Study on Investment Requirements of Developing Countries for Port Decarbonisation and Adaptation to Climate Change

Report commissioned by the
International Association of Ports and Harbors (IAPH)

CONTENTS

GLOSSARY

CAPEX	Capital Expenditure on port infrastructure
Developing Country	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 Developed Countries (see annex for the full list of countries)
Externalities	The negative effects of pollutants are a social cost for port cities and coastal areas close to ports (due to noise, dust, smell, etc.)
GDP	Gross Domestic Product
GHG	Green House Gases carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3).
IMF	International Monetary Fund
IMO	International Maritime Organization (the United Nations' specialised agency responsible for the safety and security of shipping and the prevention of marine and air 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)
NOx and SOx	Sulphur oxides (SOx) and nitrogen oxides (NOx), byproduct of (shipping) fuel burning, categorised as air emissions
OPEX	Operational Expenditure on port infrastructure
OPS	Onshore power supply
Port Area	The area that is usually under the 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 the organisations that are active in a port, including but not limited to, logistics, shipping, blue economy, energy, ship building, industrial plants, cruise, etc.
PPA	Power Purchase Agreement
PPP	Private Public Partnership
Emissions pricing instrument	An instrument that captures the external costs of emissions such as carbon or other greenhouse gasses and emission by products (such as NOX or SOX) and ties them to their sources through a price
SIDS	Small Island Developing States – a group of countries that face unique social, economic, and environmental vulnerabilities
TEU	Twenty-foot Equivalent Unit

INTRODUCTION

Introduction

Developing countries face significant investment gaps in terms of the transition to energy-efficient and climate-resilient port infrastructure. This study, commissioned by the International Association of Ports and Harbors (IAPH), is intended as a comprehensive analysis of these investment gaps, focusing on infrastructure aimed at reducing emissions and bolstering resilience against the impacts of climate change.

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

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 countries, identifies key areas where investments are most needed, and suggests actionable recommendations aimed at bridging these investment gaps. By leveraging data-driven analysis and insights from industry experts, we aim to provide a clear roadmap for the 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 issue for ports in developing countries

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

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

Framing the Challenge

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The issue of climate change mitigation and adaptation of ports in developing countries

As maritime transport was 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]

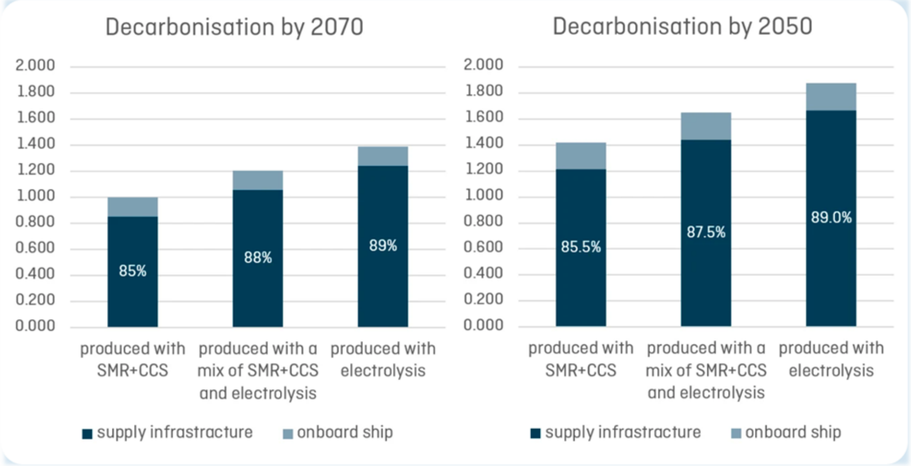
Over the past years we have seen large fluctuations in maritime transport costs. Events like geopolitical disruptions, container shortages, port congestion, the blockage of the Suez Canal and, most of all, the COVID outbreak, led to exceptionally high container freight rates. In addition, the requirements for investments in adaptation to climate change (resilience) and mitigation of climate change (sustainability) 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 their increased participation in the 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, such as being landlocked or located at a distance 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 evidenced 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 out GHG emissions related to shipping 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 estimated costs of the implementation of this decarbonisation strategy are estimated to amount $1-2 trillion.** It is assumed that developing countries bear 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 decarbonisation[1]



