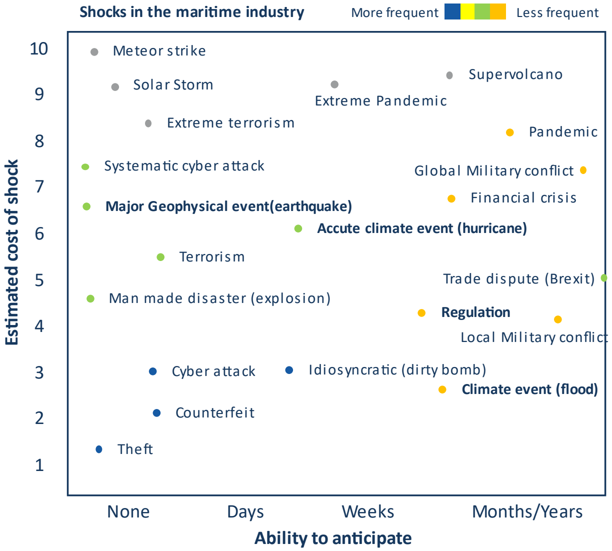
Seaports, as crucial hubs in global trade, are subject to a variety of disruptions driven by multiple factors. Four key drivers that directly affect the demand, supply, state and accessibility of port infrastructure are:

- Demographic change
- Climate change
- Geopolitical unrest
- Digitalization

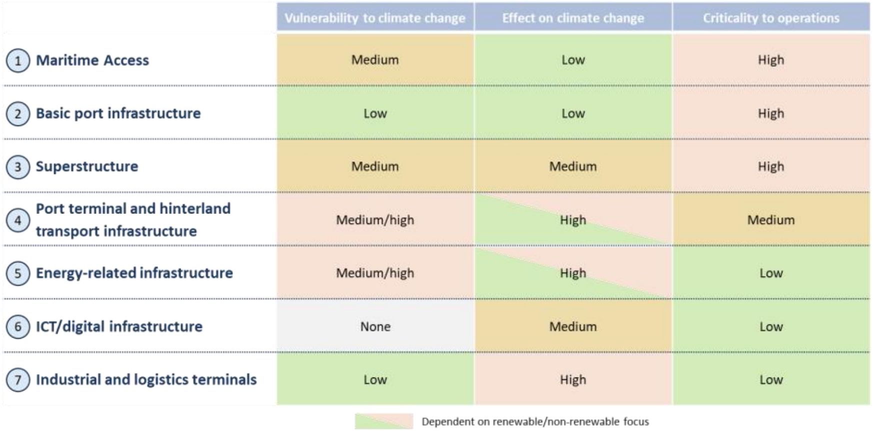
Some of these drivers are slow moving and can be well predicted, with demographics at the forefront, while others are faster moving such as geopolitical disruptions and technological changes.

Demographic changes – a slow-moving trend driver - lead directly to either growth or decline of transport demand. They are in essence at the core of "investment needs". While there is continuous uncertainty regarding trade growth, with notes of decreased globalization[4] ongoing and in the near future, projections generally suggest increases of maritime transport volumes. Strong growth, and therefore port infrastructure demand, is focused on developing nations where both population and spending power are still growing[5]. Resulting infrastructure trends from demographic change include increased depth for ports due to vessel scale increase, an increase in hub and spoke models putting stress on larger ports to perform optimally, an increase in passenger numbers, etc.

An overview of port disruptions[6]



Impact of disruptions on infrastructure



	Vulnerability to climate change	Effect on climate change	Criticality to operations
① Maritime Access	Medium	Low	High
② Basic port infrastructure	Low	Low	High
③ Superstructure	Medium	Medium	High
④ Port terminal and hinterland transport infrastructure	Medium/high	High	Medium
⑤ Energy-related infrastructure	Medium/high	High	Low
⑥ ICT/digital infrastructure	None	Medium	Low
⑦ Industrial and logistics terminals	Low	High	Low

Dependent on renewable/non-renewable focus

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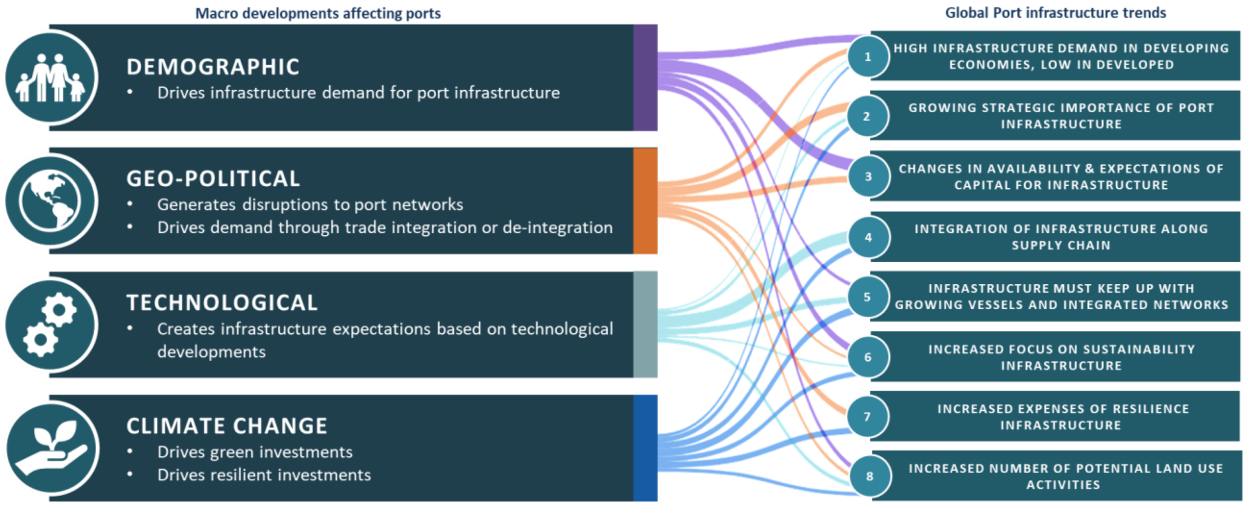
Geopolitics is the fastest moving driver by far potentially affecting the maritime industry overnight. The recent Red Sea Attacks[7] are a prime example diverging trade flows around the cape. The effects of these disruptions on actual port infrastructure are rather limited, due to their fast-moving nature, the problem suddenly arose, once the conflict in the middle east is over they will disappear just as sudden. However, what is a major driver, is if many of these short disruptions happen (as is the case today[8]) and overall geopolitical stability decreases, ports become more and more strategic assets and security driven resilience becomes ever more important, a major trend in for example Europe, Asia and the US. Additional effects of this unrest are a higher instability in the financial markets leading to different expectations of capital, directly affecting debt and equity port infrastructure investments.

Digitalization or technological developments impact infrastructure at its core. Where demographics drive the overall capacity demand **technological developments determine which capacity can and needs to be achieved by the infrastructure**. On the infrastructure needs side, examples include an increased visibility through the different steps of the supply chain, an increased need to buffer and work with smaller parcels due to Just in Time Deliveries, increased crane efficiency due to larger vessels, etc. On the "infrastructure can achieve" front increased technological innovation shows us that there is potential of a higher number of moves due to the (smart) application of new technologies such as terminal automation, increased connectivity, just in time port call operations, etc.

Climate change- the core focus of this study- stands out among the various drivers of disruption in the port industry due to its unique nature as **both a slow-moving and fast-moving trend.** This duality presents significant challenges to maritime seaports, affecting their operations and infrastructure in multifaceted ways. Investments are needed to mitigate the effect of these changes, the room for these investments is dictated by the profitability of the port and additional fund sources such as public investment schemes and grants.

Trends impacting port infrastructure



Source: MTBS

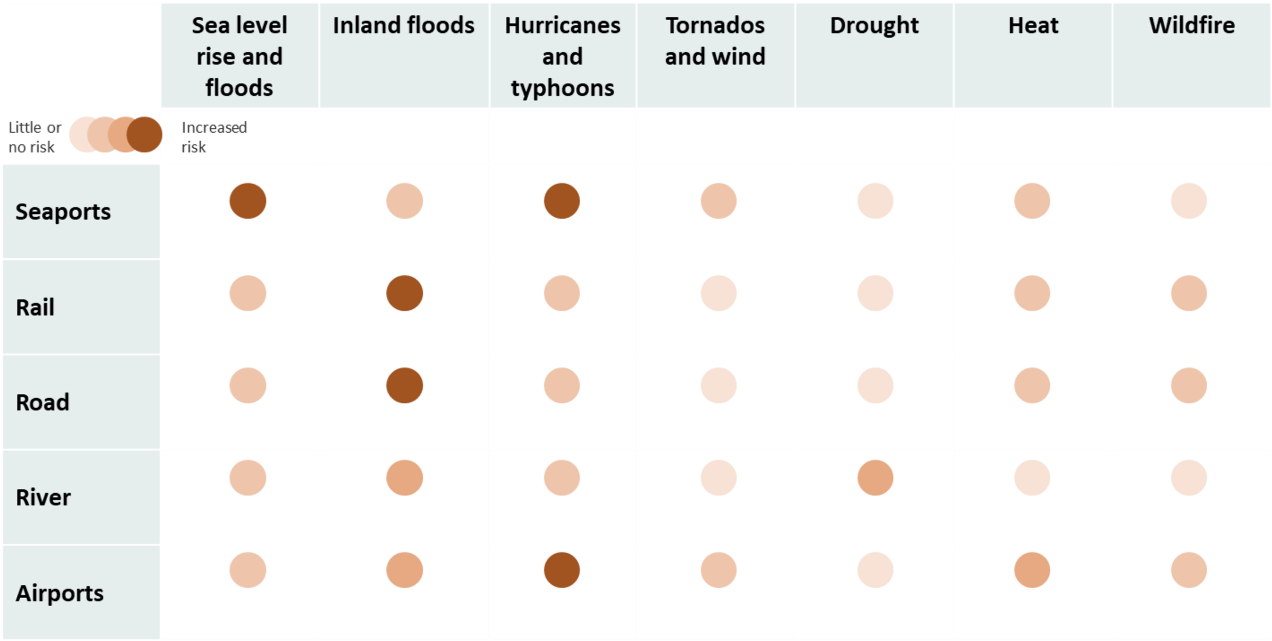
Fast Moving Disruptions of Climate Change

Climate change is increasingly manifesting through fast-moving, large-scale local disruptions. Extreme weather events, such as hurricanes, typhoons, and heavy rainfall, are becoming more frequent and intense. These events can cause immediate and severe damage to port infrastructure, including:

- **Storm Surges and Flooding**: Ports are highly vulnerable to storm surges and flooding due to their coastal locations. These events can inundate port facilities, damage equipment, and disrupt operations.

- **High Winds and Waves**: Extreme weather can produce high winds and waves, which can damage ships, docks, and cargo handling equipment, leading to costly repairs and operational downtime.

Disruptions across the maritime transport chain



- **Erosion and Sedimentation**: Increased storm activity can accelerate coastal erosion and alter sedimentation patterns, affecting port access channels and requiring ongoing dredging efforts.

- **Heat waves**: indirectly affect port operations resulting in lower efficiency or complete shutdown of the port if certain thresholds are reached.

These fast-moving disruptions necessitate rapid response and recovery efforts, highlighting the importance of robust emergency preparedness and resilient infrastructure.

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Slow moving effects of Climate Change

In contrast, climate change also exerts slow-moving, pervasive effects that gradually impact port operations over time. One of the most significant of these effects is sea-level rise. As global temperatures rise, polar ice melts, and thermal expansion of seawater occurs, leading to higher sea levels. The implications for ports include:

- **Inundation and Submersion:** Over time, rising sea levels can lead to the permanent inundation of low-lying port areas, necessitating the relocation of facilities or the construction of protective barriers.
- **Increased Salinity:** Higher sea levels can result in saltwater intrusion into freshwater sources, impacting the water quality needed for port operations and nearby communities.
- **Infrastructure Stress**: Prolonged exposure to higher water levels can place additional stress on port infrastructure, accelerating wear and tear and increasing maintenance costs.
- **Siltation:** Gradual changes in sedimentation patterns due to climate change can lead to increased siltation in port access channels and berths. This slow-moving effect necessitates more frequent dredging and maintenance to keep navigation routes clear and operational.
- **Ecosystem Shifts:** Changes in temperature and water chemistry can affect local marine ecosystems, potentially disrupting fisheries and other maritime activities that ports support and generating macrophytes. (1) see note below.

The slow-moving nature of sea-level rise and other long-term climate trends requires ports to engage in proactive planning and long-term investment in adaptive measures.

The interplay between fast-moving disruptions and slow-moving effects creates a complex landscape of challenges for ports. The increased frequency of extreme weather events demands immediate action and resilience, while the gradual yet relentless rise in sea levels and increased siltation call for strategic, long-term adaptation. Ports must address both aspects simultaneously to ensure operational continuity and safeguard their infrastructure.

Despite all these pressures ports have shown themselves to be remarkably resilient in the face of these changes. This resilience stems from a combination of strategic planning, technological advancements, robust infrastructure, smart diversification and collaborative efforts.

(1) Aquatic macrophytes impair multiple uses of water and can (i) promote losses in navigation and changes in water quality standards

Tackling the shipping impact

Port and shipping go hand in hand, without a growing demand for maritime shipments there would be no need for ports. International shipping, which carries over 80% of the world merchandise trade by volume[9], is responsible for nearly 3 per cent of all global GHG emissions. For shipping to succeed in decarbonising and help prevent dangerous levels of global warming, the sector must reach consensus regarding the regulatory framework and GHG mitigation measures of the future as soon as possible. The International Maritime Organization (IMO) developed it's initial GHG strategy in 2018 which was revised by member states in 2023. The latest IMO GHG Study 2020 estimated that GHG emissions from shipping in 2018 accounted for some 2.89% of global anthropogenic GHG emissions and that such emissions could represent between 90% and 130% of 2008 emissions by 2050[17].

Reducing the GHG emission by shipping is an urgent, but complex and challenging task. The energy use on vessels can be optimized in different ways. There are many options with regards to alternative propulsive power each with their own advantages and disadvantages.

Investment costs related to the energy transition for ports and shipowners are significant, with no clear future standard the shipping industry runs the risk to invest in technology that will eventually not be (widely) adopted. This risk is inconvenient for large major ports but for sure unbearable for smaller ports.

The costs of a newbuild liquid bulk terminal has risen over the last decade, a new technical complex tank now a days costs as much as a complete terminal 15 years ago. The higher Capex makes the business case for these types of terminals less interesting. There is however a difference in types of green fuel when it comes to costs.

GHG reduction solutions[18]

Source: own development based on IMO

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Despite these challenges the IMO aims to achieve a decarbonised shipping industry by or around 2050. To reach this goal the IMO wants to motivate the industry to significantly scale up the use of net zero and near-zero GHG fuels by 2030. The medium-term vision of the IMO is to reduce the carbon emissions of shipping by at least 40% by 2030.

The current phase of this strategic implementation is to develop a marine fuel standard that should phase out fuels that emit GHGs and build an economic incentive to drive the uptake of zero or near-zero technologies and fuels. Amongst the possible GHG reduction measures, a carbon pricing mechanism and regulatory approach currently stands out as a preferable joint package. Furthermore, the introduction of a pricing instrument has the potential to generate revenue that can be reinvested in decarbonization initiatives or infrastructure.

Converting existing facilities to make them suitable for storing and processing methanol is straightforward. Additional safety measures are needed due to the toxicity of methanol, other than that current storage and supply equipment is suitable for the processing of methanol.

Handling Ammonia and Hydrogen is not possible with equipment designed for traditional marine fuels. LNG and LPG installations can be adapted to Ammonia and Hydrogen. Ammonia is very corrosive and special measures need to be made to protect the equipment. Liquid hydrogen can cause material embrittlement and needs to be stored at lower temperatures than LNG (-253 degrees Celsius vs -163 degrees Celsius).

New LNG developments are set up with the idea to use the equipment for ammonia storage and supply over time. LNG is already adopted and Methanol ready vessels with dual fuel engines are joining the fleet mostly in dredging and construction vessels.

Moreover, contractors notice there is a need for sustainable fuel supply outside of Europe based on their own bunkering needs and from the developments towards green energy projects in many developing regions. There are no LNG bunkering facilities in sub-Sahara countries which makes it a challenge for contractors to use their LNG powered equipment and adapt it to renewable fuels. Infrastructure in the form of new tank farms and jetties or buoys is needed to accommodate many of the ambitions.

The hydrogen economy is by far the most mentioned of all renewable fuel options. Many developing countries have abundant solar and wind resources and existing scalable renewable energy infrastructure to support electrolysis production. Many more have legacy infrastructure that can be repurposed for low-carbon hydrogen production and transport. [32]

Proposals for carbon pricing or fuel standards

Proposal	Submitted by	Year	IMO reference
Universal mandatory greenhouse gas emission levy	Marshall Islands, Solomon Islands	2021	MEPC 76/7/12
Levy-based market-based measures	International Chamber of Shipping, Intercargo	2021	ISWG-GH10/5/2 ISWG-GHG 12/3/7
Zero-Emission Vessels Incentive Scheme	Japan	2022	MEPC 78/7/5
International Maritime Sustainability Funding and Reward mechanism	Argentina, Brazil,China (People's Republic of), South Africa, United Arab Emirates	2022	ISWG-GHG- 12/3/9
Emission Cap and Trade System	Norway	2022	ISWG-GHG 12/3/13

Both cause and effect

The duality of resilience and vulnerability is even more pronounced when we take into account that **ports both provide cause and effect to climate change.** Ports in developed nations often function as large industrial clusters, housing activities such as manufacturing, oil refining, and chemical processing. These industries generate substantial greenhouse gas emissions and other pollutants.

While these ports earn significant revenue from these industrial activities, driving local and national economies, the environmental cost of these operations contributes to the global problem of climate change. In addition, the success of ports is intrinsically linked to the shipping industry, which, despite being highly efficient in terms of emissions per ton-kilometer compared to other transport modes, still contributes a significant amount to global GHG emissions due to the sheer volume of global trade. Major ports handle thousands of vessels annually, each emitting CO2, sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter. The cumulative effect of these emissions is substantial, contributing to the acceleration of climate change.

In contrast, ports in developing nations are often located in regions highly vulnerable to the effects of climate change, such as tropical storms, sea-level rise, and coastal erosion. They also often have less developed infrastructure. These ports have historically benefited less from maritime trade and are only now starting to reap benefits (or in some cases don't reap benefits at all).

Adaptation vs mitigation in port infrastructure

	Mitigation (-) (increase GHG)	Mitigation (+) (decrease GHG)
Adaptation (+) **(increase resilience)**	Air conditioning Desalination Heat shelters Storm barriers	Port green space Building insulation Water storage and drainage Smart grids Multi modal transport investments
Adaptation (-) (decrease resilience)		Green bunkering Green industry feedstock Emissions regulation Energy mitigation strategies/plans

Case – Low sulfur emissions, doing bad by doing good

According to research published in the journal Nature, a major reduction in emissions of sulfur dioxide in 2020 following the introduction of new international shipping fuel regulations, led to a "termination shock" that they say could add 0.16 degrees Celsius of heat to the world's oceans over seven years, greatly accelerating global warming.

FRAMING THE CHALLENGE

Why ports are needed

Ports located in developing nations have a large impact on the economic activity and welfare of the nation and communities in question. "As much as 80% of the volume of goods in the world are transported by ship,"[8] and "With 59% of global exports and 64% of global imports passing through a developing country port, maritime transport and port infrastructure remain at the heart of economic and social development in developing countries."[9]

A disrupted or poorly functioning port can hinder trade growth, with a severe impact on both the nation and the linked landlocked developing countries. The port, along with the access infrastructure to the hinterland (such as inland waterways, railways, or roads), is a vital link to the global marketplace and needs to operate efficiently. This means that building resilient ports and safeguarding investments is not just about bracing for natural disasters. It's about maintaining a consistent flow of goods despite an ever-growing frequency of disruptions. Many developing nations depend on ports for:

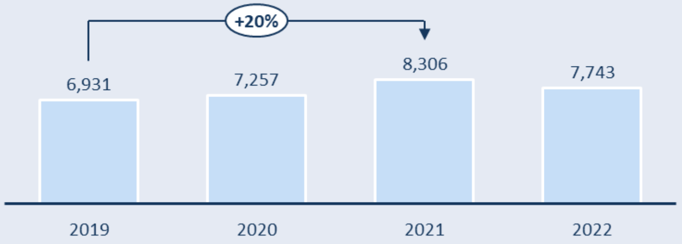
1. **Food Security:** a high dependence on imported food
2. **Disaster Readiness**: A resilient port-based supply chain enables efficient emergency supplies distribution
3. **Economic Balance**: resilient supply chain nodes to uphold business continuity and safeguard growth
4. **Tourism Support**: ports play an important role in the tourism sector, a significant revenue source
5. **Security and safety**: with smooth and fast access to territorial waters

Case – COVID impact

The interconnectedness of ports with our prosperity and well-being became clear during the COVID-19 pandemic. Society was suffering, and the port transshipment slowed down.

Ports were disrupted due to the anticipation that the pandemic would result in a severe recession or even economic crisis which caused a sharp decline in world trade. In addition to this downturn in trade sentiment lockdown measures caused disruptions and delays in many ports around the globe. As a result, the median time a container vessel spent in ports increased by 20% between 2019 and 2021.

Median time in port (hours)



Source: UNCTAD

Seaports as drivers of decarbonisation

Traditionally, high-volume fossil fuel cargos have been the primary source of income for certain ports, generating revenue from throughput dues and rental and leasehold income. However, there is a growing shift away from fossil fuels due to the urgent need to transition to a carbon-neutral economy and a decarbonised shipping sector, where alternative fuels play a crucial role. This shift presents both opportunities and challenges.

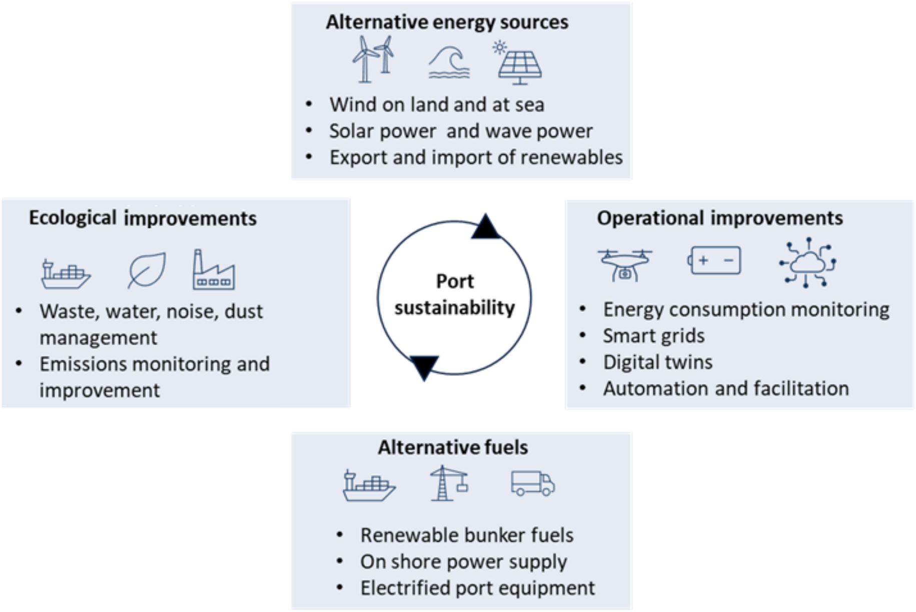
On one hand, **port authorities can capitalize on this transition by preparing their facilities for new cargo types.** This involves enhancing circular economy synergies, investing in new infrastructure such as offshore energy projects, and redeveloping existing port areas to accommodate the space requirements of these new cargoes. On the other hand, the traditional revenue model based on high-volume fossil fuels is under threat. Additionally, the generation and bunkering of renewable energy will necessitate new infrastructure. Offshore energy, particularly in northern European ports, often comes ashore in or near these ports, requiring novel or adapted infrastructure such as import and export facilities for renewables (e.g., hydrogen), wind turbines, and electricity networks.

Furthermore, **both port authorities and private operators have not only a financial incentive, but also an ethical obligation** to invest in green port infrastructure. The financial incentives are evident when considering the potential for bunker fuels and the export of renewables. Ethically, there is a pressing need to be part of the solution rather than the problem. Ports as hubs of industrial and transport activities can achieve significant impacts through even small improvements, effectively decarbonising entire transport chains. By adopting sustainable practices, ports can play a pivotal role in reducing the environmental footprint of global logistics, thereby contributing to a healthier planet.

Case – APMT co investment in solar for zero emission terminals

Achieving decarbonized operations in developing countries for terminal operators can be a challenge due to the low capacities of local networks, no green energy feedstock, bad energy infrastructure, etc. APM Terminals has as strategy to only build new decarbonised terminals. And frequently partners with local port authorities to invest in new infrastructure, for example, solar farms to supply its terminals with the required green fuel

Port sustainability segments



Alternative energy sources

- Wind on land and at sea
- Solar power and wave power
- Export and import of renewables

Ecological improvements

- Waste, water, noise, dust management
- Emissions monitoring and improvement

Port sustainability

Operational improvements

- Energy consumption monitoring
- Smart grids
- Digital twins
- Automation and facilitation

Alternative fuels

- Renewable bunker fuels
- On shore power supply
- Electrified port equipment

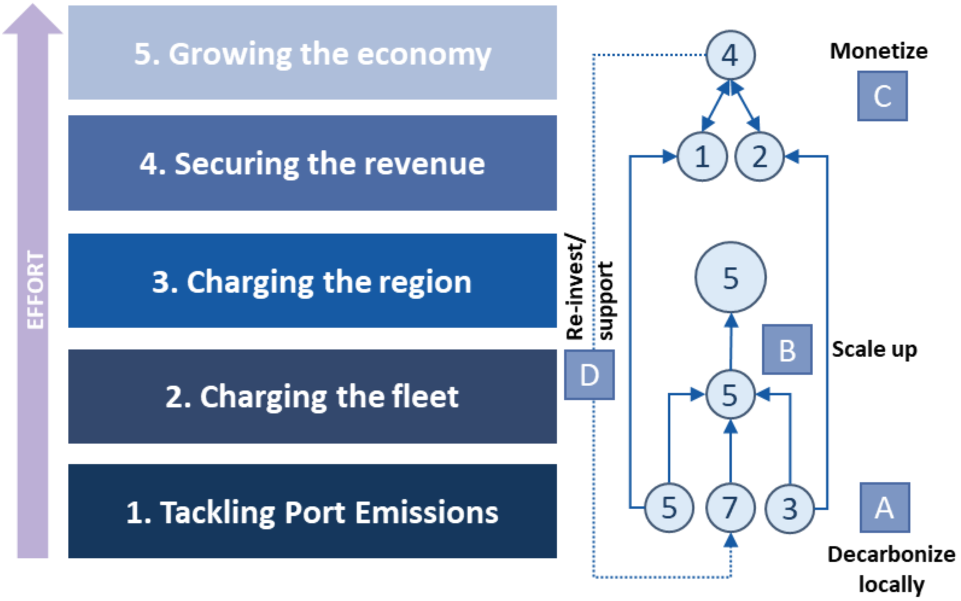
Energy Transition and Renewables a new opportunity for developing nations

As hubs in global supply chains, ports have historically acted both as buffers, producers and modal transshipment nodes for fossil energy commodities. These energy sources include coal, (crude) oil, LNG, and petroleum products. Due to the ongoing push for decarbonisation, ports need to transform and proactively evolve into renewable energy hubs to not only decarbonise their own operations and cargos but to continue to fulfil their economic engine role for the wider hinterland that is transitioning to renewable sources.

Leading ports, often in developed parts of the world are already investing in offshore wind, marine, solar, and green hydrogen capabilities[1]. These investments cover both the local industry, energy infrastructure and supplies fuel for tomorrow's clean shipping fleets.

A. The first step in achieving a clean energy port is decarbonising the on-site "polluting" activities through expanding renewable power generation and storage onsite in order to displace carbon-intensive grid electricity usage. Both the onsite industrial activities and resulting fleet movements (both sea and land) can be countered in such a way.
B. After the own operations have been decarbonised, the role of the port can be leveraged as in an industrial and transport cluster, by installing shoreside charging infrastructure, offshore wind, solar power, green hydrogen electrolysis etc. The decarbonization of the fleets is the first step but these actions also strengthen the flexibility of regional electricity grids that often suffer constraints. Ports with strong grid connections can help balance local renewable energy supply and demand both through on-site generation and acting as hub for import and export of the fuels.
C. Once onsite renewables are secured and supply chains start to take shape, ports can create significant new revenue streams for both themselves as the wider region. This is through electricity sales to users, lease fees from developers, and earnings from ancillary grid services. The export of decarbonised fuels will accelerate the global energy transition, through direct and indirect economic effects this supports local green jobs and industries.

Transition path towards a "decarbonised port"



FRAMING THE CHALLENGE

Developing nations hold just a tenth of the world's financial wealth and have only made a fifth of the clean energy investment committed by developed countries[11]. Since benefits often trail (sustainable) infrastructure investments, capital is hard to come by. Financing and the cost of capital pose substantial challenges for energy investment in developing nations, limited access to capital markets, high borrowing costs, and real or perceived investment risks deter domestic and foreign investors[12]. This means that solutions feasible and currently being implemented in the developed nations, such as electric vehicles, carbon capture, utilization and storage (CCUS), and hydrogen production or importation, may be financially inaccessible.

Economic growth emerges as the primary solution to bridge this gap, enabling developing nations to offer incentives and subsidies for energy transition and infrastructure development. However, access to cheap, affordable energy is crucial to achieving such economic growth, leaving developing nations in a Catch-22 situation.

Hydrogen is often looked at as the main driver behind the green energy wave. It has the potential to decarbonise hard-to-abate sectors such as heavy industry and (maritime) transportation[16]. Of course, hydrogen is only one element of the climate puzzle, and it will have to be combined with other green sources such as solar and wind (see figure).

Green energy from solar and wind will provide several developing nations with a new opportunity to produce, use/and or export green energy to high energy demanding nations. Green Hydrogen generated from renewable energy is earmarked as a base energy source to replace fossil fuel dependency.

Hydrogen can be used as a fuel source or as a feedstock to create synthetic fuels for heavy transportation and other industrial sectors, such as the chemical industry, refineries, fertilizer and steel production. Locally produced renewable energy can be exported in the form of Liquid Hydrogen (LH), a chemical carrier such as ammonia (NH3), or other liquified organic hydrogen carriers (LOHCs). At this stage, ammonia seems the most likely option due to the highest energy efficiency (34%-37%[13]) and lowest cost per nominal cubic meter[13]. A prerequisite for effective export is that the country is also not land locked and has the ability to use or develop a seaport for this commodity.

Case: economic contribution of the hydrogen sector[14]

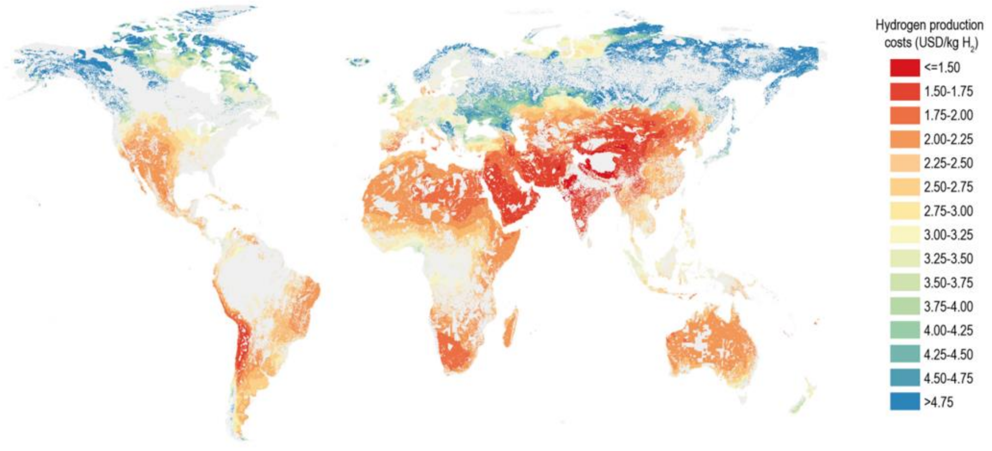
The UK government has the ambition to develop up to 10 GW of low carbon hydrogen production by 2030. Using multipliers and cost estimates made on employment and gross value added, this scenario suggests that the UK hydrogen sector could support approximately 30,000 direct jobs by 2030 and could contribute more than £7.0bn in annual GVA in 2030.

FRAMING THE CHALLENGE

The energy transition has sparked a new search for cheap production locations to produce solar and wind energy. From a global perspective, the regions with a good solar profile and possibly combined with wind energy are illustrated on the map. Countries located in these regions are earmarked to be able to generate green energy in a cost-effective manner. Research done by the IEA[23] identified Kenya, India, Brazil and India as potential countries for the production of green hydrogen at a competitive price level.

Kenya and India (see cases) have been identified as emerging markets for hydrogen production either as a feedstock or energy carrier. In Kenya, power stations are replacing diesel generators to 4 kW ammonia-based alkaline fuel cell systems as a back-up power source, including crackers to convert ammonia into hydrogen. These investments in Kenya will lead to future internal demand for ammonia and hydrogen. In India, fuel cells powered by methanol are used as a back-up power source for telecom towers. The fuel cells are now powered by methanol produced from fossil fuel which could in time be replaced with green methanol. The internal demand could be the basis to start the local production of green hydrogen, ammonia and methanol, which could be scaled up to accommodate exports of these renewable fuels once the market matures globally.

Potential regions to develop Hydrogen[23]



Middle East: Saudi Arabia, Yemen, Oman, Qatar, Bahrain, Jordan, Iraq, Syria, Kuwait, Iran, Pakistan
Indian subcontinent: India, Sri Lanka
Southern Africa: Namibia, South Africa,
Northen Africa: Egypt, Libya, Tunisia, Algeria, Morocco, Western Sahara, Mauritania
Horn of Africa: Djibouti, Somalia, Eritrea, Sudan
East Africa: Kenya, Madagascar
North America: USA, Mexico
South America: Chili, Brazil
Europe: Spain, Portugal, Italy
Asia: China
Australasia: Australia, Timor, Papua New Guinea, New Caledonia, Fiji

Note: Potential countries earmarked for cost-effective Hydrogen production based on the global heat map and having a sea border, source IEA the future of hydrogen

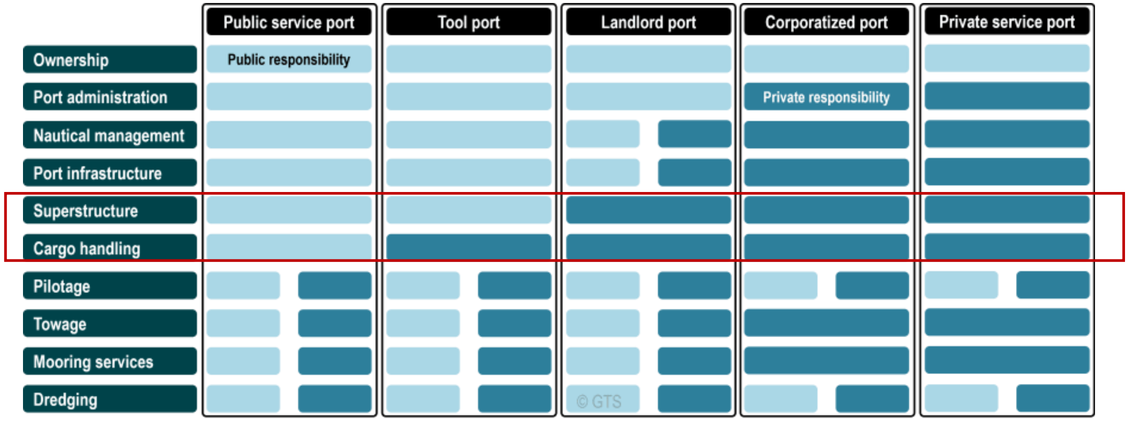
Challenges in port financing

The trends summarized above lead to investment needs in port infrastructure.

Increasing and redeveloping port capacity may sound like a logical solution to many of the trends and disruptions outlined in the previous segments, however, the expansion of seaports across the globe has become difficult[20]. Port development faces a number of challenges:

- Ports need to be deep;
- They require vast amounts of land;
- They create pollution and do not necessarily create economic benefits for their own city.

Port ownership models[19]



The decisions regarding infrastructure investments are taken by different entities within each country and sometimes is divergent from port to port depending on the port ownership model in question (see figure). The distribution of decision power depends on the port governance model in place which substantially varies across the world.

To make matters even more complex, investments in the different types of infrastructure are often done by different parties within the port depending on the port model in place.

When it comes to energy related infrastructure, investment decisions are traditionally made by the port management bodies or utility providers. This trend is shifting where there is a clear divide between centralized backbone energy infrastructure (e.g. a high voltage power network, gas related backbone, etc.) which is managed by the utility provider and decentralized local energy infrastructure (e.g. a solar farm, onshore power supply, wind on land, etc.) where the investment decision is with the private entity.

Port investment decision makers

Infrastructure segment	Typical investment decider
Maritime access	Usually decided by port managing body or government or in partnership
Basic port infrastructure	Usually a port managing body investment decision
Superstructure	Usually a private terminal operator decision, dependent on port model
Port terminal and hinterland transport infrastructure	Dependent on the location in-or outside port, port management body, local government or private terminal operator
Energy related infrastructure	Investment decision of utility infrastructure provider or the port managing body or in partnership
ICT / Digital infrastructure	Dependent on location, either port management body or terminal operator
Industrial and logistics terminals	Private operator for development port management body for first investment

The evolution of port financing

Due to the capital-intensive nature of port related infrastructure projects, a mix of public and private funding sources is often necessary. Two main types exist: (1) **Funding** involving no-interest provisions, such as state grants, or (2) **financing** involving interest-bearing loans from banks or investments from equity funds. Whilst ports in developed nations usually have a relatively large investment capacity (dependent on the size of the port in question), and the nature of port investments makes it often impossible for the port authority to realise the necessary investment without external financing. This is even more the case when we consider port infrastructure investments in developing nations.

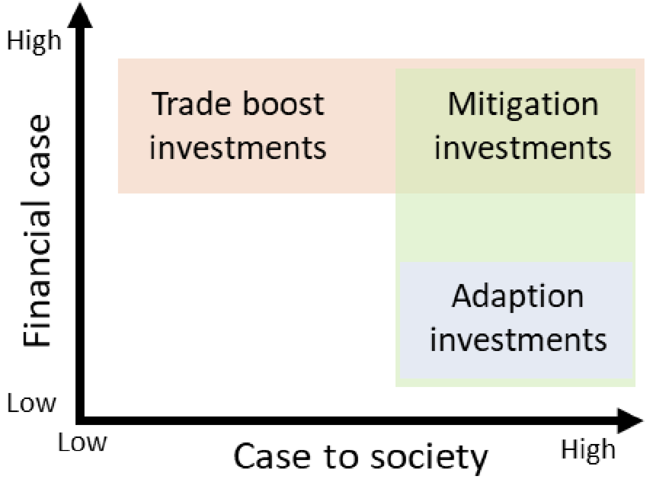
When it comes to mitigation and adaptation infrastructure investments, they often carry a high societal added value and wider economic returns beyond the port community which cannot attract private financing because of a limited return on investment for the investing port authority.

Two approaches of green financing are commonly used. The first approach are finance products of which the funds are only made available to green investments. The second approach is to incorporate “Green KPIs” into a standard financing product. The question is if this is enough to achieve decarbonisation by 2050.

New financing methods are being developed to facilitate decarbonization. The International Maritime Organization (IMO) discusses green financing during the FIN-SMART round table discussions where IMO’s Head of Project Implementation Gyogyi Gurban gave a description of the role of the IMO related to financing of green investments:

“IMO has a role to support all its Member States, such that there are no countries left behind on the journey to decarbonization. These roundtables offer a valuable platform for knowledge sharing and technical collaboration that will help level the playing field for developing countries.”[21]

Financing triggers



Methodology

METHODOLOGY

Methodology

The goal of the study is to investigate the sustainable and resilient seaport investment requirements for vulnerable and developing countries. Given the large diversity of nations and ports following metrics were used to identify the most optimal cases:

- A variety of national Port Governance structures
- Both large and small national port industries
- An overall low level of development
- A variety of geographical locations
- Both high and low vulnerability to climate change

Data is gathered by **Desk Research** and **Interviews**. The Desk Research phase is based on a literature study and the retrieval of data from organisations such as UNCTAD, World Bank and UNComtrade. The data is used as input to determine the conditions that needs to be met to **achieve decarbonised operations and climate resilient ports**. In addition, based on the data obtained from these sources, the countries are categorised from a macro-economic perspective.

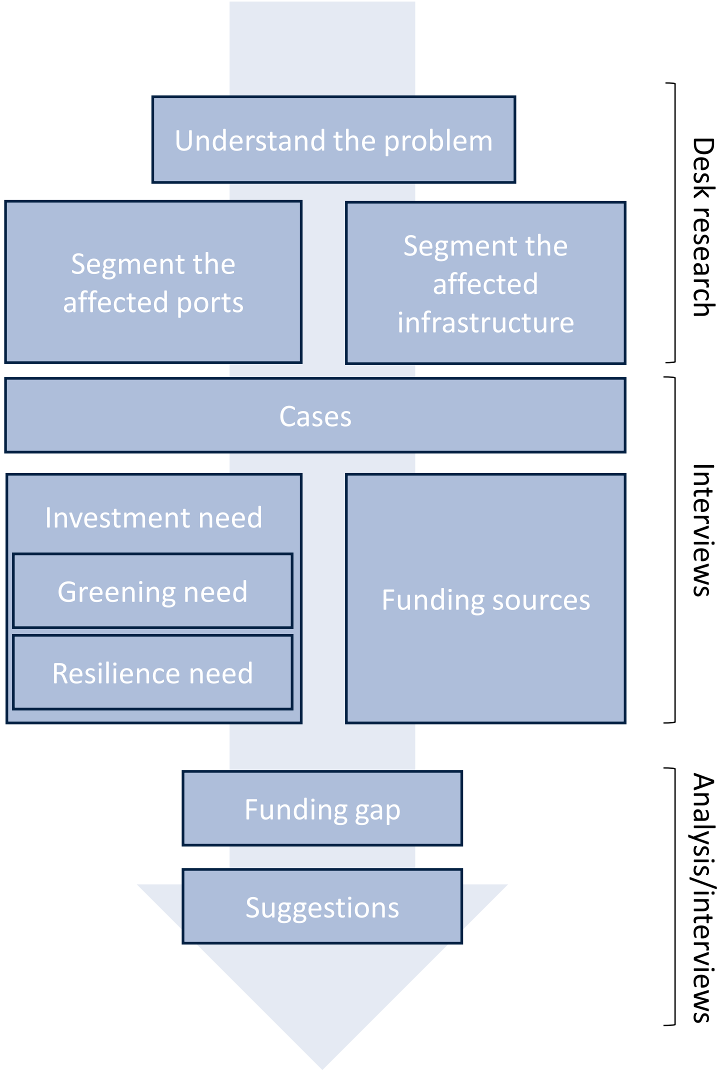
The goal of the **Interviews** is to obtain specific information on the ports in the considered countries. Multiple stakeholders are interviewed from across port authorities, financial institutions, governmental organisations, bunker terminal owners and port construction firms.

These interviews focused on the impacts on port-related infrastructure both within the ports and in the wider hinterland.

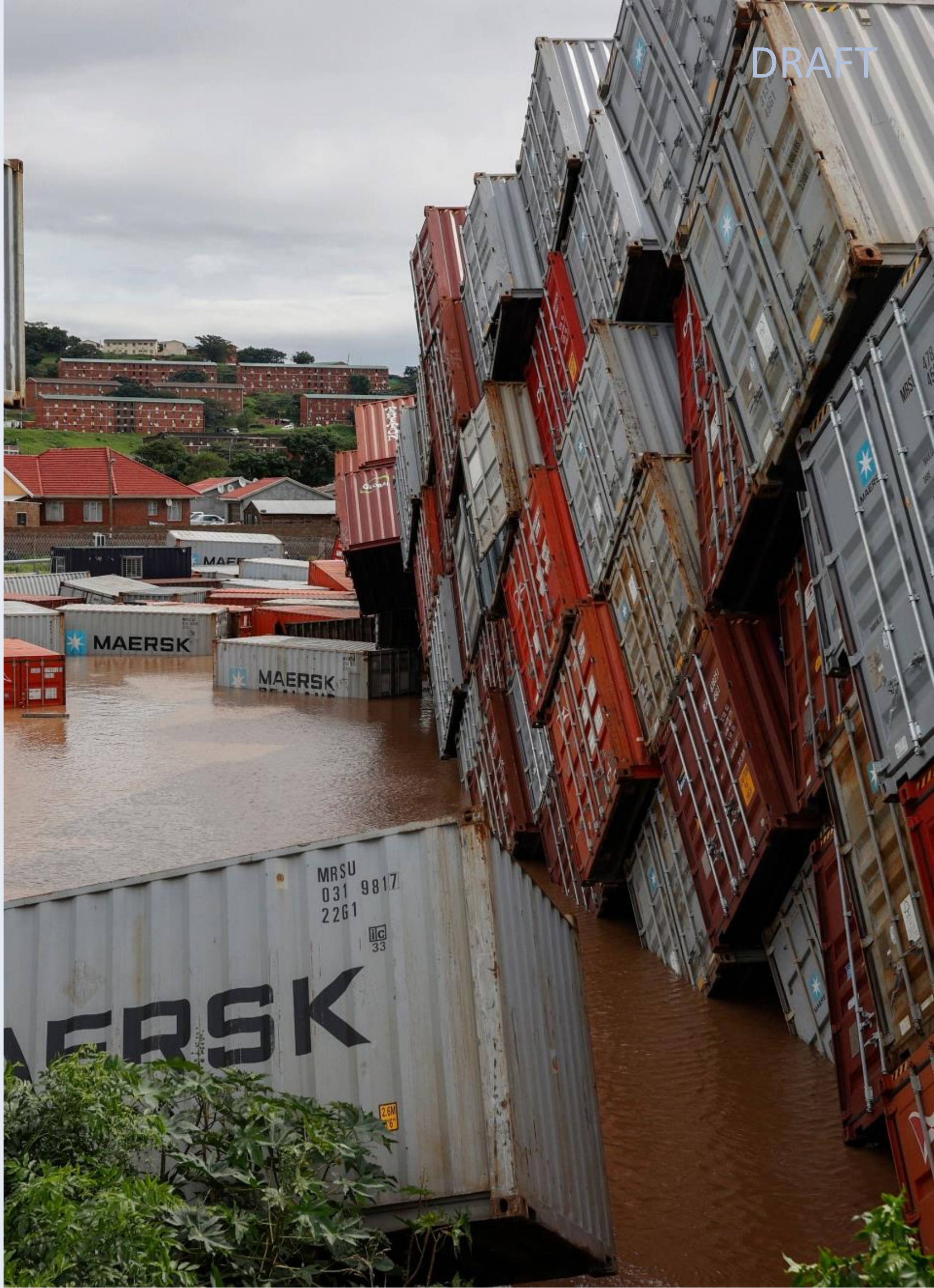
The research findings for each case are discussed in separate sections. **Two main topics are covered being firstly the impact of the energy transition and secondly the impact of climate change in the form of climate resilience adaptation.**

The results from the 5 cases are used as base case scenarios for comparable ports worldwide. The last step is to identify the number of ports that are comparable to the cases we have observed during the study.