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

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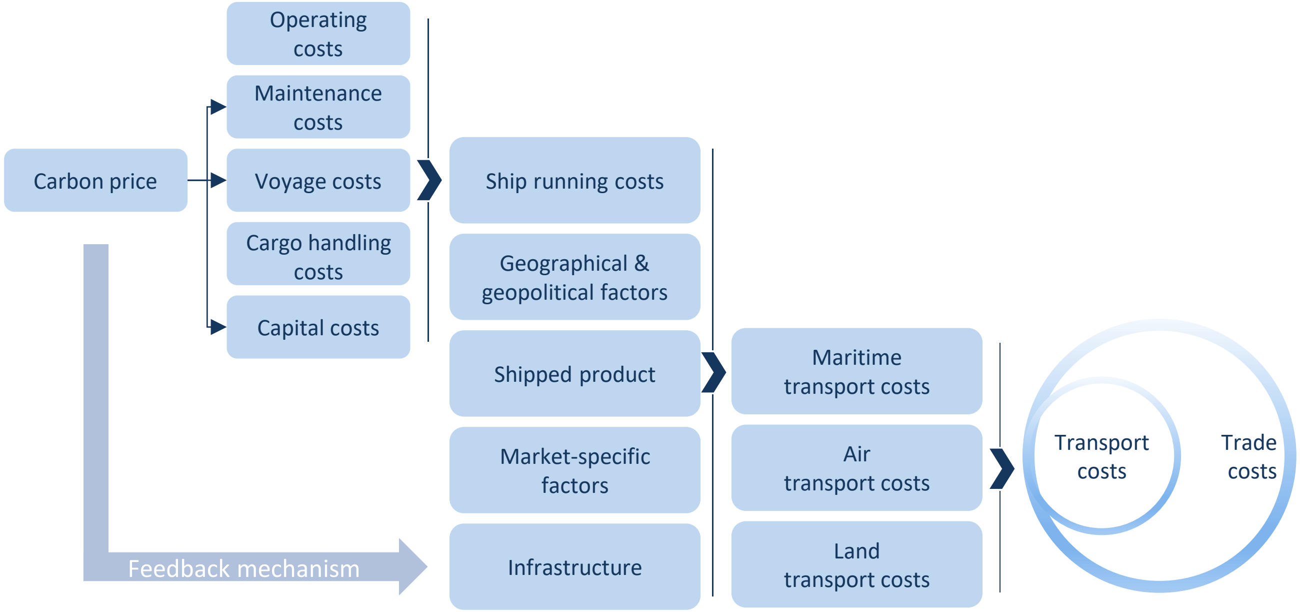
Between now and 2050, it is estimated that mitigation investments (e.g. green bunkering, renewables/electrification for terminal operations, fully decarbonised ports) and adaptation investments (heightening, dredging, storm walls, etc.) could run into the hundreds of billions to trillions of dollars. Both types of investments increase transport costs without necessarily increasing port revenue/quality of service. Without targeted actions and investments, **the more vulnerable developing countries could bear, as a consequence, the double shock of the impacts (disruptions) of climate change, and of the increasing shipping costs**.

As mentioned before, smaller economies generally incur higher maritime transport costs. These countries often require enhancements of their port facilities to provide improved shipping services, accommodate larger vessels and reduce waiting times before port entry (and they do already). Introducing a carbon pricing instrument requires a pricing mechanism that is directly related to the carbon or GHG emissions of the charged product or service. A carbon pricing instrument 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, projections show increases of up to 1% of the GDP of individual countries and an impact of less than 0.1% 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 extremely important that the financial resources generated by the pricing mechanism be reinvested to facilitate a just transition, supporting ports in developing countries to reach net zero (mitigation) and protect vulnerable communities against the onslaught of climate change (adaptation).