The number of ports comparable to each specific case is used to scale the results from the study to a worldwide impact value. The end result is an overview of the impact that climate resilience adaptation and the energy transition will have on ports in developing countries.



Case studies

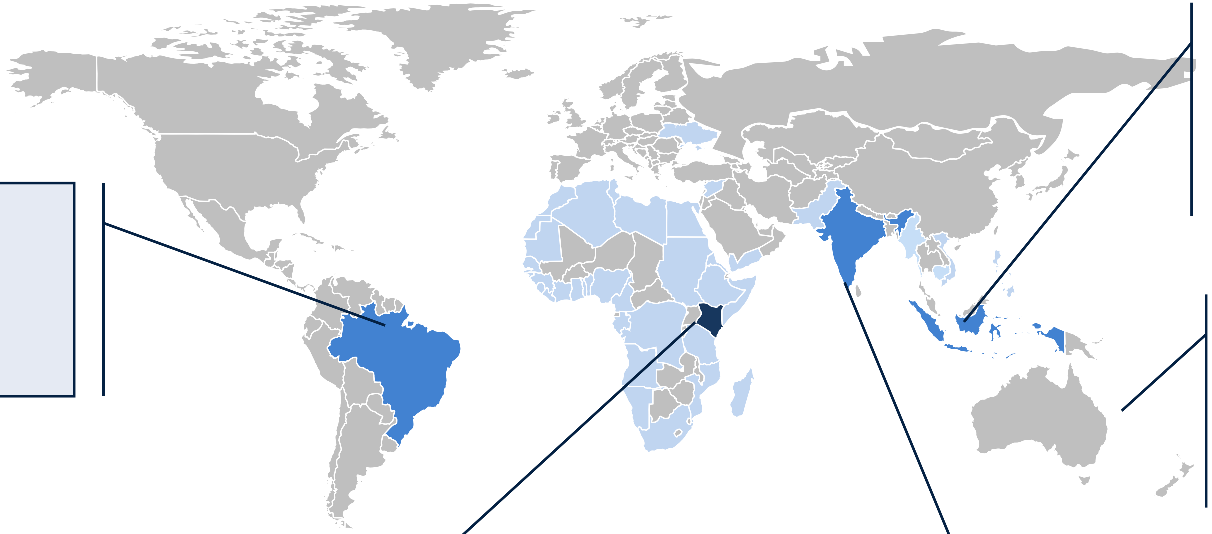


CASE STUDIES INTRODUCTION

The 5 cases

The 5 selected nations are part of the group of seaborne developing nations (see annex). And they were selected due to their geographical spread and high variety of ports, port models, vulnerability levels, trade and economic parameters. For each of the countries multiple interviews were held with local representatives and followed up with interviews with international experts. Each of the cases outlines the current challenges and developments for adaptation and mitigation infrastructure.

Case coverage and developing maritime nations



Country:	Indonesia
GDP (per capita):	$ 4,070
# ports:	1700
Interviews:	3

Country:	Brazil
GDP (per capita):	$ 8,830
# ports:	176
Interviews:	2

Country:	Solomon Islands
GDP (per capita):	$ 2,084
# ports:	2
Interviews:	2

Country:	Kenya
GDP (per capita):	$ 1,754.00
# ports:	15
Interviews:	3

Country:	India
GDP (per capita):	$ 2,089
# ports:	229
Interviews:	3

■ Countries out of scope
■ Developing seaborne countries
■ Cases in scope

DEEPDIVE CASE – KENYA PORT SYSTEM

General overview

Kenya is located on the east coast of the African continent. The country has a population of 54 million people and has one of the largest economies among all African countries. Until 2019, before the pandemic, Kenya was one of the fastest growing economies in Africa, with an annual average growth of 5.9% between 2010 and 2018.

The World Bank shows a GDP per capita (constant 2015 US$) of $1,754, **this makes Kenya a relatively weak economy compared to the rest of the cases and the developing world.**

The Kenyan ports offer a significant contribution to the national economy with an estimated direct contribution of port operations making up 5% of the GDP and indirect contribution of 12% of the GDP.

With respect to vulnerability[23], the country is ranked 150 out of 185 countries. Kenya is classified as having a **high vulnerability and low readiness**. According to the index the vulnerability is decreasing over time. The readiness score has recovered in the last few years from a relapse up to the levels seen around the year 1995.

The high score on vulnerability is mainly caused by the healthcare situation with the lack of medical staff being a major driver. The low readiness is mainly caused by the low level of social readiness stemming from the low level of education and innovation. **Infrastructure wise, Kenya is relatively resilient according to the index due to low dependency on imported energy the low projected impact of sea level rise impacts.**

Macro Economic[22] Indicators Kenya 2022

Inhabitants
54M
▲1M

GDP per capita in USD
$1754
▲49

Surface area in km²
580k

Coastline in km
536

Railline in km
1917

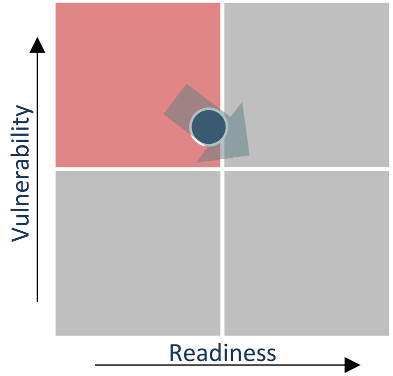
GDP contribution agriculture
21%

GDP contribution services
55%

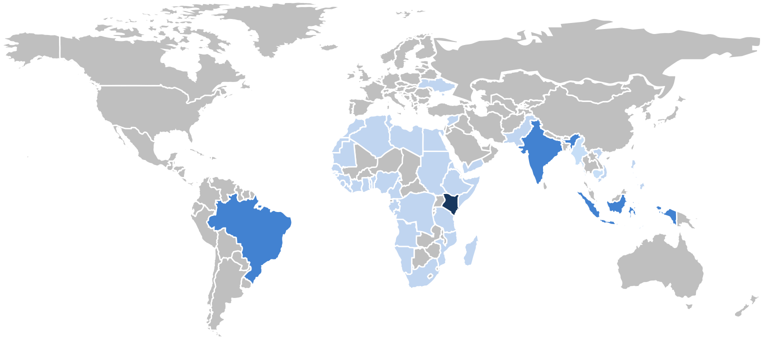
GDP contribution industry
17%

GDP contribution manufacturing
7%

ND-GAIN Country Index[23]



🟥 Vulnerable, not ready
🟦 Vulnerable, ready
🟨 Not vulnerable, not ready
🟩 Not vulnerable, ready



DEEPDIVE CASE – KENYA TRADE ROLE

Trade characteristics

The country's top five main trade partners are all located in Asia except for Tanzania. The trade split clearly supports the **Kenya's role as a transit hub from Asia to Europe and gateway to East Africa.**

Imports[24]		Exports[24]	
U.A.E	17%	Uganda	43%
China	10%	Tanzania	7%
Russian Federation	10%	China	6%
India	9%	Rwanda	5%
Tanzania	8%	U.A.E	5%

Kenya is a net importer in terms of volume, importing mainly mineral fuels and oils. The main export commodities are coffee, tea and mineral fuels and oils. The major commercial seaports are Mombasa and Lamu. The country is centrally located acting as both a **transshipment hub for East West cargo heading to the red sea or to the south of Africa** and as an import-export node for inland corridors servicing Eastern and central Africa with notable trade partners as Uganda, Rwanda and Tanzania.

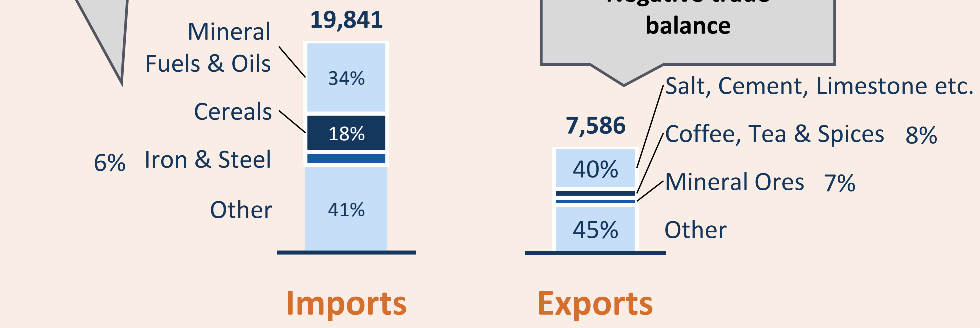
The two major seaports, eight smaller ports and two inland container depots are managed and **operated by the Kenya Ports Authority (KPA)** which is a state-owned organisation. The total cargo throughput of KPA is 35.96 Million MT and 1.62 Million TEU.

KPA manages different sizes of ports each with different challenges. KPA does not operate all terminals themselves and is looking for a more traditional landlord structure in their major ports of Mombasa.

The largest port is the port of Mombasa. Since 2018, KPA has the mandate over the smaller ports in the Lake Victoria region.

The smaller ports are part of the intermodal corridor linking land locked African countries to the seaports on the east coast of Africa. Primary goods transported via this route are staple goods.

Trade volumes 2023 (million tons)[24]



Large dependence on food imports

Negative trade balance

DEEPDIVE CASE – KENYA PORTS ENERGY LANDSCAPE

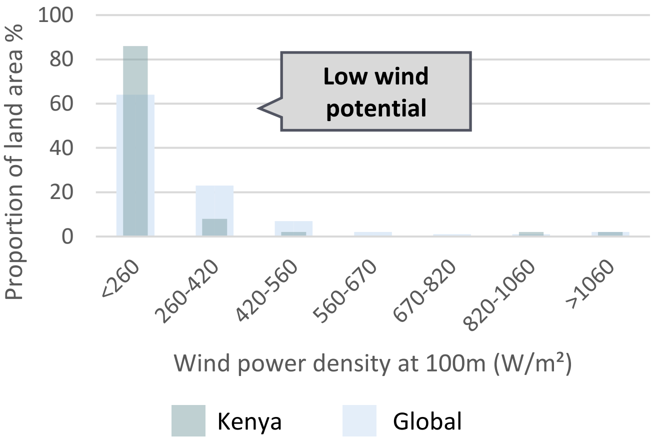
Most of the energy consumed in Kenya is already generated from renewable energy sources. 75% of the total energy supply is renewable with geothermal energy as the biggest share in the renewable electricity production followed by hydro power.

The average levelized cost of energy in the country is 0.09. To further increase the share of renewable energies the country has the option to both use solar and wind as energy sources.

Around 5% of the surface of the country is located in an area with a wind power density of over 820 W/m² which exceeds the worldwide proportional area with this wind power density. In addition, the country has a high theoretical solar potential of 5,780 kWh/m² and is ranked as the 31st country with the most solar potential.

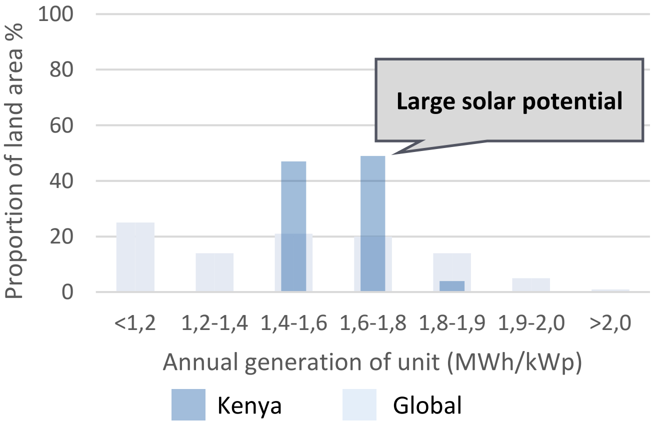
Overall, 75% of the energy used by the country is already renewable and the potential to produce a lot more renewable energy offers significant export opportunities in the future. **Given the large solar potential Kenya Ports Authority plans to offer onshore solar power to ships at berth along with alternative fuels. The polluting emissions of the port will be reduced by both the proposed alternate energy systems and new shore power arrangements. The country expects in the future to produce, export and supply green hydrogen to ships, logistic companies and the manufacturing industry.**

Distribution of wind potential[25]



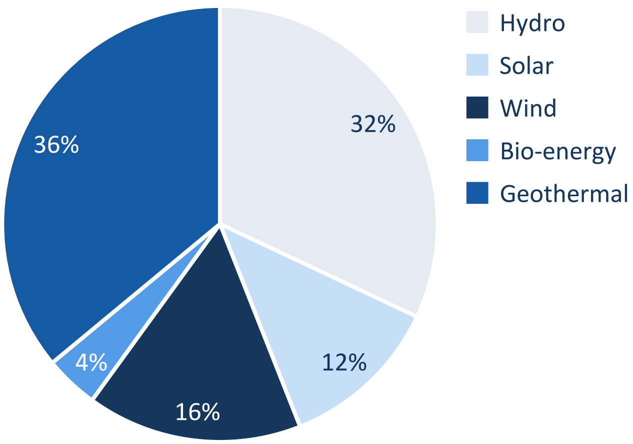
Low wind potential

Distribution of solar potential[25]



Large solar potential

Renewable energy capacity in Kenya[25]



Share of renewables in final energy consumption[25]

75%

Share of renewables in electricity generation[25]

87.8%

LCOE[26]

0.09

Solar theoretical potential[26]

5,780 kWh/m²

DEEPDIVE CASE – KENYA MAIN ISSUES

Main climate threats and the effects they have on the ports in Kenya

There are four main climate threats identified for the Kenyan ports. These climate threats affect the seaports, railways, roads and rivers in the country. The key climate change risk for Kenya is from **extreme disruptions, in particular droughts and (rain related) floods**. The frequency and intensity of such events is likely to increase because of climate change. They also often lead to adverse knock-on effects, such as soil erosion, land degradation, and pest breakouts. The climate change impact on port areas is likely to have broader effects on the Kenyan economy, as damage to the port infrastructure would have ramifications for trade, but also tourism across the country.

Rain flooding

The effects of increased rainfall is most severe at Lake Victoria where the water level rose to levels that **make (lake)ports inaccessible to ships**. Port facilities became permanently submerged and local infrastructure such as buildings and access roads were damaged. Seaports, including the higher located port of Mombasa, frequently suffer from rain flooding as well. The heavy rainfall led to **flooded access roads and railways and the interruption of port operations**. Cargo needs to be evacuated to prevent damage.

Coastal flooding

The rising sea level increases the coastal flood risk especially during storm surges. These surges lead to submerged quays which can sometimes become a permanent condition.

Extreme heat

Heat induced stress affects roads and buildings and the port equipment in Kenya suffers from increased wear and tear. Heat stress is a concern for port the employees, especially to the equipment operators and employees working outside.

Storms

Kenyan ports are occasionally affected by tropical cyclones and the occurrence of these storms is increasing due to climate change. The resulting storm surges and extreme rainfall leads to poor water drainage and an increase in rain flooding. Macrophytes in Lake Victoria form floating islands due to heavy storms and pose navigation risks to vessels.

Overview of impacted port infrastructure

	Sea level rise and floods	Inland floods (rain)	Storms	Drought	Heat
Seaports	▨	▨	▨		▨
Rail		▨	▨		▨
Road		▨	▨		▨
River		▨	▨		▨

Source: interviews

DEEPDIVE CASE – KENYA RESILIENCE NEED

The mitigating measures against the main climate threats

There are five different measures identified to mitigate the effects caused by the four climate threats that Kenya faces.

Raising quays

To solve the issue of permanently submerged infrastructure quays, some quays need to be raised. Depending on the state of maintenance, this could mean a full replacement of piers and quaysides. Raising quaysides is a challenge as all fixed infrastructure located on the quay needs to be raised as well. This makes it often more efficient to build a completely new quay close to the old one. This has an operational advantage as well as the old quay could be in operation until the new one is finished. **The government of Kenya initiated the building of 9km of new seawalls which will protect the coastline and ports from storm surges and increased sea levels.**

Drainage

Improving the drainage of the ports and its surroundings prevents rain flooding of the port area and its access roads reducing the risk of operational downtime.

Seawalls

The construction of seawalls protects the ports and coastline against high water levels and erosion. **Plans from KPA to update quays, breakwaters and revetments are under development. An issue outside the span of control of KPA is the flooding of the access routes towards the ports including the railways.** There are no plans yet as these need to be developed together with (local) government.

Status of resilient infrastructure development in Kenya

Implemented	Under development	No initiative
	Raising quay	Drainage installation
	Seawalls	
	Heat shelters	
	Early warning system	

Source: interviews

Heat Shelters & air conditioning

Preventing the risk to health from extreme heat requires the construction of accessible heat shelters and the procurement of port equipment with sufficient cooling capacity. It is vital for the air-conditioning in the port equipment to be properly maintained to ensure that all staff in the port have access to heat shelters, particularly those working outside of an air-conditioned office. **This can, however, increase maintenance costs of equipment and lead to new carbon emissions.**

Early warning system

An early warning system against macrophytes can ensure safe navigation for vessels operating in the affected areas. **To mitigate the navigational hazards, caused by the Macrophytes in Lake Victoria which form floating islands, an early warning system has been developed and currently in a testing phase.**

DEEPDIVE CASE – KENYA DECARBONISATION NEED

Impact of the energy transition on the ports in Kenya

The energy transition is topical and noticed by KPA on a national and international level with regulation being implemented by the Kenyan government and international agencies such as the IMO. **To achieve a decarbonised port three different categories within the port will need to be decarbonised being :**

- **Port operations (equipment)**
- **Bunker supply**
- **Port industry**

Port operations

KPA has invested in hybrid port equipment which can run on both electricity and fossil fuels. The port of Mombasa is producing its own green energy mainly by 1.5mw of installed solar power with plans to increase this to 5mw in the near future. The electricity produced by the solar power station is used to drive the hybrid port equipment. During the night, KPA's own power supply is not generating enough energy to run the harbour equipment and alternative sources are needed.

The ports have two options, running the equipment on diesel or making use of the national power grid. KPA has the ambition to transfer from the hybrid port equipment to full electric equipment.

However, this transfer will not start before sufficient supply of green energy to run the equipment around the clock is guaranteed. Until then the port will continue with hybrid equipment.

Bunker supply

Decarbonised fuel is not yet available in Kenya. Worldwide, the adoption of decarbonised fuel is slow which also impacts Kenya. There are initiatives to produce bio-fuels and green hydrogen within the country. Private parties are investigating investment opportunities in hydrogen production facilities with the aim to set up a supply chain for local demand. It is the ambition of Kenya to become a hydrogen hub within the East African region.

The port of Mombasa started with a pilot to provide shore power which should make the use of auxiliary engines in port redundant. Shore power is already available for the smaller service boats used in the port by KPA and shore power for merchant vessels is still under development.

Port industry

To run the complete port, a total estimated 6mw to 7mw of electrical power is needed. Installing enough green energy production capacity for the whole port is an option to fully decarbonise the ports and making the use of the central power grid obsolete. 85% of the electrical power supply in Kenya is being produced using green energy it could also be a decision to use the central power grid and wait for the central grid to become 100% renewable.

Status of GREEN infrastructure development in Kenya

Implemented	Under development	No initiative
Hybrid Equipment	Full Electric Equipment	Decarbonised Bunker Fuel
Shore Power KPA Vessels	Shore Power Merchant Vessels	
1.5 MW of Solar Power	4.5 MW of Solar Power	

DEEPDIVE CASE – KENYA CONCLUSION

Investment costs

The ports in Kenya are investing in climate resilience and decarbonisation projects**. Most climate resilience investments are related to both rain and coastal flood risks.** Flood related investments are capital intensive and can costs up to billions of USD dollars, for instance the initiative to build a seawall to protect the Kenyan coastline.

Smaller ports need to make significant investments as well. Due to the (permanent) flooding of port infrastructure, **completely new facilities need to be built.** The associated costs are in the order of building a new port.

In general, the country is on track with green investments. A total of 85% of the electricity is produced using renewable sources which will facilitate ports in the energy transition. The Port of Mombasa has also made progress by installing solar power. Transferring from full diesel driven equipment to hybrid or electric equipment when 85% of the provided electricity via the central grid is already renewable will help in reaching decarbonisation goals.

The country has the ambition to become a significant player in the production and supply of green fuels such as hydrogen, however for this to become a reality a solid business case is needed. The view of the ports in Kenya is that to finance the investments a hybrid solution between public and private parties is needed. The common view is that development partners such as the trademark Africa Group could play a role.

The Government of Kenya published a National Adaptation Plan (2016) together with additional climate change action plans whose key messages are integrated in Kenya's broader development strategy, Vision 2030, and Kenya's NDCs. Mobilizing financing for adaptation is another key constraint. Despite these challenges, Kenya's adaptation efforts have led to improvement over recent years in Kenya's climate vulnerability index, although it remains quite low due to preexisting social and economic vulnerabilities. To achieve that, it would be necessary not only to support the Kenyan government in further developing and updating its climate change action strategy, but also to focus more on the process for effective adoption, reporting, monitoring, and evaluation, as detailed in this report.

The effects of climate change are noticed in Kenya at the seaports and the inland ports. Each of these ports have their own challenges that require investments up to billions of USD to prevent flooding. Steps are made to decarbonise the port sector with the port of Mombasa being a good example. The ports in Kenya are of the opinion that funding of the needed investments should be a hybrid effort between public and private parties.

Case – Kenya Lake Turkana Wind Power Project

Currently Africa's largest wind farm with over 310 MW of capacity. The project also attracted the largest private investment in Kenya's history of $650 million.

Africa has huge renewable energy potential – home to 60% of the best solar resources globally – however, the continent receives less than 3% of energy investments worldwide.

As the region which has contributed to the climate crisis the least, yet suffers significant impacts now and into the future, the international community must partner with Africa and invest in its clean energy future.

DEEPDIVE CASE – KENYA CONCLUSION

Port Resilience

The most disruptive climate challenge for Kenyan ports is risk of flooding. The main ports are occasionally forced to cease their operations due to flooding disruption. **The risk of closure can be reduced, and this is actively attempted by installing sufficient drainage capacity.**

Due to the rise of the water level in Lake Victoria, **smaller lake ports in the region have become (partly) inaccessible for ships.** Permanently flooded infrastructure should be considered as a full write off and will need to be replaced. **The costs of rehabilitating these facilities are equivalent to the replacement value.** Additionally, a plan is developed to build seawalls that will protect the harbours and coastal areas.

Storms are also the cause of the navigational hazards near Lake Victoria due to the floating islands of macrophytes. KPA plans to solve this with an early warning system, the costs of such a system are of a lower magnitude than replacing or building new infrastructure.

Port decarbonisation

The energy transition is addressed by KPA on a national and international level with regulation being implemented by the Kenyan government and international agencies such as the IMO. The ports target three main action groups: (1) port operations decarbonisation (equipment), (2) Green bunker supply (3) decarbonisation of the of the port industry. **Some of the more notable measures to transfer to a fully decarbonised port include a (pilot) project providing shore power and changing from the use of fully diesel driven port equipment to hybrid equipment. In addition, the port installed a solar power plant which it plans to expand in the near future.**

Overall, Kenya is a country with a lot of decarbonisation potential due to its high availability of solar power. The ports are actively investing in decarbonisation initiatives but with the notable exception of decarbonised fuels. The country has the ambition to become a significant player in the production and supply of green fuels such as hydrogen, however for this to become a reality a solid business case is needed. The largest challenge lies in the adaptation measures which need to be taken to keep the ports operational. Construction of new infrastructure- replacing submerged infrastructure- and replacement of destroyed hinterland networks are amongst the largest challenges. When looking at the levels of "Transition path towards a decarbonised port" the ports are still very much in phase one – Tackling Port Emissions. Due to its high percentage of renewables, the country is well positioned to create a domestic market for green hydrogen derivatives which can also open up export opportunities, enhancing Kenya's balance of payments.

DEEPDIVE CASE – INDONESIA PORT SYSTEM

General overview

Indonesia is an archipelago in Southeast Asia with over 17,000 islands and one of the largest maritime countries in the world based on total number of ports (>2000) and a strong maritime culture.

The World Bank shows a GDP per capita of $4,070 which makes Indonesia a medium strength economy in this investigated peer group. **Today, Indonesia is the world's fourth most populous nation and 10th largest economy in terms of purchasing power parity.** According to the World Bank's October 2023 economic report, Indonesia's economic growth is underpinned by a pick-up in private consumption and positive terms-of-trade, putting extra importance on the Indonesian port system.

With respect to vulnerability[23], the country is ranked 98 out of 185 countries. Indonesia is classified as high vulnerability and high readiness. According to the index the vulnerability is decreasing overtime. The country is vulnerable with respect to food with the projected change in cereal yields and agriculture capacity as the main drivers of the food vulnerability. With regards to infrastructure the country is vulnerable due to the number of people living under 5m sea level

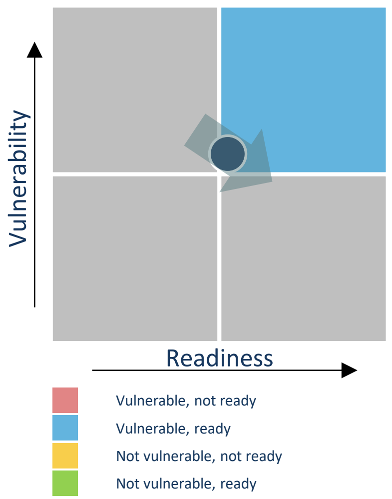
Reliable ports in Indonesia are necessary to provide sufficient food in case yields and agriculture capacity are not sufficient for the provision of food to the country's inhabitants. As the country is an archipelago this means that all inhabited islands need their own port facilities.

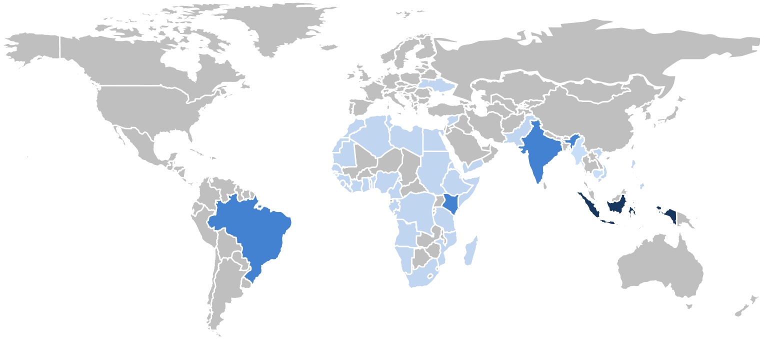
The biggest readiness improvements are to be made on social readiness , education and innovation in particular. In Indonesia, climate change is likely to impact water availability, health and nutrition, the ability to manage disaster risk, and urban development, particularly in coastal zones, with implications for poverty and inequality.

Macro Economic[22] Indicators Indonesia 2022

Inhabitants 275.5M ▲1.7M	GDP per capita in USD $4070 ▲180
Surface area in km² 1.917M	
Coastline in km 54.7k	Railline in km 5480
GDP contribution agriculture 12%	GDP contribution services 41%
GDP contribution industry 41%	GDP contribution manufacturing 18%

ND-GAIN Country Index[23]





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1) Vulnerability according to Explore ND-GAIN Country Index: https://gain-new.crc.nd.edu/

2) Source: World Bank

DEEPDIVE CASE – INDONESIA TRADE ROLE

Trade characteristics

Imports[24]		Exports[24]	
China	18%	China	35%
Australia	14%	India	19%
Singarpore	8%	Japan	6%
Malaysia	6%	Rep. Of Korea	6%
USA	6%	Philippines	6%

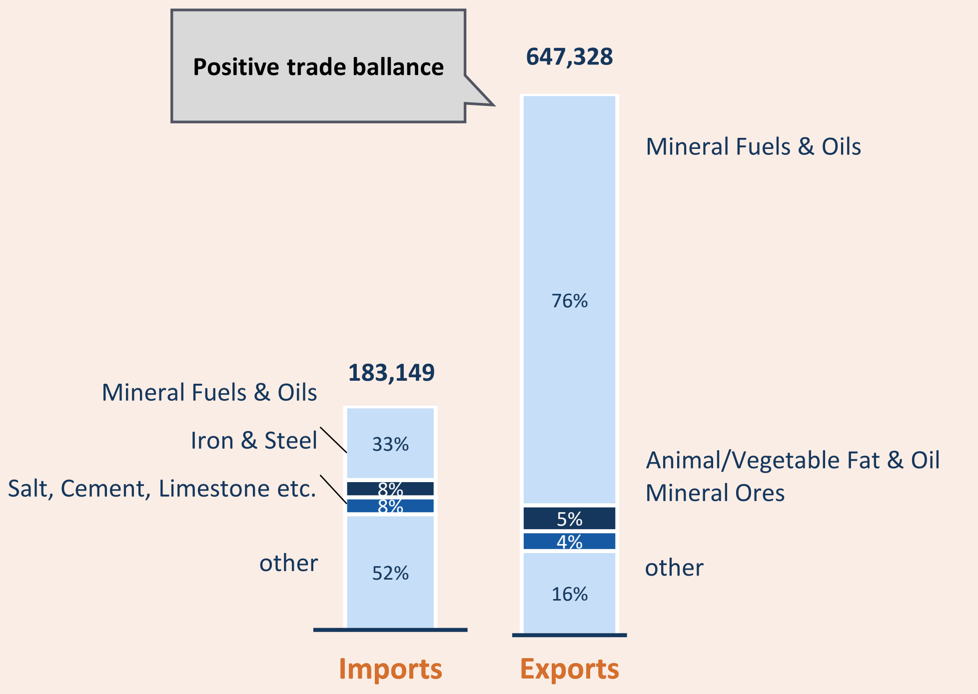
Indonesia has an abundance of natural resources which is reflected in the high export volumes in relation to its imports. The main export commodities are palm oil, natural gas, coal, and rubber.

In 2021, Indonesia registered a trade-to-GDP ratio of 39.5 percent; its year-on-year merchandise trade grew by about 40 percent and accounted for 91 percent of Indonesia's total trade. From 2017-2021, Indonesia's merchandise exports grew by 11.8 percent, faster than the Asia Pacific region's 9.6 percent annual average growth during the same period. Indonesia’s GHG emissions from shipping in 2018 are estimated to represent about 3.7 percent of global total shipping emissions

The major commercial ports are Tanjung Priok (Jakarta), Tanjung Perak (Surabaya), Belawan (Medan), and Makassar. These ports are located in the west of Indonesia.

In contrast with the ports located in the west, the ports in the east are ports on small islands that facilitate local trade and are vital for the food supply of the local communities. Their hinterlands are small and lack the presence of industrial activity or large volumes of exportable resources. **As a consequence, the ports in the east struggle with profitability.** These ports are, however, important to the local society as they are a lifeline when it comes to the supply of food and other basic necessities.

Trade volumes 2022 (million tons)[24]



DEEPDIVE CASE – ENERGY LANDSCAPE INDONESIA

In Indonesia the renewable energies have a share of 21% of the total energy supply of the country. Coal is the main source of energy for Indonesia followed by oil and together they represent 65% of the total energy supply. Indonesia committed to raise the share of renewables in its power generation mix from its current level of 19 percent to 34 percent by 2030.

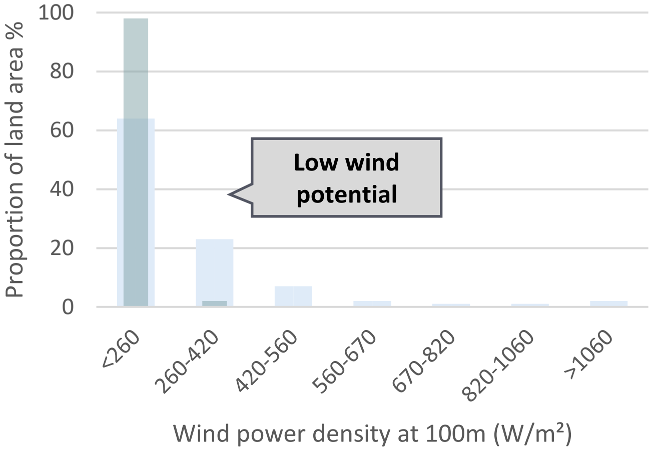
Solar represents 21%, the contribution of wind (1%) and bio-energy (2%) are negligible.

The Indonesian government made steps in 2023 on renewable energies by creating a national budget, reducing the VAT on electric vehicle with a battery and introducing subsidies.

The potential for wind energy in Indonesia is low with 98% of the area of the country having a wind power density of less than 260 W/m². **The potential for solar is average but at a constant year round supply,** the country is ranked as the 136th country regarding solar potential.

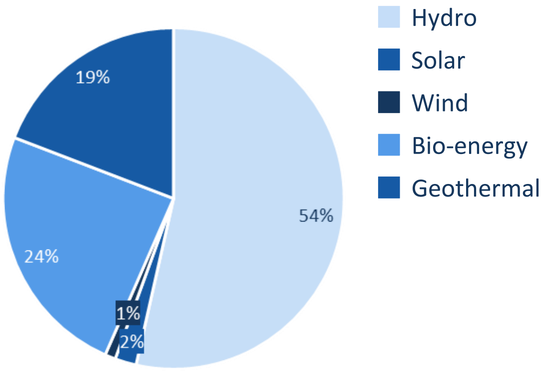
The viability of maritime renewable fuel/energy projects depends on a secure and reliable supply of low-cost zero- and low-emission bunker fuels. To date, the shortfall in production capacity remains large. For example, the announced green hydrogen and green ammonia production capacity along the East Asia-Europe corridor is less than 10 percent of what would be required by 2030 to achieve full decarbonization by 2050 according to the Global Maritime Forum.

Distribution of wind potential[27]

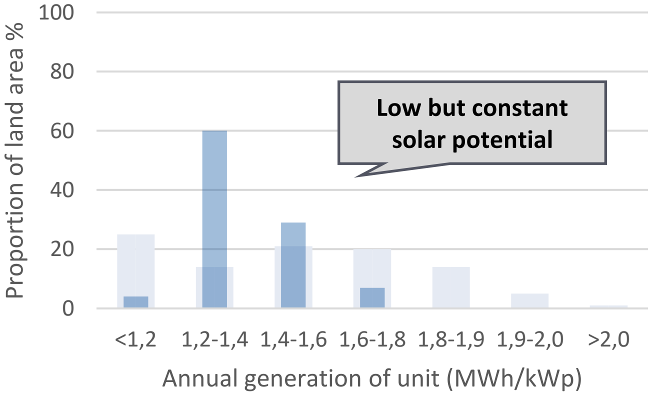


Low wind potential

Renewable energy capacity in Indonesia[27]



Distribution of solar potential[27]



Low but constant solar potential

Share of renewables in final energy consumption[27]	Share of renewables in electricity generation[27]
21%	20.1%
LCOE[26]	Solar theoretical potential[26]
0.11	4,625

DEEPDIVE CASE – INDONESIA MAIN ISSUES

DRAFT

Main climate threats and the effects they have on the ports in Indonesia

Indonesia faces several issues regarding climate change. Indonesia is highly vulnerable to climate change impacts, including extreme events such as floods and droughts, and long-term changes from sea level rise, shifts in rainfall patterns and increasing temperature. The climate threats affect the seaports, railways, roads and rivers in Indonesia. In addition to the changing climate, parts of the country are sinking, for example for example, 40% of the city of Jakarta is now already below sea level.

Coastal flooding

Ports in the east of Indonesia struggle with the rising sea level which threatens to flood the port facilities. Many berths are already (permanently) flooded and out of order. 70% of the ports in the east of Indonesia need to cease operations on a regular basis due to flooding. Emergency berthing is being created; permanent solutions are lacking. The estimated average rate of sea level rise in Indonesia is around 0.6 cm/year adding to this issue.

Storms

The country suffers from the increase in the number of severe storms with lots of precipitation and high wind speeds. These storms mostly affect the western ports. Leading to downtime in port operations, for instance, cranes cannot be used during high wind speeds. Although very few tropical cyclones hit land in Indonesia, extreme marine weather events that occur in other areas may cause significant impact (in the form of massive high waves and storm surges) to vulnerable coastal areas.

Rain flooding

The local storms are accompanied by heavy precipitation and are the cause of severe flooding. Indonesia is not unfamiliar to floods; in the past they occurred regularly in the month of January. Due to climate change they now happy all year round.

Overview of impacted infrastructure

🇮🇩	Sea level rise and floods	Inland floods (rain)	Storms	Drought	Heat
Seaports	🟧		🟧		🟧
Rail		🟧	🟧		🟧
Road	🟧	🟧	🟧		🟧
River		🟧			

Source: interviews

DEEPDIVE CASE – INDONESIA MAIN ISSUES

The mitigating measures against the main climate threats

There are several mitigating measures that can make the ports of Indonesia more resilient. **The main ports in the west of Indonesia are still fully operational whilst 70% of the ports in the east already have continuity issues when it comes to port operations**. **The small island ports in the east are the most effected and have the smallest budget.** A differentiation between the large ports in the west and the small island ports in the east should be made when considering investment potential and requirements.

Raising quays

Both the main ports in the west and small island ports in the east need to **raise the level of their piers, jetties and quays to mitigate sea level rise**. Ports in the east with sufficient budget are developing construction plans or even completed the works on their infrastructure as their facilities already became inoperable. Some of the infrastructure is replaced by new infrastructure with higher deck levels, some is replaced fully.

Status of RESILIENT infrastructure development in Indonesia

Implemented	Under development	No initiative
	Raising quay	Drainage installation
	Seawalls	
	Heat shelters	
	Early warning system	

Drainage

Additional drainage would work for ports that suffer from rain floods but are located above sea level. The small island ports will not benefit from additional drainage as they are facing larger and more consistent coastal flooding issues – also here replacement or relocation seems like the only option.

Seawalls and Breakwaters

Seawalls and breakwaters will protect the harbours from waves and current minimizing erosion. The impact of waves is reduced during high water level conditions. They are however expensive to construct, and they do not protect against coastal flooding. For the small island ports seawalls and breakwaters are not a solution to the flooding of the jetties and quays, in addition it is not financially feasible to install seawalls or breakwaters at these ports. There is a plan under development to protect the city of Jakarta and its seaport with a 32-kilometre sea wall which should be finished by 2030 with an estimated cost of $60 billion.

DEEPDIVE CASE – INDONESIA DECARBONISATION NEED

Impact of the energy transition on the ports in Indonesia

The government in Indonesia is not confident of reaching decarbonisation by 2050 and states 2060 as a more realistic target, although there is no roadmap yet. Regarding carbon footprint reduction, **the country is now mainly focused on implementing LNG and pushing towards biofuels in the future**. Most of the electrical energy in Indonesia is generated using fossil fuels. The adoption of renewable energy resources is going slow in Indonesia.

Port operations

The large ports in the west of Indonesia are adopting **shore power connections to provide electricity to moored vessels,** making the use of auxiliary engines in port unnecessary. For smaller ports in the east- these kind of investments are not realistic. These ports are already struggling to finance port resilience investments that are needed to continue operations today, let alone they are able to finance green investments.

The ports in the west, mainly on the island of Java are **investing in low emission equipment like hybrid cranes**, however, emissions reductions will likely only be achieved in the long-term as the **electricity is still sourced from coal powered electricity plants.**

Bunker supply

The ports in Indonesia are still very much fossil fuel oriented except for a few carbon reduction initiatives in the bigger ports focussing on LNG and biofuels. **The small ports in the east are not considering green fuel infrastructure and most likely will not have it on their agenda for the next 6 to 7 years due to their difficult financial situations**. In general, the ports will need the government to form a clear vision and present a national roadmap towards decarbonisation before the required investments are likely to take off.

Port industry

For the port industry, the same applies for bunker supply and port operations. No serious investments are expected as long as there is no clear vision from the national government including a road map to decarbonisation.

Status of GREEN infrastructure development in Indonesia

Implemented	Under development	No initiative
Shore Power Vessels	Full Electric Equipment	Decarbonised Bunker Fuel

Source: interviews

DEEPDIVE CASE – INDONESIA CONCLUSION

Investment costs

Indonesia is in an early phase of adopting both port resilience and port decarbonisation measures. The ports are mainly investing in climate resilience (adaptation) projects for the western region. These investments are capital intensive and can cost up to billions of dollars for an individual. Coastal flooding is an issue in the country especially for ports in the east, whilst major ports in the west face rain flooding. **The small island ports lack business opportunities and thus, have trouble financing the needed port resilience investments.** Investments related to energy transition are therefore not a priority and more importantly, not feasible at this stage. **The production and provision of green bunker fuel is the most capital-intensive decarbonisation investment that the country will have to make in the future,** however, Indonesia is not in a position to become a first mover in maritime decarbonization and requires greater certainty from industry before adopting new technologies. As **there is no clear roadmap from the government on climate resilience and the energy transition, ports are forced to finance their investments on their own making them dependent on private investments and NGOs.**

Port Resilience

Indonesia's small islands in the eastern part of the country have the biggest challenge when it comes to adaptive measures. These small island ports are vital for the food supply for local communities, however, 70% of them are already suffering from downtime due to flooded infrastructure. With a small hinterland that lacks industrial activity, these ports lack the required capital to invest in the required infrastructure. Additionally, for these ports to stay operational they will need to rebuild their jetties and or quaysides, **costs involved are of the order of building a completely new small port.**

The larger ports in Indonesia are more profitable, therefore are able to invest in adaptive measures. In addition, these larger ports are located in the densely populated areas of the country where they can benefit from the higher pressure of the government to protect the people and the (port) infrastructure. An example is the plan that is under development to build a 32-kilometre-long seawall that protects both the city of Jakarta and its port.

Port decarbonisation

The biggest difference between the larger ports in the west and the smaller ports in the east is noticed on the topic of port decarbonisation. Where the smaller ports are struggling to finance the much-needed resilience investments and don't have any money to spend on decarbonisation, the bigger ports do invest in sustainable projects such as electric port equipment. **The government of Indonesia has a wait-and-see attitude regarding decarbonisation**. Although no clear roadmap towards decarbonization has been developed, the government deems decarbonisation by 2050 unrealistic and holds the opinion that 2060 will be the first realistic deadline to become decarbonised.

Without a central vision from the government Indonesia will struggle in both port adaptive and mitigation measures. The eastern region will need to face potential relocation of ports and communities whilst the western region is looking at phase 1, tackling port emissions and investing in adaptive measures. Given its large export volume of Mineral Fuels & Oils and location close to main shipping lanes the country could try to pivot to a decarbonised fuelling strategy but for this a centralized strategy and international support will be required.

DEEPDIVE CASE – BRAZIL PORT SYSTEM

General overview

Brazil is the largest and most populous country in South America. With a 7.500 kilometre coastline, Brazil is the world´s fifth-largest country by area in the world, besides being the country that borders all countries in South America aside from Ecuador and Chile. **Due to this, Brazilian ports contribute with more than 90% of the country´s trade in terms of volume.**

The Secretary of Ports of the President (SEP-PR) of the Ministry of Transport oversees the Brazilian port system. All ports in the country are under the regulatory bodies ANTAQ (National Agency For Waterway Transportation) and MTPAC (the Ministry of Transportation, Ports and Civil Aviation). A port authority oversees each port, whereas activities undertaken in Brazil´s jurisdiction waters are under control of the Brazilian Maritime Authority.

The World Bank shows a GDP per capita of $8,830, this places Brazil amongst the strongest position in this investigated peer group.

The indirect contribution of the transport sector of Brazil which includes the port sector is estimated at 12%.

With respect to vulnerability[23] the country is ranked 86 out of 185 countries. **Brazil is classified as low vulnerability and low readiness.** According to the index the vulnerability is decreasing overtime. The readiness score fell back after 2013 to the level of the years 1995 until 2000.

The main vulnerability score driver is the status of the human habit caused by the status of paved roads, urban concentration and the **projected change of flood hazard, which is directly related to the ports.**

On the readiness topic Brazil could improve on its economic readiness and social readiness with biggest improvements points being innovation and social inequality.

Macro Economic[22] Indicators Brazil 2022

Inhabitants
215.3M
▲1M

GDP per capita in USD
$8.83k
▲0.21k

Surface area in km²
8.52M

Coastline in km
7.49k

Railline in km
32.6k

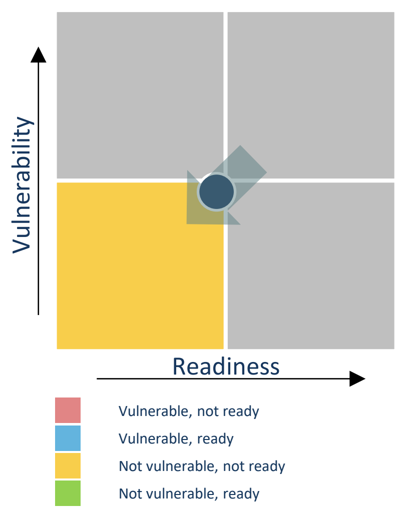
GDP contribution agriculture
6%

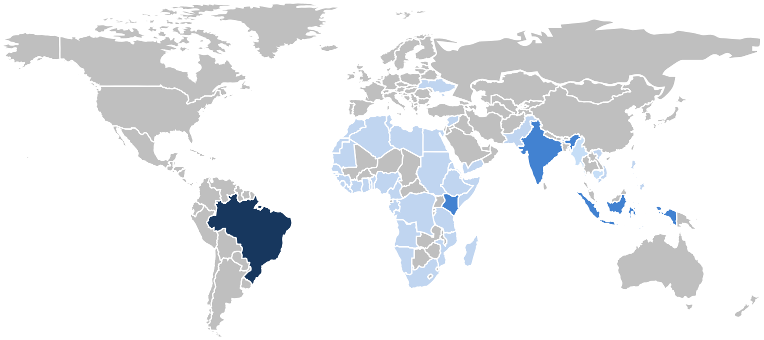
GDP contribution services
58%

GDP contribution industry
20%

GDP contribution manufacturing
11%

ND-GAIN Country Index[23]





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1) Vulnerability according to Explore ND-GAIN Country Index: https://gain-new.crc.nd.edu/
2) Source: World Bank

DEEPDIVE CASE – BRAZIL TRADE ROLE

Trade characteristics

Brazil has an abundance of natural resources, which is reflected in the high export volumes in relation to its imports. Main export commodities are mineral ores, oil seeds & oleaginous fruits, cereals and sugars.