Impact of carbon pricing on trade costs[3]



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Ports and port infrastructure

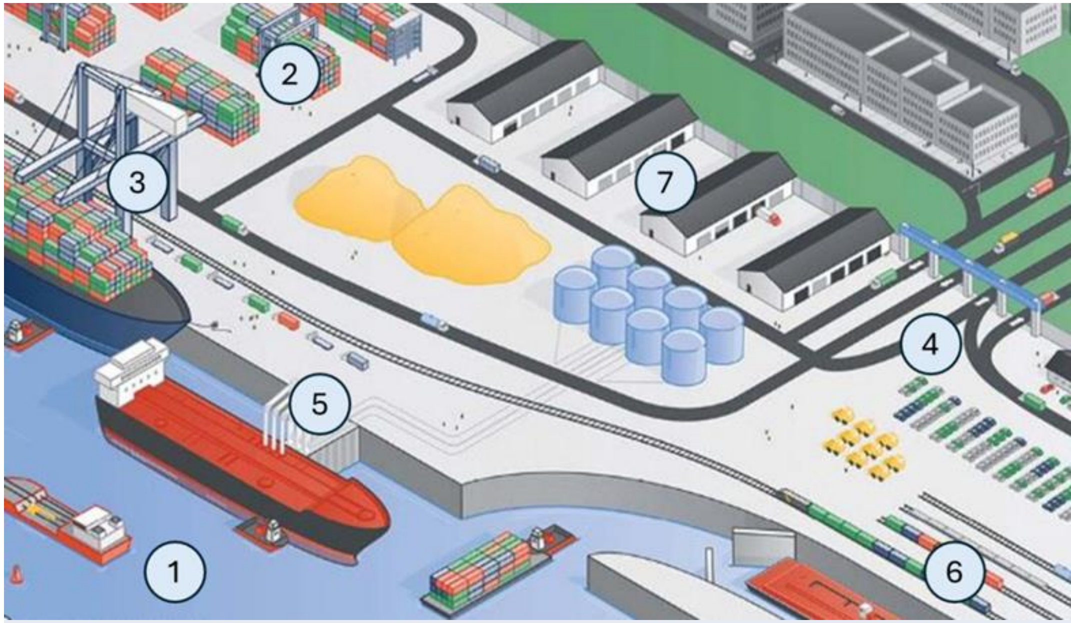
There is no uniform definition of a "port." According to different sources, a port setting may include different activities and infrastructure. Some common elements of all the definitions are intermodal interfaces, land adjacent to water, centres for industrial activities, logistics nodes, and many others.

Whereas ports in developed countries are often seen as mature, developed transport and industrial clusters, in developing countries they are often seen as literal lifelines for the survival of the local communities. This highly varied typology of ports across the world is also apparent in terms of the types of infrastructure seen in ports.

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

We should point out that **this study focuses on ports in developing countries.** Whereas, in developed countries, ports have evolved from their 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 countries often offer a more "basic" direct benefit to the economy and community. The upcoming decarbonised energy industry provides ports with the opportunity to become energy producers and maximise their contribution to the economy in developing countries.

Relevant types of port infrastructure



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

Poorly maintained access infrastructure slows down vessels and increases congestion, which in turn increases the carbon emissions of a port.

Impact of climate change

Changing currents and water levels can lead to the formation of silt deposits in channels or to submerged 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 infrastructure consists of berths/ quay walls, jetties and floating pontoon ramps in tidal areas, internal basins, backfills and land reclamation.

Impact on climate change

Poorly maintained infrastructure increases congestion, which in turn increases the carbon emissions of a port.

Impact of climate change

An increase in weather phenomena can lead to damage to the basic infrastructure.

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③ Superstructure

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

Impact on climate change

Older equipment generates CO2, poorly maintained equipment increases congestion, which in turn increases the carbon emissions of a port.

Impact of climate change

An increase in weather phenomena can lead to damage to the superstructure.

④ Port terminal and hinterland transport infrastructure

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

Impact on climate change

Poorly maintained equipment increases congestion, which in turn increases the carbon emissions of a port. Poor or lacking infrastructure impacts the modal split of a port.

Impact of climate change

An increase in weather phenomena can lead to damage to the transport network, the formation of silt deposits or low water levels in the channels.

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⑤ Energy related infrastructure

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

Impact on climate change

The 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 of climate change

An increase in weather phenomena can lead to the over- or underutilisation of renewable networks/energy grids or to the damage thereof.