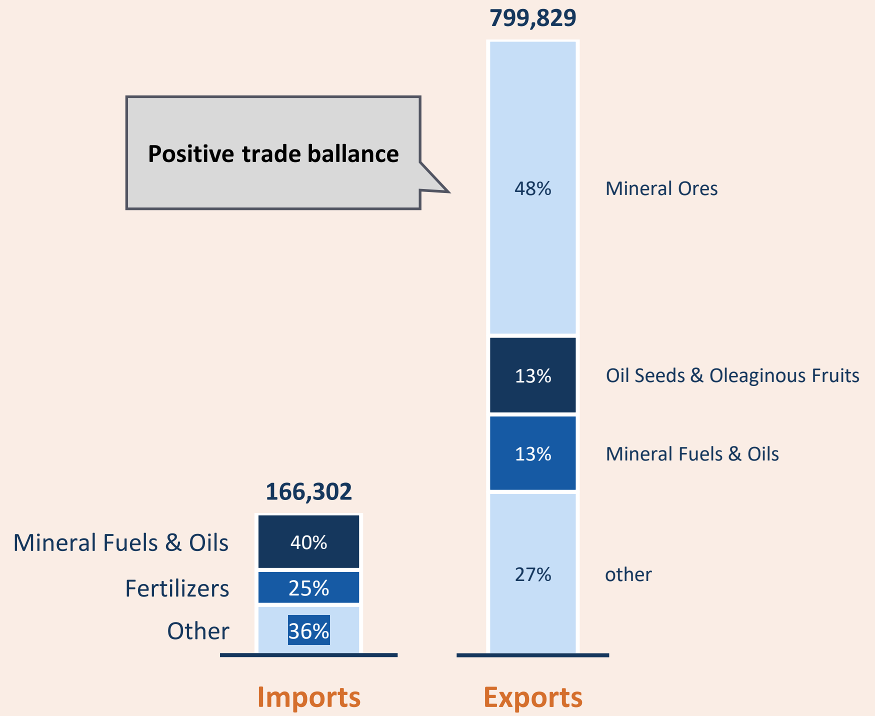
Imports[24]		Exports[24]	
USA	18%	China	54%
China	15%	USA	5%
Russian Federation	14%	Malaysia	3%
Argentina	6%	Netherlands	3%
Australia	4%	Japan	3%

The top 5 main trade partners with respect to Import and Export are spread over 5 continents. China stands out as trade partner with respect to exported goods, primary attributable to the trade in commodities much needed by the Chinese industry.

Practically 95% of all Brazilian foreign trade is handled by Brazilian ports, with port facilities along its extensive coast and rivers. **A large part of port traffic is coastal with Brazil serving a hub function for neighboring countries – making it a key port economy in the regin.**

Brazil has a total of 47 public ports and 129 private ports, as well as numerous smaller ports and terminals. Brazil has both public and private operated ports. The major commercial ports are Santos, Rio de Janeiro, Paranaguá, and Itaqui, these are all public operated ports. Porto do Açu is a private operated port, it is the only 100% private and landlord port in the country, being commissioned in 2014 it is one of the newer ports in Brazil.

Trade volumes 2023 (million tons)[24]



DEEPDIVE CASE – BRAZIL PORT ENERGY LANDSCAPE

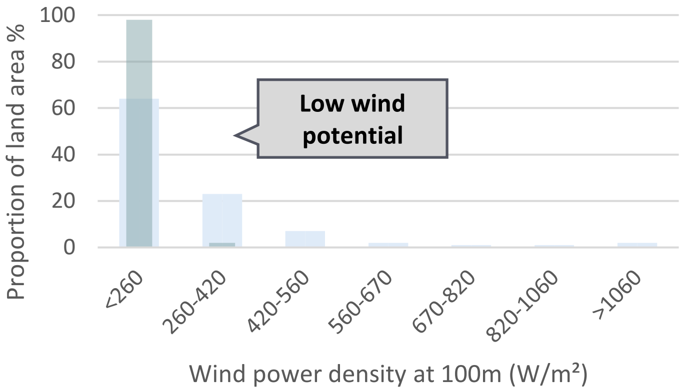
In Brazil 48% of the total energy consumption is made up of renewable energy – the Northeast accounts for almost 83% of renewable energy generation capacity thanks to the solar and wind energy generation capacity, of 27.8 gigawatts (GW). Most of the renewable electricity originates from hydro power followed by solar and wind energy. **As a result, ports such as Suape, in Pernambuco, and Pecém, in Ceará, are moving to raise funds and structure hydrogen production projects, targeting the domestic market and exports.** Companies from countries such as Australia, The Netherlands and France announced investments of USD 21 billion in the development of green hydrogen plants in the port of Pecém.

Provided there is sufficient capacity, switching from diesel powered equipment to electrical equipment powered by the central grid would significantly reduce the emissions in all ports given the relatively large focus on renewables in the country.

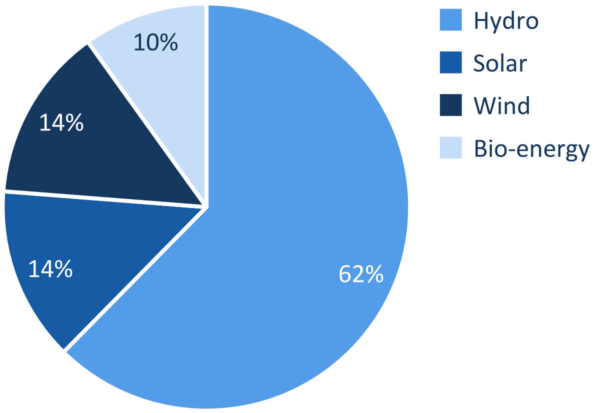
The potential of wind energy in Brazil is low with the biggest part of the country being classed with a wind power density of less than 260W/m².

The country has an average theoretical potential of 5,276 kWh/m² of solar energy production and is ranked as the 89th country with respect to Global Photovoltaic Power Potential.

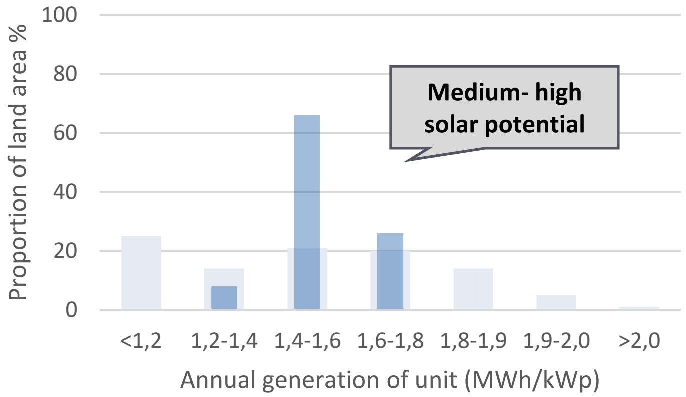
Distribution of wind potential[28]



Renewable energy capacity in Brazil[28]



Distribution of solar potential[28]



Share of renewables in final energy consumption[28]	Share of renewables in electricity generation[28]
48%	87.7%
LCOE[26]	Solar theoretical potential[26]
0.12	5,276 kWh/m²

DEEPDIVE CASE – BRAZIL MAIN ISSUES

Main climate threats and the effects they have on the ports in Brazil

The Brazilian government presented a study[31] that identified the main climate threats for the Brazilian ports. These type of studies and the simcosta system form the basis for the Brazilian public ports in developing their port adaptation plans. The operation of ports can have significant environmental impacts, including air and water pollution, habitat destruction, and noise pollution. As a result, **there is a growing awareness of the need for sustainable and environmentally responsible port practices**, in addition, Many of Brazil's ports have outdated infrastructure that limits their capacity and efficiency. This includes insufficient docks, piers, and cargo-handling equipment, as well as inadequate access roads and railways.

Storms

The increase in intensity and occurrence of storms threatens port operations. Ports need to cease operations temporarily due to hight wind speeds during storms disrupting the supply chain. The effects of storms is noticed by the ports and is identified as a major threat in the governmental study[31].

Rain flooding

A major threat and already relevant cause of the supply chain disruption is rain flooding. **Even for modern ports such as Porto do Açu which opened in 2014, rain flooding is an issue.** The port is designed using recent 100-year extreme value climate conditions and flood issues are less common than in older ports. However, the infrastructure connecting the port to the hinterland is not designed using recent 100- year extreme value data and as a result, access roads and rail connections occasionally flood due to extreme rain.

Coastal flooding

Sea level rise or coastal flooding is identified by government research[31] as one of the main climate threats for Brazilian ports. Again, this is not an issue for a modern port such as Port do Açu. Older port, for instance Porto Itaqui which is operational for over 50 years will, in time have to deal with sea level rise issues.

Heat

Being located close to the equator heat is an issue for the ports in Brazil. The main issue is related to health and safety of operators. Port equipment needs to be properly cooled and maintained, heat shelters and heat action plans are needed. The heat action plans need to describe how to act and react during extreme heat periods to prevent incidents.

Overview of impacted infrastructure

	Sea level rise and floods	Inland floods (rain)	Storms	Drought	Heat
Seaports	▨		▨		▨
Rail		▨	▨		▨
Road		▨	▨		▨
River		▨	▨		▨

Source: interviews

DEEPDIVE CASE – BRAZIL RESILIENCE NEED

The mitigating measures against the main climate threats

At this stage Brazilian ports are aware of the threats but **did not implement adaptation measures yet**. Plans and roadmaps are being developed based on findings of studies from the government and Brazilian Universities. Porto do Açu is a relative new port that does not require adaptation yet as current expected 100 years extreme weather conditions were taken into account during the design of the port.

Older ports such as Porto Itaqui will need to take mitigating measures but did not develop or implement them yet. Compared to a private port the public ports indicate they struggle with **hurdles such as strict public procurement standards**.

Status of RESILIENT infrastructure development in Brazil

Implemented	Under development	No initiative
		Drainage installation
		Raising quay
		Heat shelters
		Seawalls
		Storm warning system

Source: interviews

Raising quays

As stated in the introduction of this chapter there are no initiatives yet to update the infrastructure. Raising quays might be necessary for older ports. Newer ports will be exposed the rising sea level to a lesser extent as more recent climate data is used during the design phase of the port.

Drainage

With the increased rain intensity due to storms additional drainage is needed to prevent the ports and the access roads to the ports from flooding. There is currently no initiative on this type of infrastructure ongoing except in new terminal developments (with the exception of the wells Porto Sudeste project).

Seawalls

To protect the ports from extreme waves especially in combination with rising sea levels higher seawalls are needed across most of Brazil's ports.

Heat Shelters & air conditioning

To prevent health and safety issues due to heat all port equipment will need to be equipped with proper cooling. In addition, shelter form the heat is needed for persons working in the port.

Water Treatment and Reuse System[34]

To make use of the rain water and reduce the use of water from wells Porto Sudeste developed and implemented a dedicated drainage system. The system keeps clean rainwater separated from water that flows through the yards. Used sanitary water is cleaned and reused was well. The resulting sludge is transformed into fertilizer.

DEEPDIVE CASE – BRAZIL DECARBONISATION NEED

Impact of the energy transition on the ports in Brazil

The ports in Brazil are aware of the relevance of the energy transition and they are involved in studies examining the impact and the actions needed to decarbonise the ports and affiliated activities.

Pending on the port both national as international partnerships are formed to investigate the topic and develop action plans.

Three objectives of the ports can be identified, firstly prevent further damage to the climate, secondly comply with upcoming regulation and legislation and thirdly develop new business opportunities.

In concrete terms the impact is especially noticeable in the investment in decarbonised port equipment and the infrastructure needed for decarbonised energy supply. **Brazil is a leading country with respect to renewable energy production. The country expects to export energy generated from Wind and Solar power in the form of Methanol, Ethanol, Hydrogen and Ammonia.** The transition fuel LNG is used in certain ports as energy source for electricity generation and as a fuel for trucks.

The progress on decarbonisation and the investments related to decarbonisation differs from port to port. Porto do Açu for instance already has installed shore power and developed an action plan to invest in decarbonised port equipment. Porto do Itagui did not take initiatives yet on these topics, they are still in an investigation phase.

Porto do Açu has a decarbonisation plan based on three pillars being:

- Efficiency
- Green energies
- Green solutions for the logistic chains

Efficiency

The efficiency pillar is focused on topics as energy, electrification, cargo handling and e-navigation.

Green energies

The green energy pillar covers topics as feedstock for low carbon industry, energy hubs and the production of green energy for example by local small scale solar and wind generation.

Green solutions for the logistic chains

The green solutions for the logistic chain topic is closely related to the green energy topic, it however is specifically focused on the logistic chains by focusing on shore power, low carbon solutions for port users and green corridors.

Porto do Itagui is the founder and coordinator of the Brazilian Alliance for Port Decarbonisation. The port has a partnership with Valencia Port Foundation. The knowledge from the partnership is used as basis for the development of road maps and actions plans of the port with respect to decarbonisation.

Status of GREEN infrastructure development in Brazil

Implemented	Under development	No initiative
Shore Power KPA Vessels	Full Electric Equipment	Decarbonised Bunker Fuel

Source: interviews

DEEPDIVE CASE – BRAZIL CONCLUSION

Infrastructure cost

Due to the low level of development of adaptive measures for climate change in Brazil, information on actual costs was not provided. **Overall, we found that the most capital-intensive investments related to climate resilience and adaptation in this region are raising the quaysides and installing seawalls**. Investments in green bunker fuel production and supply infrastructure are the most capital-intensive energy transition related investments. Although the investments in port resilience and in energy transition are both capital-intensive there is a difference. The port resilience investments are needed to ensure the continuity and the long-term existence of the port, they do not add or improve the earning capacity of the port, they will increase the cost level and reduce the profitability level of the port. Intended early warning system are considered the less capital-intensive investments which are still required.

The energy transition investments create new business opportunities with an earning capacity, i.e. the costs of these investments should be covered by the profit of the new business opportunities that they create, increasing the overall profitability of the port. Due to these substantial differences the funding sources will differ as well. **The installation of solar power generation for onsite electricity and generation of renewables in the long run is amongst the cheapest options.** Investments related to a profitable business models such as decarbonated energy and fuel production or shore power can be financed by traditional financing methods. Investments needed from a resilience perspective not creating or improving a business model would need alternative sources of financing. A combination of private and public investments is suggested where incentive for private investments is needed.

Brazilian ports are facing climate threats which affect the trade within their ports. Both private managed and operated ports as the public ports have investments needs that run up to billions of USD. Private ports are able to attract funding faster as they are able to include the companies that trade their goods via the port. Priority is given to port resilience investments, decarbonising investments following suite once there is a solid business case or if the ports are forced to implement them due to regulations.

Port Resilience

The Brazilian ports will mainly face flooding, coastal flooding, storms and heat stress. To prevent coastal flooding major infrastructural changes are required such as increasing the height of breakwaters, quays and sea walls. Rain flooding can be prevented by improved drainage.

The issues are less pressing for new ports as they are designed based on more recent 100 years extreme weather conditions that already start to take the effects of climate change into account.

There is awareness of the topic and the need of port adaptation in light of port resilience. The approach and progress of the implementation differs strongly from port to port.

(continued on next page)

DEEPDIVE CASE – BRAZIL CONCLUSION

DRAFT

(Contd.) The port sector indicates that the government should facilitate the investments not only by providing funds available but also by creating incentives for private investors to invest in port resilience and port decarbonisation assets and projects.

Involving the private sector may help to speed up the adjustments. The suppliers of goods transported via the ports will benefit from investments that guarantee the continuity of the port operations and as such could be investment partners in resilient infrastructure

Port decarbonisation

Almost all ports in Brazil are investing in decarbonisation. Porto do Açu has installed shore power connections and other ports are making plans to install shore power. Investments plans for electric equipment are under development in some of the major ports but still in early phases. Even though wind potential varies across the country there is a large potential for renewables power generation, mostly on the east coast. As a result, certain ports are moving to raise funds and structure hydrogen production projects, targeting the domestic market and exports.

The Brazilian port sector is still very much under development. On the adaptation front a lot of effort needs to be made to protect the ports from climate change disruptions and investments will be very high. The newer ports will be able to cope with adaptive investments whilst new greenfields will need to keep the increasing storm frequency and intensity in mind. Of all the investigated cases- Brazil is the furthest in using its strong global export position combined with tis strong potential renewable energy generation as a lever to develop an export-oriented hydrogen/renewables economy. The progress on decarbonisation and the investments related to decarbonisation differs from port to port with some ports still focussing on phase 1- Tackling Port Emissions, whilst others are actively looking at securing revenue and growing the economy (phases 4 to 5). The major challenges to be overcome to speed up this development are the local procurement regulations.

DEEPDIVE CASE – INDIA PORT SYSTEM

DRAFT

General overview

India is located in South Asia on the Indian subcontinent and has the largest population in the world. The World Bank shows a GDP per capita (constant 2015 US$) of $2,089 this places India in category 1 of our GDP classification presented in the methodology.

The ports play a significant contribution to the economy of the country with an estimated direct contribution of port operations of 5% of the GDP and indirectly 12% of the GDP.

As of 2022, there are 12 major ports and 217 non-major ports (not linked to size) across the country. **Major ports are under the administrative control of the Ministry of Ports, Shipping and Waterways of the Government of India, while non-major ports fall under the jurisdiction of State Maritime Boards of respective state governments—this also includes private ports.**

With respect to vulnerability[23] the country is ranked 116 out of 185 countries. India is classified as high vulnerability and high readiness. According to the index the vulnerability is decreasing overtime. The readiness score increased from 1995 to 2013 to face a setback in 2014. since 2014 the readiness is recovering.

India is most vulnerable on health care and food supply. Biggest issues are with the availability of medical staff and the projected change of cereal yields. **The country is also vulnerable to the projected change of flood hazard which has an influence on the ports within the country.**

The level of innovation and education is negatively influencing the readiness of the country.

Macro Economic[22] Indicators India 2022

Inhabitants
1.417B
▲0.01B

GDP per capita in USD
$2089
▲128

Surface area in km²
3.29M

Coastline in km
7k

Railline in km
68.1k

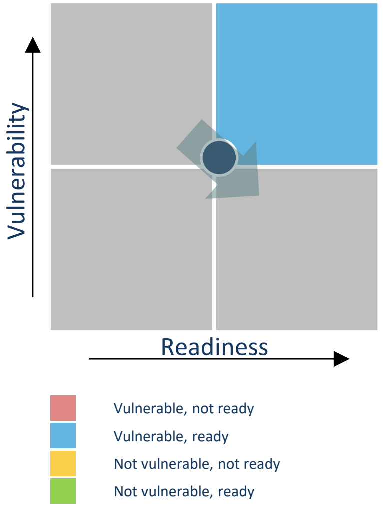
GDP contribution agriculture
16%

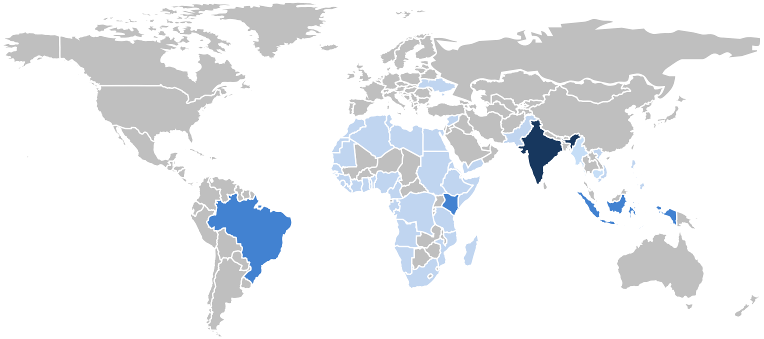
GDP contribution services
48%

GDP contribution industry
25%

GDP contribution manufacturing
13%

ND-GAIN Country Index[23]





1) Vulnerability according to Explore ND-GAIN Country Index: https://gain-new.crc.nd.edu/
2) Source: World Bank

DEEPDIVE CASE – INDIA TRADE ROLE

Trade characteristics

The economy if India is one of the fastest growing economies in the world. It is estimated that the real GDP grew with 6.9%[22] from 2022 to 2023.

Imports[24]		Exports[24]	
Russian Federation	17%	China	19%
Indonesia	15%	Bangladesh	9%
United Arab Emirates	8%	Netherlands	6%
Australia	7%	USA	6%
USA	7%	United Arab Emirates	5%

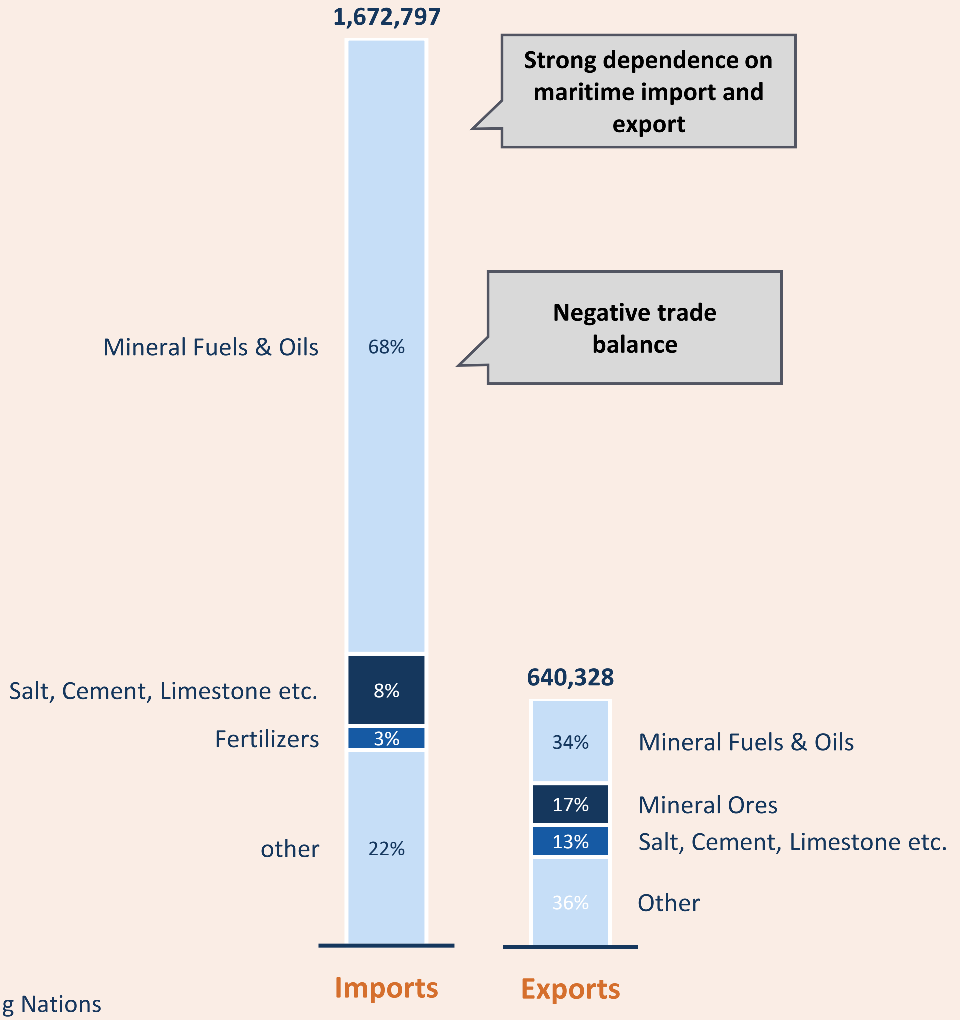
India being a peninsula, its maritime linkages have historically involved trade, religion, and culture; these early associations, however, were severed over time. Especially after independence, the focus of India's foreign outreach had become almost entirely continental.

India is a net importer in terms of volume, importing mainly crude oil, gold, and electronic goods. Main export commodities are petroleum products, gems and jewellery, and pharmaceuticals.

3 out of 5 trade partners, both for import and export, are located on the Asian continent. The other trade partners are located on the European, North American or the Australian continent. **The Indian ports both increasingly serve as a gateway to the vast Subcontinent as well as a transhipment hub on east-west cargo flows. This makes them key hubs of growing importance in the global trade network, located on strategic shipping routes.**

The major commercial ports are Mumbai, Chennai, Kolkata, and Visakhapatnam.

Trade volumes 2023 (million tons)[24]



Strong dependence on maritime import and export

Negative trade balance

DEEPDIVE CASE – INDIA ENERGY LANDSCAPE IN PORTS

India is very much dependent on fossil fuels (46% coal, 23% oil) with only 24% of the total consumed energy being renewable (of which 89% bio energy).

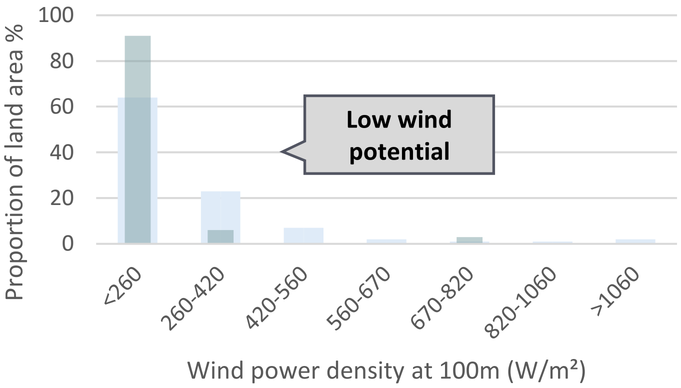
The average levelized cost of energy in India is 0.07 which is the lowest LCOE of the 5 cases in this study.

Most parts of the country are classified as areas with less than 260W/m^2 wind power density where the potential wind powered energy is low. There are however areas in the country in the class with 670-820W/m^2, these areas are interesting with respect to wind powered renewable energy production.

With respect to solar the country has a potential of 5,098 kWh/m^2 which ranks the country as the 104th country with respect to solar energy production potential.

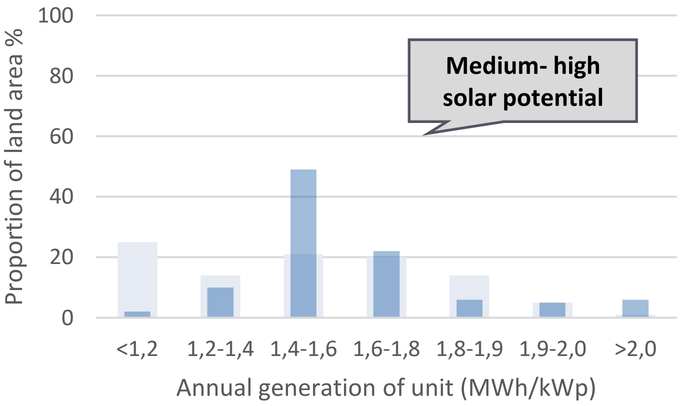
Given the potential for renewables and large dependency on fossil fuel there is a lot to be gained in India. The transition towards renewable sources of energy including solar power, wind power, tidal power have already been initiated at many of the major ports of the country. **The Ministry of Ports, Shipping and Waterways is planning to increase the use of renewables to 60 percent of the total power demand of each of its major Ports from a present share of less than 10% which will require substantial investments but benefit the wider economy as a whole.**

Distribution of wind potential[29]



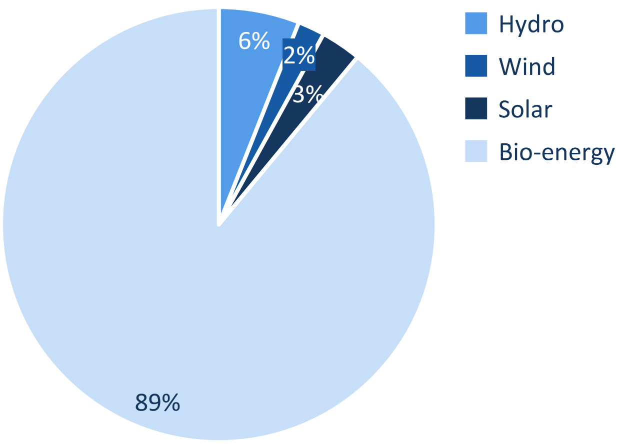
Low wind potential

Distribution of solar potential[29]



Medium- high solar potential

Renewable energy capacity in India[29]



Share of renewables in final energy consumption[29]	Share of renewables in electricity generation[29]
24%	22.4%
LCOE[26]	Solar potential[26]
0.07	5,098 kWh/m^2

DEEPDIVE CASE – INDIA MAIN ISSUES

Main climate threats and the effects they have on the ports in India

India is facing extreme heat and storm threats. The storms are accompanied by heavy rainfall causing rain floods as well. The effects have more impact on smaller ports than on the bigger ports. **Indian ports are estimated to be able to cope with climate change effects for the coming 5 to 6 years.**

Storms

Cyclones can have an effect on the port for 12 to 48 hours pending on the intensity of the storm. The storms affect both the port and continuity of the maritime operations. Most harbours in India are well protected natural harbours as a result **damage to the infrastructure due to storms is minimal.** Main issue are high wind speeds and heavy rainfall causing the maritime operations and port operations to be disrupted. Most of the infrastructure at these ports, including the cargo-handling equipment, cargo-storage areas and administrative and residential buildings are not designed to withstand sustained wind speeds greater than 160 kmph making cyclones amongst the biggest climate disruptors in the region.

Rain Flooding

Extreme precipitation events, such as heavy monsoon rains or cloudburst events, also pose a risk to port operations. In past only ports on the east coast needed to deal with heavy rainfall due to the monsoon. With the increase in tropical storms, ports on the west coast are suffering from heavy rainfall as well. The ports, and especially the bigger ports are able to handle the extreme rainfall. Mumbai port for instance has an excellent drainage system. Heavy precipitation poses a greater risk to hinterland connections such as roadways, railways, power connections, communication lines, waste services and staff-access to the port, due to flooding.

Extreme Heat

Extreme temperature events or heatwaves are a problem causing stress on personnel through reduced work efficiency and health of the port staff. The impact on equipment is rather limited. It requires sufficient cooling capacity for operators operating harbour equipment and heat shelters for personnel working outside. **Tropical countries such as India are particularly vulnerable to extreme heatwaves which will only become more frequent.**

Overview of impacted infrastructure

	Sea level rise and floods	Inland floods (rain)	Storms	Drought	Heat
Seaports	🟧		🟧		🟧
Rail		🟧	🟧		🟧
Road		🟧	🟧		🟧
River					

Source: interviews

DEEPDIVE CASE – INDIA RESILIENCE NEED

The mitigating measures against the main climate threats

Pending on the ports mitigating measures are necessary. The port of Chennai plans to modernize its infrastructure. Most other ports don't have any plans to modernize their infrastructure yet.

Drainage

Additional drainage could be installed in the future. Ports on the west coasts are more and more facing heavy rain and rain floods due to the increase in heavy tropical storms. As stated, Mumbai has sufficient drainage, other ports need to improve on their drainage systems. Initiatives for new drainage systems have not started yet.

Weather prediction and port capacity increase

Weather predictions are used to anticipate on incoming storms. In combination with a capacity increase this could prevent supply interruptions. The ports try to handle ships and send them back to sea before the storm affects shipping operations. This method creates peak loads on the port from both an operational and storage capacity perspective, therefore an increase in capacity is needed.

Status of RESILIENT infrastructure development in India

Implemented	Under development	No initiative
	Raising quay	Drainage installation
	Seawalls	
	Heat shelters	
	Early warning system	

Source: interviews

Heat Shelters & air conditioning

Operators of port equipment and workers need to be protected to heat by having sufficient cooling and shelter from heat in the form of heat shelters. There are no specific initiatives to improve the current heat shelter facilities or cooling facilities.

Heat Action Plans

The Indian government has implemented Heat Action Plans at various levels being state, district and city. The plans includes Early Warning Systems, Public Awareness Campaigns, Cool Roof Initiatives and Urban Planning. During heat waves, working hours are rescheduled if possible. This avoids workers needing to do their job during the hottest part of the day, and thus reduces extreme heat exposure.

Hinterland connections

City planners are working on mitigating measures to resolve the problem of flooded roads and railways due to heavy rainfall.

DEEPDIVE CASE – INDIA DECARBONISATION NEED

Impact of the energy transition on the ports operated in India

The energy transition on the agenda in India, both on a technological as a legislative level. Green corridors are being introduced between port and city areas where zero emission equipment for transport of goods need to be used.

Most ports are still using conventional trucks powered by diesel engines. Several solutions are being studied and implemented such as trucks running on a fuel mix with renewable fuels, fully electric trucks and hydrogen trucks.

In general, India is actively moving away from fossil fuels (mainly coal) to renewable energies. Out of 12 major ports 5 to 6 are running on renewable energy already. The port of Mumbai is for example for 75% to 80% powered by renewables.

Port operations

Ports in India are implementing shore power connections for vessels to reduce the use of auxiliary engines while being in port. The port of Chennai already has shore power connections available. Difficulties they are encounter are non-standardized electricity reception points on ships. **Installing solar power to produce renewable energy is sometimes difficult due to the lack of available land for the PV-cells.**

Bunker supply

India has the ambition to become a green hydrogen hub by creating production and bunkering facilities. The country keeps a close eye on how European nations develop their green fuel facilities and regulation. 3 out of 12 major ports are working on hydrogen export hub plans. An identified risk here is the fast-changing outlook regarding ship propulsion technologies and fuel selection. For example, 7 years ago, the industry was mainly focussed on LNG as the main vessel fuel where a shift is now made to Ammonia and Methanol.

Port industry

One of the challenges for the port industry in India is the lack of vacant area around the existing ports for the development of green industries. Most investments are coming from private parties they need to navigate an evolving situation where new investments with increasing CapEx are needed - while the concession agreements stay unchanged. This puts pressure on the profitability.

Status of GREEN infrastructure development in India

Implemented	Under development	No initiative
Hybrid Equipment	Full Electric Equipment	Decarbonised Bunker Fuel
Shore Power	Shore Power	
Solar Power	Solar Power	

Source: interviews

DEEPDIVE CASE – INDIA CONCLUSION

Infrastructure costs

India is making strides in port adaptation and mitigation measures but still has a long way to go. Most ports in India don't have plans yet to upgrade port infrastructure in relation to adaptation. **Major investments in breakwaters, higher quays and improved drainage are expected in the future with investment costs ranging in the hundreds of billions due to the large number and size of Indian ports**.

Today, the ports mainly focus on storm warning systems and decarbonisation of the port equipment. **Many ports are in the process of replacing the diesel driven equipment with electrical or hybrid equipment.** Replacing port equipment requires up to hundreds of millions of dollars depending on the size of the port. Investments in the production and supply of renewable fuels are not maturing yet although plans are being made by private parties. **The Indian port sector is in favour of a viability gap funding, especially related to the green bunker fuels. The market for these fuels is not matured enough to provide a viable business case for the investments at the moment so support is required to achieve a first mover advantage, but a business case will probably become prevalent in the near future giving evolving regulation and technologies.**

Port Resilience

Ports in India are mostly threatened storm disruptions. Heavy rainfall due to storms affect regions outside the traditional monsoon areas. These ports are often not accustomed to the risk of rain flooding. Issues arise mostly outside the ports on the access routes and hinterland networks.

To deal with the storms from an operational perspective early warning systems are being developed. These systems are used to time the moment when port operations need to be temporarily ceased.

Heat threats are mitigated by heat action plans in combination with sufficient cooling and shelter.

Port Decarbonisation

India keeps track on the developments in Europe to minimize the risk of investing in technologies that won't make it to full maturity. The Indian port industry is already investing in decarbonised port equipment and the installation of shore power.

Multiple decarbonisation options for port equipment are investigated and adopted. Electrically powered equipment is already in use and hydrogen powered equipment is an option for the future.

Ports in India are struggling mostly with available land for the development of renewable infrastructure and the inflexibility of old school concession contracts when it comes to the new climate change investment needs. The ports do face disruptions from increased extreme weather events but for the moment these remain mostly operational. When it comes to mitigation, private parties are driving the initiatives and they are trying to develop the ports into the decarbonised bunkering hubs of the future. The focus here is on hydrogen although a lot of uncertainty on the most prominent fuel type hinders fast development. India is in a prime position to leverage its large renewable energy generation capacity and key position on strategic shipping routes in a future green bunkering economy.

DEEPDIVE CASE – SOLOMON ISLANDS PORT SYSTEM

General overview

The Solomon Islands are located in the pacific ocean and is geographically dispersed nation consisting of 9 provinces across 6 major islands and over 900 smaller islands, a third of which are inhabited. The World Bank shows a GDP per capita of $2,084, this places the Solomon Islands in the weaker economic segment of the investigated peer group.

The ports of the Solomon Islands play a significant contribution to the economy of the country, 95% of the GDP is depending on port operations. About 85% of the island's population live in rural and often remote villages, relying heavily on multimodal transport for access to essential goods, services, and livelihood opportunities

With respect to vulnerability[23] the country is ranked 148 out of 185 countries. The Solomon Islands are classified as high vulnerability and high readiness. According to the index the vulnerability is decreasing overtime. The readiness score increased from 2012 to 2020.

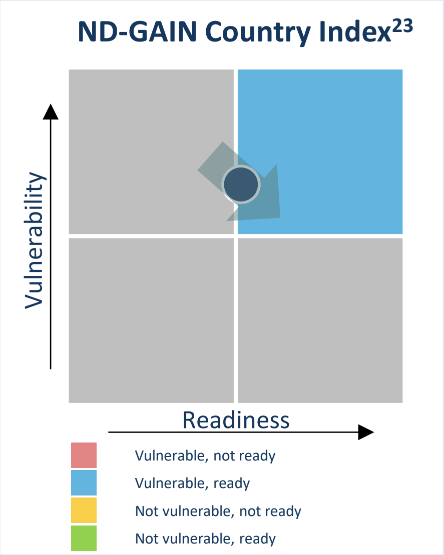
The Solomon Islands are most vulnerable on human habitat and infrastructure. Flood hazard, change in warm periods and projected change of sea level rise are the most critical vulnerability categories with Projected change of sea level rise impacts being amongst the worst infrastructure indicators in the index.

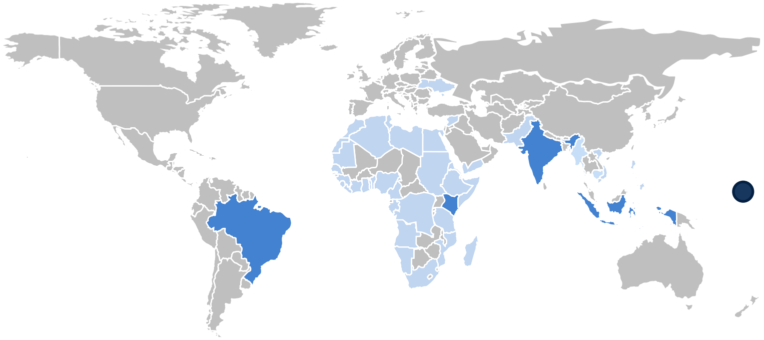
On a readiness level categories to improve are the economic readiness and the ICT infrastructure.

Macro Economic[22] Indicators Solomon Islands 2022

Inhabitants	0.724M ▲0.016M
GDP per capita in USD	$2084 ▲65
Surface area in km²	28.9k
Coastline in km	5310
Railline in km	0
GDP contribution agriculture	33%
GDP contribution services	47%
GDP contribution industry	18%
GDP contribution manufacturing	8%

ND-GAIN Country Index[23]





1) Vulnerability according to Explore ND-GAIN Country Index: https://gain-new.crc.nd.edu/
2) Source: World Bank
3) IMO

DEEPDIVE CASE – SOLOMON ISLANDS TRADE ROLE

Trade characteristics

Solomon Islands had a total export of US$569m and total imports of US$601m making them a net importer. The electricity of the Islands is produced using fossil fuel powered energy stations hence the mineral products being the largest category of imported goods.

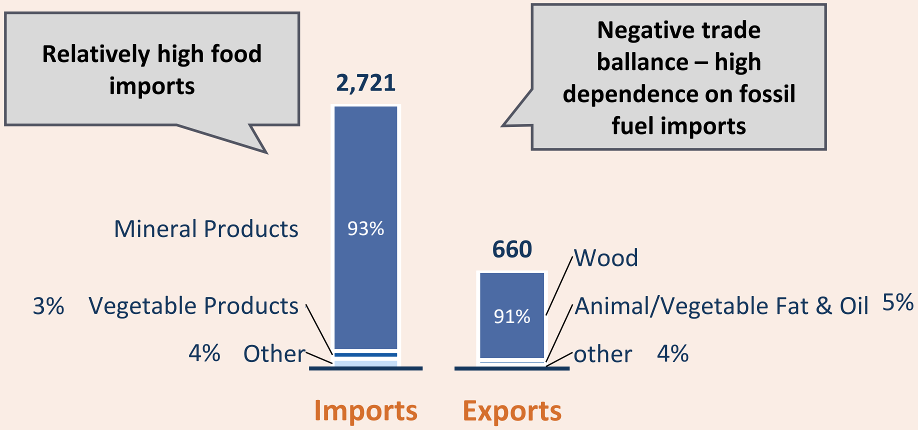
Imports[24]			Exports[24]
Singapore	90%	China	77%
China	2%	India	7%
Australia	2%	Philippines	2%
Malaysia	1%	Switzerland	2%
Vietnam	1%	Other Asia	2%

The second largest category of imported goods are vegetable products and third largest is foodstuffs which is a reflection of most of the food consumed on the islands being imported.

The Solomon Islands have two international ports, being port Honiara and port Noro, which act as hub to supply the many small ports in the country. Port Honiara and port Noro are managed by the Solomon Port Authority which is a state owned company working under a landlord and operator model whilst the Solomon Islands Maritime Authority (SIMA) oversees safety regulation, vessel inspection, and search & rescue coordination.

95% of the exported goods from the Solomon Islands are shipped via the two international ports. The Ministry of Infrastructure and Development is responsible for constructing, rehabilitating, and maintaining publicly owned assets.

Trade volumes 2018 (million tons)[24]



Relatively high food imports

Negative trade ballance – high dependence on fossil fuel imports

DEEPDIVE CASE – SOLOMON ISLANDS ENERGY LANDSCAPE IN PORTS

According to the statistics, 44% of the total energy supply is in the Solomon islands made up out of renewables. However, only 7% of the country's electricity is produced using renewables as source of energy. 80% of the renewable energy in the country is originating from solar power followed by bio-energy and hydro power. As of 2020, close to 45 percent of electricity at SIPA's ports came from renewable sources

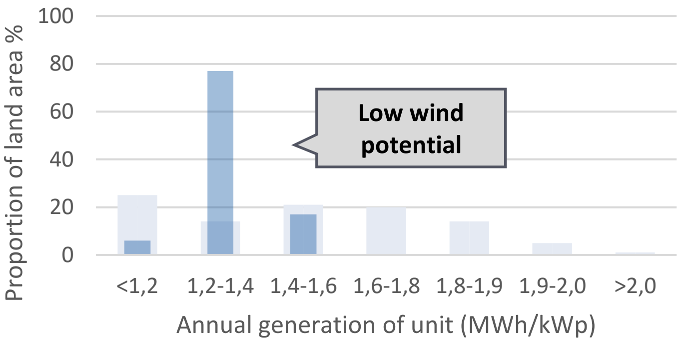
The levelized cost of energy for the Solomon Islands is 0.12 which is the same as the LCOE of Brazil.

The Solomon islands are located in a region where more than 95% of the area has a wind power density of less than 260W/m^2 which is the lowest classification. As a consequence, there is not a big potential for wind generated electricity.

With respect to solar the country's average potential is 4,402 kWh/m^2 which ranks the country as the 152nd placed country regarding solar energy potential. The country has a lower score than the other cases considered in this study but does has the advantage of a small seasonality impact making it a year-round generator.

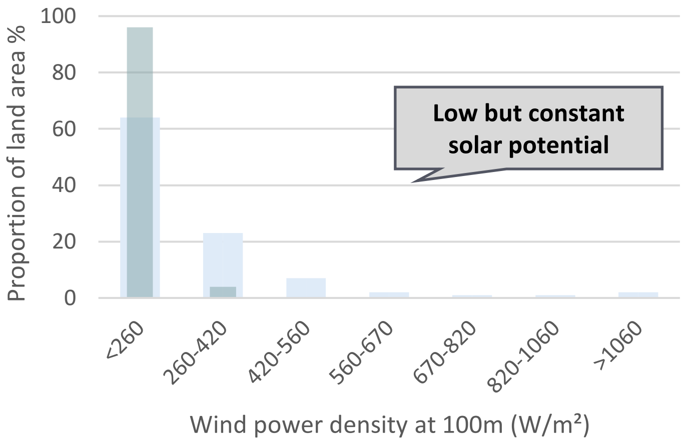
With support of the World Bank Solomon Islands Port Authority has also undertaken the Green Ports initiative in order to support rural communities, by providing decarbonised power to those who could not previously access any form of energy.

Distribution of solar potential[30]



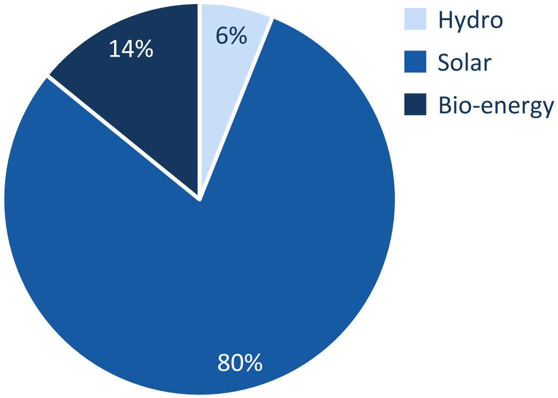
Low wind potential

Distribution of wind potential[30]



Low but constant solar potential

Renewable energy capacity in Solomon Islands[30]



Share of renewables in final energy consumption[30]	Share of renewables in electricity generation[30]
44%	7%
LCOE[26]	Solar theoretical potential[26]
0.12	4,402 kWh/m^2

DEEPDIVE CASE – SOLOMON ISLANDS MAIN ISSUES

Main climate threats and the effects they have on the ports in the Solomon Islands

The Solomon Islands experience the influence of several climate threats being, sea level rise, increase of storms/cyclones and even earthquakes. The storms are accompanied with high wind speeds, waves and rain. In addition, earthquakes in the region-caused by climate induced land submergence, can cause tsunamis.

Coastal flooding

A main threat to the islands and the ports in particular is the rise of sea level. Some of the jetties in the country are not useable anymore and need to be elevated or replaced. **Over time given the position and altitude of the islands, the archipelago is at risk of disappearing completely.**

Rain flooding

The ports themselves do not suffer from rain floods. However, during storms the flooding of the hinterland connections is an issue due to lack of sufficient drainage. A change in the weather patterns is noticed intensifying the problem.

Storms

The change in climate is noticed in the increase in the number and intensity of the storms that pass the Solomon Islands. These storms are accompanied by the already discussed heavy rainfall. They are also accompanied by strong winds which affect lifting operations and thus the loading/unloading operations of vessels. The yearly occurrence of storms is quite unpredictable, historically the Solomon Islands experience a storm on average 2 times a year.

Earthquakes & tsunamis

An underreported effect of climate change is the increase in earthquakes and tsunamis. Due to the rise in sea level and the increased pressure on the seabed the number of earthquakes in increasing. The Solomon Islands experience more and heavier earthquakes, the last one was 1,5 years ago with a magnitude of 7.1. Earthquakes, when occurring offshore can cause tsunamis which can be the cause of serious damage and loss of life as showcased by the tsunami in 2013 where 5 Solomon Islands citizens lost their life.

Overview of impacted infrastructure

	Sea level rise and floods	Inland floods (rain)	Storms	Drought	Heat	Earthquakes and tusnamis
Seaports	▨		▨		▨	▨
Rail						
Road		▨	▨		▨	▨
River						

Source: interviews

DEEPDIVE CASE – SOLOMON ISLANDS RESILIENCE NEED

The mitigating measures against the main climate threats

The Solomon Islands are focused on port resilience to fight the rise of sea level, rain flooding, storms, earthquakes and tsunamis. The small local ports are facing the biggest challenges.

Raising quays

To mitigate the rise in sea level the deck level of the current jetties need to be raised by at least 1 meter. Raising the deck level of a jetty that is operational is extremely challenging, in practice new jetties are build and after becoming operational the old jetties are demolished. **Depending on the port the location of the old jetty will be used to build another, new and higher jetty increasing the capacity of the port as well as the resilience.**

Status of RESILIENT infrastructure development in Solomon Islands

Implemented	Under development	No initiative
Raising quay	Raising quay Earthquake resistant infrastructure	Drainage installation

Source: interviews

Drainage

Additional drainage for the transport routes connecting the port to its hinterland is needed. The ports are in contact with both the disaster management centre and the ministry of infrastructure to install better water management systems.

Seawalls

The seabed close to the islands has a steep slope and a result the water depths near the islands increase rapidly to depths over 100m. **Due to these water depths seawalls and breakwaters are not a realistic option from both the construction and financial perspective.** Fortunately, the ports on the Solomon Islands tend to be naturally sheltered.

Earthquake protection

The Solomon Islands do invest in building infrastructure that is more resistant to earthquakes. Due to the costs, they are not able to build infrastructure that can resist high magnitude earthquakes.

DEEPDIVE CASE – SOLOMON ISLANDS DECARBONISATION NEED

Impact of the energy transition on the ports on the Solomon Islands

The Solomon islands still for a large part powered by fossil fuels. The costs of electricity is rising due to the increase in oil price. **The port is on a path of gradual transformation to renewable energy with a focus on solar power, wind power is too capital intensive**. A 20% cost reduction on energy cost is achieved by the port authority by installing solar power infrastructure. Offshore solar power is an option, but risks are involved in the form of storms and cyclones. Smaller buildings, perimeter lights and boom gates are 100% powered by renewable energy at the time of writing. The power for the perimeter lights is saved in batteries to provide electricity during the night. The Solomon Islands made a lot of progress by taking part in the GreenVoyage2050 project financed by Norway and executed by SIMA. Under this project data on fuel consumption, training for crew on energy efficient ship operations and port efficiency have been identified.

Port operations

Transitioning from diesel driven port equipment to electric equipment is investigated but will not lead to a decarbonised operations as almost all electricity on the Solomon Islands is generated using fossil fuel powered power stations. The same applies for the installation of shore power. The country is working on hydro powered power station, it will take at least 5 to 6 years before affordable green energy will be available at a scale sufficient to install shore power. Once available the shore power will not be provided to all ships. The power consumption of for instance cruise ships, which consume 10 to 15MW of power demands to much energy from the anticipated infrastructure. Container vessels consuming 1 to 3 MW of power would be able to make use of shore power.

Bunker supply

The ports in the Solomon Islands are not ready to provide green fuels. **The costs of the needed infrastructure are too high to make it a solid business case.**

Port industry

Decarbonising of the port industry will follow the pace of the country transitioning from fossil fuel powered electricity plants. Steps can be made by installing solar power on the buildings in the port, however this will not be sufficient to provide decarbonised energy 24 hours a day 7 days a week.

Status of GREEN infrastructure development in Solomon Islands

Implemented	Under development	No initiative
Hybrid Equipment	Full Electric Equipment	Decarbonised Bunker Fuel
Solar Power	Solar Power	Shore Power

Source: interviews

DEEPDIVE CASE – SOLOMON ISLANDS CONCLUSION

Investment Costs

The current investments in the Solomon Islands are mainly climate resilience related. Green energy related investments are considered if they can lead to cost reductions and the capital investments are within a reasonable budget of the port authority or government. Private investments are needed to finance the climate resilient assets and energy transition. **The government of the Solomon Islands has a limited budget and is not able to cover the financing demand with public funds.** The GreenVoyage2050 project helped the Solomon Islands to develop its National Action Plan and was financed by Norway. The most capital-intensive investments are infrastructure related and in particular the replacement of existing jetties with climate resilient jetties.

Green bunker fuel production and supply is not included in the current planning as there is no business case making it impossible to fund such investments.

The effects of climate change are already affecting the society on the Solomon Islands, the main issues are jetties in local ports being inaccessible due to flooding. As a consequence, **the supply of food and other first necessities is under pressure.** To mitigate these risk **harbour infrastructure needs to be replaced**, investments that can run op to billions of USD. The country does not have the public means to finance this investment gap on its own therefore private investments and investments from NGOs are needed.

Port Resilience

There is a strong need for port resilience measures in the Solomon Islands from an economic and social perspective. The country faces issues due to sea level rise, storms, heavy rain and earthquakes. 95% of the economy depends on the port activities and most of the food supply is imported via the ports.

Points of action are the replacement of existing jetties with jetties that have a 1m higher deck level. The connection to the hinterland needs to be improved by installing better water management systems as the access routes may flood during heavy rainfall. New build constructions should be designed to have a level of earthquake resistance as they are becoming more common and more intense.

Port Decarbonisation

Funds for investments in the Solomon Islands are limited and therefore investments aimed at securing the continuity of port operations are prioritised. With regard to decarbonisation this means projects that require limited investments and result in a reduction of costs will be considered. Projects that do not have a financial benefit or that are not financed by external parties such as is the case with the GreenVoyage2050 project are not feasible at this moment.

Of all investigated cases, the urgency of climate adaption is the highest for the Solomon Islands. Surprisingly, this does not mean that port decarbonisation initiatives are discouraged. The ports are actually at a phase 3 charging the region, providing solar power to surrounding communities. Even though the Islands have a solid solar power potential, the total generation capacity will be too low to generate some form of export economy, limiting any future business case driven investments.

Discussion

DISCUSSION

Throughout the interviews a duality became apparent in climate change related infrastructure investments for developing nations. Namely that even though all ports are struggling with similar issues, they are all also vastly different in both their way of handling their climate change challenges and they way of being impacted. This section delves further into the commonalities and differences identified in literature and through the interviews.

Survival comes first

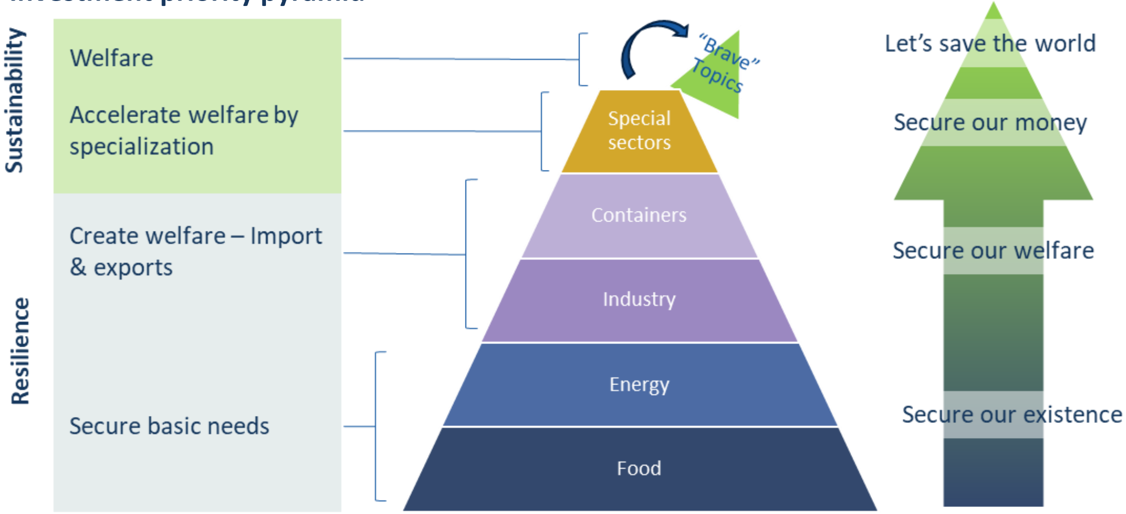
From the case interviews it became apparent that ports tend to prioritize resilience investments over decarbonisation investments, the higher the vulnerability and the smaller the port the more prominent this development. The small island ports in Indonesia and on the Solomon Islands are the most outspoken in this regard.

Ports are vital to the economy of the region they serve; the first goal of a society is to assure sufficient basic needs like food, energy and housing. Once basic needs are secured the focus can shift to earning money and climate adaptation plans. **When climate impacts threaten the existence of a society, adaptation actions are given priority**. The pyramid below shows a hierarchy of needs that need to be satisfied before investments at the level above are considered. Resilience investments ensure trade can be continued; they directly affect the availability of secure basic needs and the creation of welfare.

Decarbonisation investments can be considered as brave topics, the effects are noticed on the long term and not always at the geographical location where the investments are done. When lower level needs are being threatened "Brave" topics become less urgent and there is a tendency to sacrifice them for emergency topics.

That is what happens in the small island ports, secure basic needs are being threatened due to the lack of resilience and prioritized over decarbonisation investments.

Investment priority pyramid



DISCUSSION

Vulnerability and size go hand in hand

Small ports, both in size and management structure, are more vulnerable to shocks than large ports. This is both the case for climate shocks and investment capabilities required for mitigation. While the small island ports in Indonesia are flagged as ports that need to prioritize resilience over decarbonisation, the larger ports are often considered less "vulnerable". Major ports in Indonesia do have the size and leverage to introduce mitigation measures as well as decarbonisation investments.

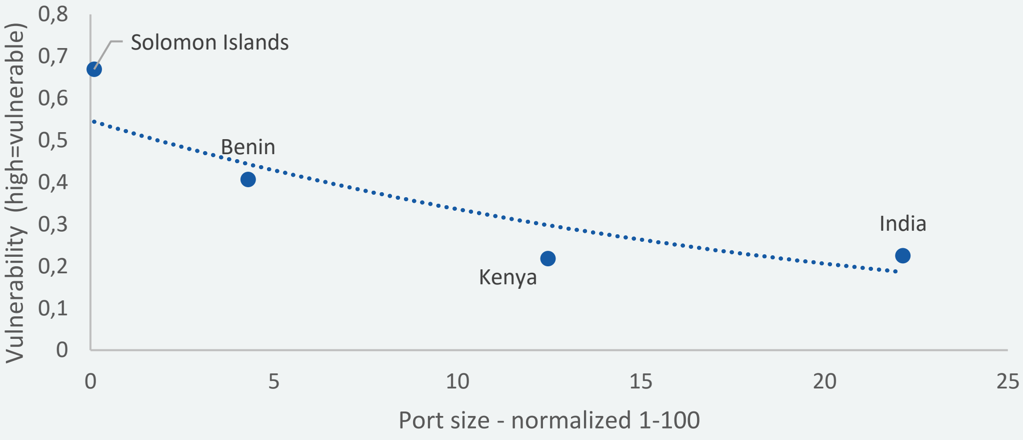
Even though the small ports are often extremely important for the survival of the local communities, they are the ones struggling most for their continued existence. Following reasons were identified:

- **Less budget availability from national government**
- **Less budget availability from income of port services**
- **Lower quality of existing infrastructure both for climate protection and trade**
- **Smaller port management organisation limiting the potential for knowledge on development**

Whether or not ports have the budget to do the necessary investments is not just related to the country in which the port is located but also to the size of the port. The geographical location dictates the climate risks, and the size of the port dictates the available budget to mitigate the climate risks.

The need for financing aid should therefore be determined based on the port size and inherent capabilities and not just on the country a port is located in.

Vulnerability vs port size



DISCUSSION

Chasing the business case

Throughout the cases we saw that often investments are not done due to – lack of budget, stringent regulation, lack of national strategy or lack of available space. The most prominent reason for waiting with fleet decarbonisation initiatives is the uncertainty in the market on final fuel selection and high price of the (current) technology required.

In some cases, terminal operators and governments are not waiting for these risks to be fully mitigated and are already investing, al be it often with a bankable business case solar for e.g. is already competitive with grey power in certain cases.

Over a timespan of 10 years solar power in combination with battery storage is cheaper than grey electricity. There are only a few locations in the world that can supply electricity at a lower costs than solar[35].

Installing solar on the rooftops of the buildings on the terminal only provides 10% of the energy demand of the terminal**. Power Purchase Agreements (PPA) with nearby solar farms and the legislation that allows for these partnership is needed to provide sufficient solar energy.**

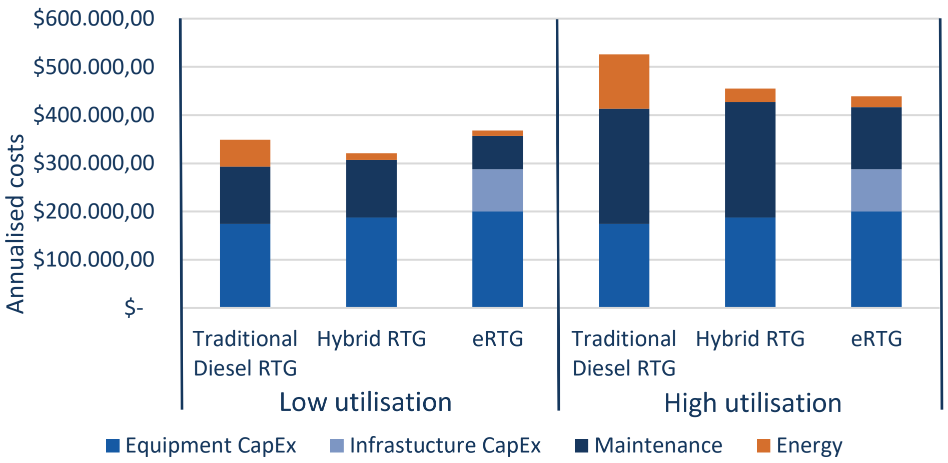
The costs of electrical equipment with a low utilisation is on par with traditional (diesel fuel powered) equipment. The costs of high utilised electric equipment is lower than for high utilised hybrid electric or high utilised traditional diesel equipment. When automated stacking solutions are desired, the equipment needs to be electric which is another incentive to invest in electric equipment.

The combination of full electric port equipment and PPAs can result in a fully decarbonised port terminal. Decarbonising a port in countries where PPAs are not allowed is a challenge, different stakeholders need to be aligned to get approval for practical solutions.

Improvement of air quality and the positive effects on the health of the local people in cities adjacent to the port and climate goals can support the case to approve renewable energy production facilities but will not be sufficient arguments on their own. Experience shows that financial incentives for the stakeholders involved are needed to convince the decision makers that ports need to be decarbonised.

Building a decarbonised greenfield port is less challenging than transforming an existing terminal into a decarbonised terminal. If infrastructure upgrades on the port authority side are needed to decarbonise an existing terminal new and complicated discussions arise who will finance these upgrades, which can even lead to the renegotiation of concession agreements.

Costs of diesel equipment vs hybrid and electric equipment[36]



DISCUSSION

Allocation of funds remains an issue

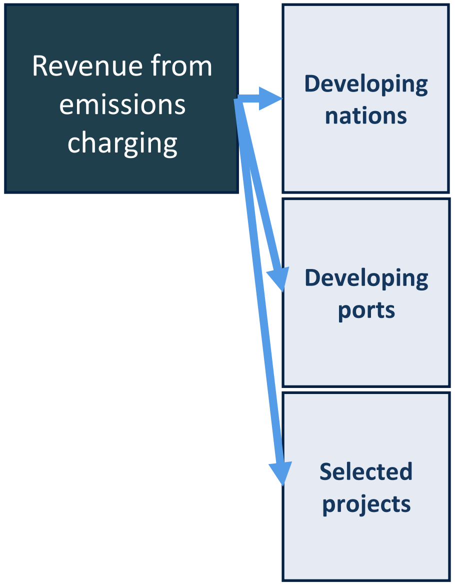
The core challenge regarding funding decisions is how to identify which investments require support and **how to assess not just the societal indirect and direct value but also which countries need help the most**. Large maritime economies (such as India and Indonesia in this study) often have a larger budget at their disposal. Even though this is often not distributed evenly amongst all ports with the larger ones getting a larger part of the cake. The core risk when looking at support mechanisms for developing nations is the misallocation of investment, i.e. putting public money in infrastructure projects that do not create sufficient value for users and society at large to justify the use of public funds. This risk is relevant as the value creation cannot always be accurately predicted.

We already touched upon certain examples, the actual use of port infrastructure is subject to uncertain factors such as the general development of the economy (large ships need other infrastructure), the need for a port is dependent on the local demographic evolution (climate migration is leading to derelict areas removing the need for local ports). **The effects of decarbonisation and resilience are also still in an early level of development themselves, both in concession pricing or investment business case development.** This leads to a risk of inefficient use of public funds.

Assuming that the GHG levies as described in the first chapter come into effect, allocation of the revenue from the charging mechanisms will be key. Parameters from literature and findings of the interviews indicate that at least :

(1) Vulnerability to climate change
(2) Dependency on maritime transport
(3) Cargo value and type (economic benefit of increased investments);
(4) Increase of transport costs due to charging scheme;
(5) Food security;
(6) adaptation vs. mitigation investment;
(7) Cost-effectiveness (adapt to rebuild); and
(8) Socio-economic impact and development should be considered.

Fund allocation levels



	Advantages	Disadvantages
Developing nations	- Low administration - Clear rules	- More powerful nations can skew selection process - Difficult split mechanism
Developing ports	- Medium administration - Similar funds in existence - Best knowledge of local situation	- More powerful nations can skew selection process - Vulnerable vs developing allocation risks
Selected projects	- Allows for both private and public funding	- High administration - Quality dependent on project sponsor

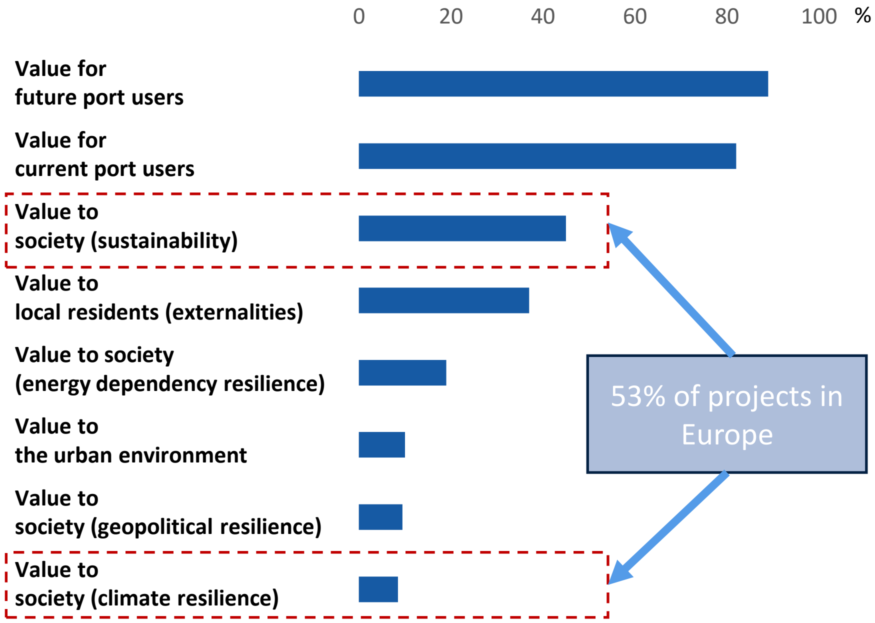
DISCUSSION

Wait and see for alternative fuels

As we have outlined in section one, traditionally port investments only make sense if they create "value." This value is traditionally economic or societal value. The value created by the investments is attributed to either port users (shipping lines, terminal operating companies, and other service providers), society (local or regional economy) at large, or both**. Port users are to some extent the ones that "pay" for the investment indirectly. The charges for shipping lines and tenants are mechanisms through which the port managing body captures the value they create for users.** This type of economic added value is, as explained in previous sections, less prevalent in developing nations, both through the pyramid of sustainability and the fact explained in chapter one that many ports in developing nations are not well connected to the network and generate low value to users. The societal value creation is based on externalities, i.e., effects of the investments that reach beyond the boundaries of traditional economic activity. They are harder to monetize and traditionally include direct and indirect economic benefits, increased efficiency of transport infrastructure, increased safety, and security. local and regional economic development and associated employment creation. Most notably for our discussion today one of these values is reduced emissions. This business case becomes quantifiable through policies such as carbon pricing.

Viable and financeable infrastructure investments are expected to produce a value to both society and the market relative to their costs, e.g. be a bankable business case. Not all viable investments generate however, the necessary financial return to make them attractive from a commercial (private) perspective. The overall uncertainty of future fuel to be used coupled with the limited private interest in the business cases in these regions created a "wait and see" approach with most interviewees. **Hard figures on the necessary investment were not provided, however in literature zero- and low-emission bunker fuel supply infrastructure investments account for nearly 90 percent of the estimated \$1.4 to \$1.9 trillion needed to fully decarbonise the shipping industry by 2050[37].**

Value creation of European port infrastructure investments[33]



Financing the green potential

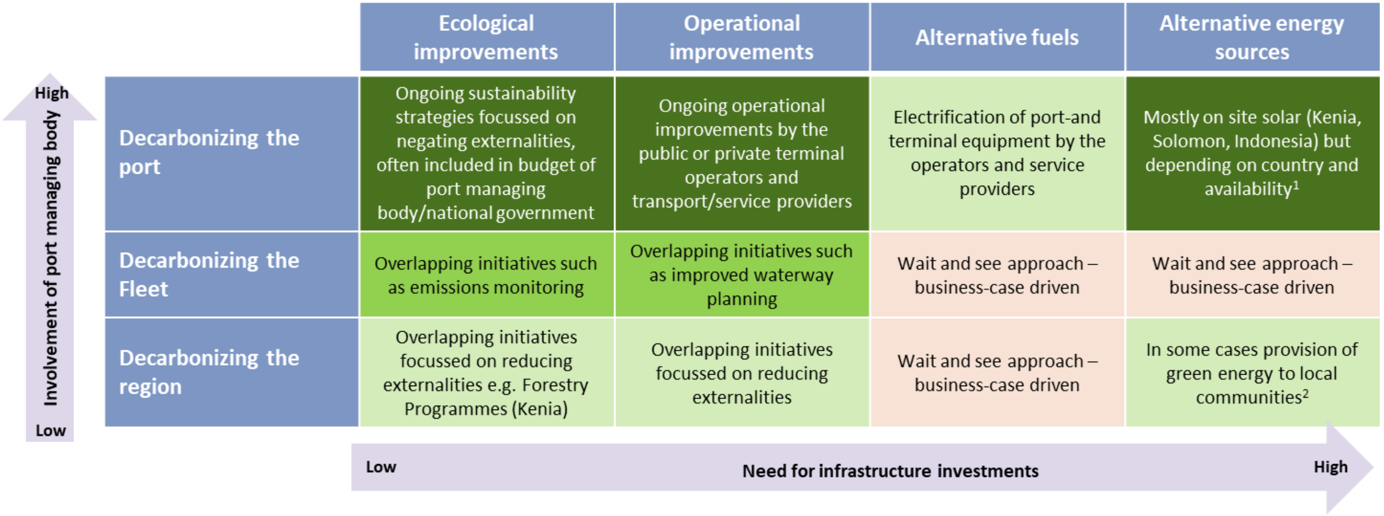
During the interviews, we focused on the potential benefits and costs of (1) decarbonizing the port and using the port to (2) decarbonize the region. Many of the ports interviewed were included in national sustainability plans and roadmaps or had plans of their own (e.g., India National, Kenya National-Ports, etc.). Following a simplified model as introduced in section one, we can map the current initiatives and gap with fully decarbonized ports on the figure below. The Y-axis shows that the involvement and decision power of port managing bodies decreases the more regional decarbonization investments become. The more regional the impact of the projects, the higher the investment and the more complex the stakeholder field. With alternative fuels, this stakeholder field can even extend beyond the national border where entire supply chains are structured as a joint venture or complex PPP arrangement with supply and offtake agreements.

As mentioned before, decarbonization-related investments are often more feasible than resilience-related investments. Ecological and operational improvements are often not infrastructure-related and more of a tactical nature, and investments in alternative energy sources are often business-case driven.

The largest gap is visible in the alternative fuel segment or in the fleet decarbonisation segment (both land and sea) where there is still too much uncertainty for ports in developing nations to invest in (un)certain technologies.

In this segment a large role for the international managing bodies and regulators is visible where more certainty- and therefore derisking of investments can be created.

Decarbonisation investments per type



	Ecological improvements	Operational improvements	Alternative fuels	Alternative energy sources
Decarbonizing the port	Ongoing sustainability strategies focussed on negating externalities, often included in budget of port managing body/national government	Ongoing operational improvements by the public or private terminal operators and transport/service providers	Electrification of port-and terminal equipment by the operators and service providers	Mostly on site solar (Kenia, Solomon, Indonesia) but depending on country and availability[1]
Decarbonizing the Fleet	Overlapping initiatives such as emissions monitoring	Overlapping initiatives such as improved waterway planning	Wait and see approach – business-case driven	Wait and see approach – business-case driven
Decarbonizing the region	Overlapping initiatives focussed on reducing externalities e.g. Forestry Programmes (Kenia)	Overlapping initiatives focussed on reducing externalities	Wait and see approach – business-case driven	In some cases provision of green energy to local communities[2]

1: See case studies, most countries are focussed on solar due to the low costs and availability, Brazil is a notable exception using wind on the North Coast for Green Hydrogen initiatives https://www.czapp.com/analyst-insights/brazilian-ports-get-ready-for-energy-transition-with-green-hydrogen/ 2: https://www.supplychain-outlook.com/ports/solomon-islands-port-authority-sipa-green-port-pioneers

DISCUSSION

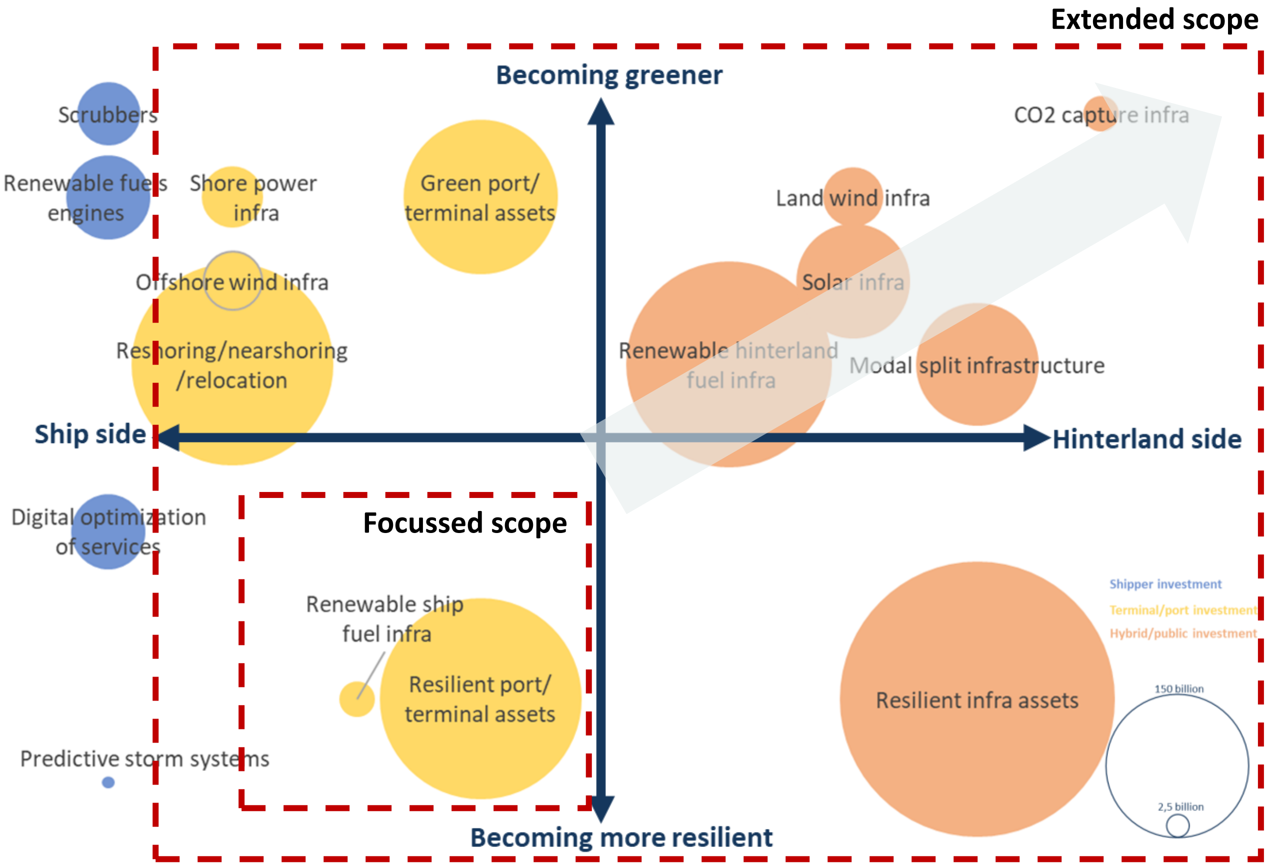
Where to draw the line

The case interviews outlined a large number of examples both on the climate issue side and the ongoing development project side. These projects and issues range from local flooding of terminals to flooding of entire coastal bound intermodal links (see case chapter).

Given the complexity of both the port industry and the effects of climate change, it will be of utmost importance to clearly define the allocation of potential funds. If the results from the prior assessment studies made by the IMO hold up and a potential revenue of about 100 billion USD will be generated , choices will have to be made when it comes to which projects are in scope of support and which are not.

Ports are strongly interconnected to their urban centres and hinterland networks. Often the failure of one network can be the end of the port.

Scope of potential financial support mechanism



DISCUSSION

Pathways to resilience

Capital for infrastructure investment availability is becoming more scarce and protective measures are very costly. Hence, strategies to support the most vulnerable ports should also be regarded in respect to the effectiveness over the investment lifetime. Early understanding of the resilience cost may influence the strategic choices between protection, conversion, or replacement. For existing ports to cope with the increased weather intensity, be it flooding, storm surges, or other disruptions, infrastructure like additional breakwaters is needed and existing ones need to be adjusted or raised.

When coastal flooding is an issue, it is, from the perspective of contractors (engineers, dredging firms), often more cost-efficient to build a completely new facility and move the port equipment to the new terminal once the terminal is ready instead of upgrading an existing one. The sum of the impact of the downtime of a terminal on the supply chain and on the costs of the terminal operator for redevelopment often exceeds those of relocating a terminal to a new nearby location. As a consequence, projects to raise existing quays and terminals are rare to non-existent.

The feasibility of port resilience investments is not only dependent on the capex requirement of a specific project but also on the prospects of the hinterland. Several islands are threatened with becoming completely submerged due to sea-level rise such as the Maldives and Tuvalu. In the Maldives, the inside of atolls are being filled with sand to create new land that is protected by the outside of the atoll. Tuvalu is an example where the costs to elevate the soil level of the islands exceed the current value of the land, making it hard to justify such a project from a business case perspective.

Level 1: Protect

Hard: protection-based strategy, comprising, for example, breakwaters, sea walls and/or dikes
Soft: sediment renewal programs

Level 2: Adapt

Raising, draining, floating, elevating, diverting, dredging (access channels)

Level 3: Advance

Create new land through dredging and heightening of new barriers in sea, protecting old infrastructure

Level 4: Retreat

Relocate ports and or communities to new less vulnerable locations

Increasing impact (but not cost)

Case: six - "100 year storms" in a decade

Port infrastructure is built upon a 100-year return conditions assumption. This assumption is often not ready for the increasing speed and influence of climate change. The climate is changing rapidly, there are projects that were completed less than 10 years ago and already experienced multiple times weather conditions that should only occur once every 100 year.

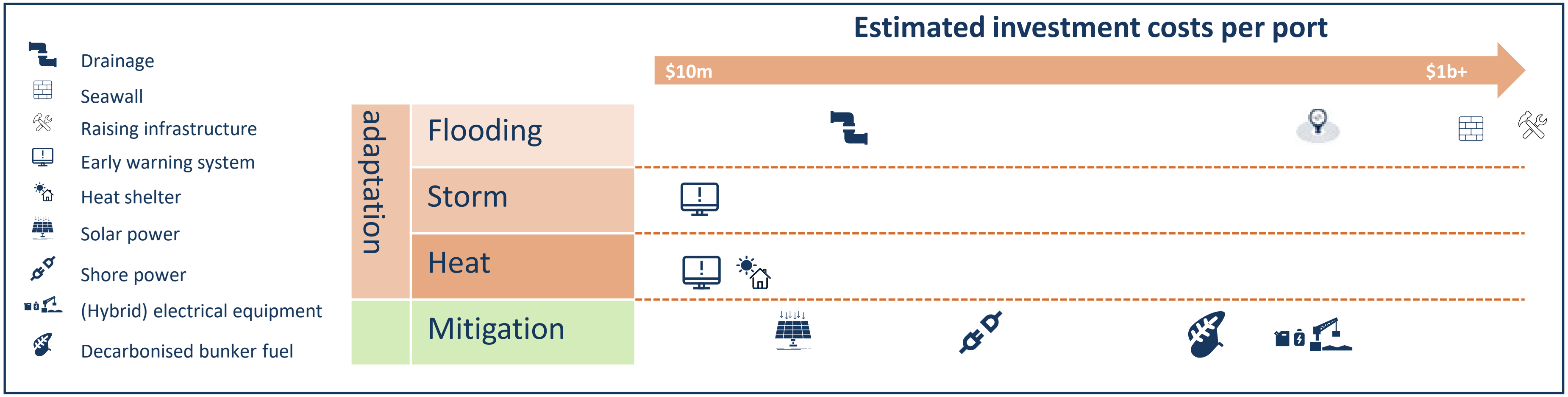
DISCUSSION

One size does not fit all (1/2)

The original intention of this study was to perform a full quantification of the investment needs across all developing nation ports by extrapolating the identified infrastructure developments. This proved to be a close to impossible task since **port infrastructure costs vary widely depending on port size, location, existing infrastructure, existing activities, prior adaptation and mitigation plans, etc.** The figure below shows a qualitative mapping of the different investments identified during the case interviews. None of the interviewees wanted to put a firm number on the price of the required investments. However, a couple of interesting things stand out:

1. The adaptation investments were estimated much higher than the renewable investments;
2. The option of “raising infrastructure” seems in many cases just not feasible;
3. The required investments were quite similar across all ports (size of investments varied widely).

Range of identified adaptation and mitigation investment costs for ports in interviews



DISCUSSION

One size does not fit all (2/2)

The figure to the right shows the challenge when trying to quantify required infrastructure investments across a multitude of ports. For each of the adaptive and mitigating investments for which there is data available, and which are above 1 million, we included estimated data points for small, medium, and large ports.

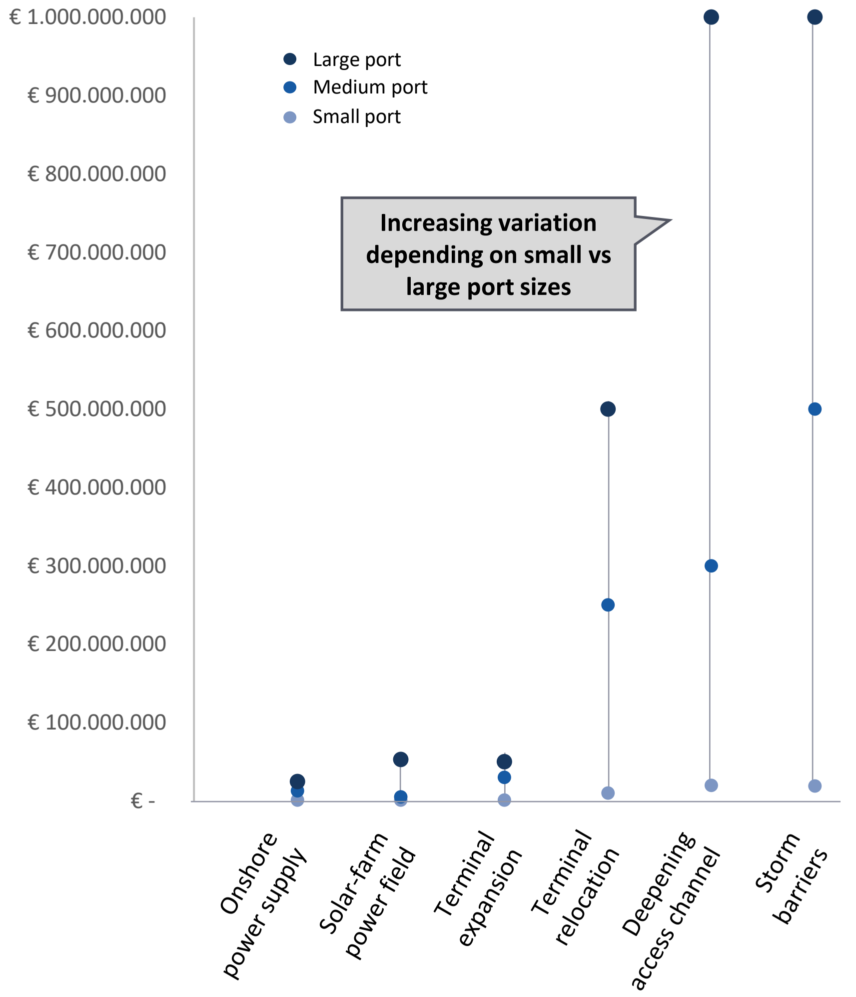
We have identified 51 developing nations which contain a total of 126 commercially oriented ports. They have been classified as small to large based on estimated throughput and the CIA world factbook. We have built a couple of very basic scenarios:

1. Protect at all cost, mitigate when necessary
2. Protect large and medium and relocate small, mitigate where possible
3. Protect large, adapt medium relocate small, mitigate all

The outcome of these scenarios estimates the total investment needs between 55 and 83 trillion USD in mitigating and adaptive port infrastructure in the 51 identified developing nations.

Please note that this is a very crude calculation and only intended to be used as indication of the size of the issue, it excludes many adjacent costs and only focuses on the identified costs in this study. A full quantification is only possible if a full bottom-up assessment of each of the ports would be made.

Range of adaptation and mitigation investment costs for ports



Increasing variation depending on small vs large port sizes

CONCLUSIONS

- **The importance and added value of ports is beyond any doubt.** However, where ports in developed nations are generators of welfare and industrial clusters, **ports in developing nations are literally lifelines of local communities.** In addition, they often have less access to funds and capital for further development both in traditional and climate related infrastructure.
- Due to the wide range of activities possible in a port area, **ports are both one of the causes of climate change but also at the forefront of all negative effects.** They are a direct result of trade imbalances and industrial clustering effects leading to often high concentrations of local emissions and a supporting function in both the decarbonisation and sustaining of the shipping industry.
- Port infrastructure is a complex matter with **many levels of infrastructure, often controlled and managed by different entities in the port**. This makes investment decisions in adaptation and mitigation infrastructure especially complex. Due to the high social importance of energy transition investments, we see public authorities getting more involved in decarbonisation related investments.
- **Port infrastructure is affected by slow-moving and fast-moving drivers, including demographic change, climate change, geopolitical change, and technological change.** Climate change is the exception among these drivers since it has both a slow and fast-moving set of effects hitting the port infrastructure.
- **Climate change affects ports at their core**, they are often located in areas of the world where the effects of climate change are more prominent, with heavier storm surges, direct effects of siltation or flooding, higher waves and winds, etc. **Traditionally, port infrastructure is designed to deal with these events for a foreseeable time window of 100 years, but we now see that more and more extra events are happening in a shorter timespan, putting pressure on the infrastructure**
- **Developing nations are often more vulnerable to the effects of climate change than their more developed counterparts.** This is a result of a smaller scale leading to fewer in-house capabilities for climate adaptation management, less developed infrastructure, lower funds for infrastructure (re) development, other priorities for investment, etc.
- **Tackling climate change in the maritime industry means tackling both adaptation and mitigation for ports (and ships).** Adaptation is focussed on keeping ports trading and making sure that they are protected against the onslaught of climate change disruptions. Mitigation entails trying to get the port to carbon neutral as soon as possible. Only through a combination of both actions can we both protect ourselves and stop climate change in its tracks.

CONCLUSIONS

- **The suggested carbon pricing mechanisms of the IMO both carry promise and risk for developing nations**. On the one hand they will increase transport costs putting even more pressure on countries which already have lower efficiency infrastructure and are less connected to the global trade network. On the other the revenue of this tool can be used to help the countries invest in adaptation and mitigation measures by providing a reserve to support the **just transition of these countries.**
- For shipping decarbonization to succeed and help prevent dangerous levels of global warming, t**he sector must reach consensus regarding the regulatory framework and GHG mitigation measures of the future as soon as possible**. Investment costs related to the energy transition for ports and shipowners are significant, **with no clear future standard the shipping industry runs the risk to invest in technology that will eventually not be (widely) adopted.**
- Port infrastructure financing is already challenging today, **most bankable projects require a combination of a positive socio-economic impact for the region and a bankable business case.** This business case will become even more challenging in the future given the changes in investment risk and pay back requirements, this is even more the case for **adaptive based measures like building storm barriers, where there is no underlying economic business case except the potential protection from future economic loss due to disruption of the activities.**
- The five investigated cases handled a wide variety of developing nations, from large port economies to small, both countries with many ports and few ports, some with a mix of small and large ports, etc. **The results showed that these ports mostly deal with similar issues when it comes to mitigation and adaptation investment needs. The types of required infrastructure may vary and but overall, the need and findings were relatively similar. Wat was vastly diverging was the actual estimation of costs and feasibility of the investments depending on the port size and country in question.**
- During the case interviews it became apparent that **ports tend to prioritise adaptation (resilience) investments over mitigation (decarbonisation) investments**, the higher the vulnerability and the smaller the port the more prominent this development. The small island ports in Indonesia and on the Solomon Islands are the most outspoken on this.
- **The costs of climate adaptation are a magnitude higher than those associated with mitigation**. Construction of storm barriers, relocation and adaptation of existing ports and soil related works are amongst the three largest groups. Mitigation efforts are also costly, but the in-port investments are rather limited compared to adaptation measures. For examples assuming similar prices to LNG terminals decarbonising the maritime fuel on port-based investments would run up to $100million per port for physical terminals or around $50million per port for barge solutions.
- **Most mitigation related measures in developing countries are planned at an ad hoc basis**, e.g. upon request of a terminal operator (sometimes with joint investments) or regulatory driven. This is partly due to the high uncertainty of fuel selection in the future and uncertainties on future supply and demand networks linked to renewables.

CONCLUSIONS

- Developing nations hold just a tenth of the world’s financial wealth and have only made a fifth of the clean energy investment committed by developed countries. **Economic growth emerges as the primary solution to bridge this gap,** enabling developing nations to offer incentives and subsidies for energy transition and infrastructure development.
- **Green energy from solar and wind will provide several developing nations a new opportunity to produce, use/and or export green energy** to high **energy demanding nations**. Green Hydrogen generated from renewable energy is earmarked as a base energy source to replace fossil fuel dependency.
- **Mitigation measures are often business case driven, appetite from the private market is higher for these types of investments than for adaptation measure**s. A carbon tax which goes further than the shipping sector and also targets the firms in the ports could therefore be a strong incentive for both public and private port entities to further green their operations. This will however result in higher transport costs over time
- **Smaller ports are more vulnerable than large ports**, underlying factors are (1) Less budget availability from national government, (2) Less budget availability from income of port services, (3) Lower quality of existing infrastructure both for climate protection and trade, (4) Smaller port management organization limiting the potential for knowledge on development. When a just transition in the maritime sector is the goal, they should therefore be first in line when it comes to support allocation.
- If infrastructure investments in developing nations will be supported through **revenue of shipping carbon tax mechanisms it is important that the allocation of the funds is as efficien**t, just and transparent as possible. This means that decisions need to be made on level of dissemination (country, port, project) and parameters of viable investments, with a minimum of vulnerability to climate change; dependency on maritime transport; cargo value and type (economic benefit of increased investments); increase of transport costs due to charging scheme; food security; adaptation vs. mitigation investment; cost-effectiveness (adapt to rebuild); and socio-economic impact and development should be considered.
- When coastal flooding is an issue, it is, from the perspective of contractors (engineers, dredging firms), **often more cost efficient to build a completely new facility and move the port equipment to the new terminal once the terminal is ready instead of upgrading an existing one**. The sum of the impact of the downtime of a terminal on the supply chain and on the costs of the terminal operator for redevelopment often exceed those of relocating a terminal to a new nearby location. This practice is comparable to the waterfront redevelopment we have seen in urban ports in the past century, **at a certain point infrastructure becomes obsolete given new external conditions.**
- Port decarbonisation infrastructure cost vary widely depending on port size, location, existing infrastructure, existing activities, prior adaptation and mitigation plans etc. Based on a very crude calculation we **estimate that the total investment needs for adaptation and mitigation port related investments in developing nations lies between 55 and 83 trillion USD**

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Annex

List of countries included in calculation:
Algeria, Angola, Bangladesh, Benin, Cabo Verde, Cambodia, Cameroon, Comoros, Congo, Rep., Côte d'Ivoire, Djibouti, Egypt, Eritrea, Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, Honduras, India, Kenya, Kiribati, Korea, Dem. People's Rep., Liberia, Madagascar, Mauritania, Micronesia, Morocco, Mozambique, Myanmar, Nicaragua, Nigeria, Pakistan, Papua New Guinea, Philippines, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sri Lanka, Sudan, Syria, Tanzania, Timor-Leste, Togo, Tunisia, Ukraine, Vanuatu, Vietnam, Yemen

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P72: Scenario distributions of investments in port size groups

Scenario 1	Small	Medium	Large
Onshore power supply	0%	0%	10%
Solarfarm power field	20%	20%	20%
Terminal expansion	20%	20%	10%
Terminal relocation	20%	10%	0%
Deepening access channel	5%	5%	5%
Storm barriers	100%	75%	50%

Scenario 2	Small	Medium	Large
Onshore power supply	50%	50%	50%
Solarfarm power field	50%	50%	50%
Terminal expansion	25%	20%	10%
Terminal relocation	50%	10%	0%
Deepening access channel	5%	10%	10%
Storm barriers	25%	75%	50%

Scenario 3	Small	Medium	Large
Onshore power supply	90%	90%	90%
Solarfarm power field	90%	90%	90%
Terminal expansion	25%	60%	10%
Terminal relocation	50%	10%	20%
Deepening access channel	5%	10%	10%
Storm barriers	25%	75%	75%

P72: Assumptions for high-low cost estimations for infrastructure investments

Onshore power supply	FuelEU Maritime proposals.
Solarfarm power field	https://www.marketwatch.com/guides/solar/solar-farm-cost/
Terminal expansion	Based on CAPEX database of MTBS, various online datapoints
Terminal relocation	Based on CAPEX database of MTBS, https://esfccompany.com/en/articles/infrastructure/how-much-does-it-cost-to-build-a-seaport/, various online datapoints
Deepening access channel	Based on CAPEX database of MTBS, various online datapoints
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Not included in calculation:

Green bunker terminal costs due to high uncertainty of future fuel supply, link to hinterland network cost, link to import export capacity cost.
Heat shelters, storm warning systems, drainage systems all estimated below $100.000,00.
Replacement of port equipment with hybrid/electric similar to fossil cost
Any investments outside the port area including supporting infrastructure investments.
Any costs for interruption of operations during construction works.