⑥ ICT/digital infrastructure

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

Impact on climate change

Potential positive impact through the increase of trade facilitation

Impact of climate change

None

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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 of climate change

An increase in weather phenomena can lead to damage to the buildings and infrastructure.

Important remarks regarding port infrastructure

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

Port operations, but also new port development plans relating to both land and sea activities, may have negative impacts on the environment (direct emissions, 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 the optimisation of activities, or reducing other negative effects for local communities, such as noise or waste (recycling activities, natural walls).

In addition, these **categories of investments 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. As such, the effect and impact analysis of investments in mitigation and adaptation is very complex.

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Drivers behind port infrastructure

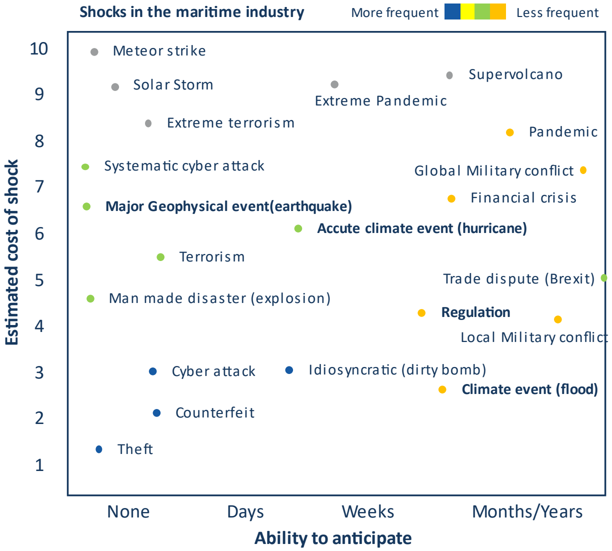
Seaports, as **crucial global trade hubs**, are subject to a variety of disruptions driven by multiple factors. Four key drivers that directly affect the demand, supply, state, and accessibility of port infrastructure are:

- **Demographic changes**
- **Climate change**
- **Geopolitical unrest**
- **Digitalisation**

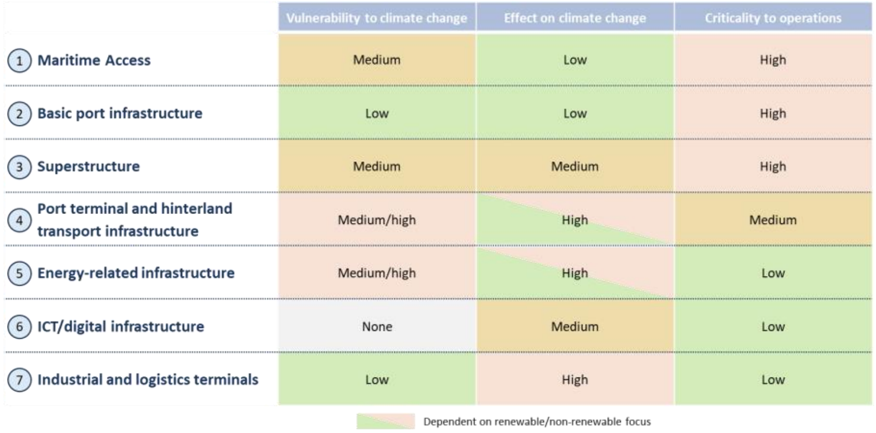
Some of these drivers are slow moving and can be predicted with sufficient accuracy, with demographics being at the forefront, while others evolve faster, such as geopolitical disruptions and technological changes.

Demographic changes – a slow-moving trend driver - leads directly to either the growth or decline of transport demand. They are, in essence, at the core of "investment needs". While the uncertainty regarding trade growth is continuous, with a trend of decreased globalisation[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 countries where both population and spending power are still growing[5]. Resulting infrastructure trends from demographic changes include increased depth for ports due to the increase in vessel scale, an increase in hub and spoke models placing stress on larger ports to perform optimally, an increase in passenger numbers, etc.

An overview of port disruptions[6]



Impact of disruptions on port 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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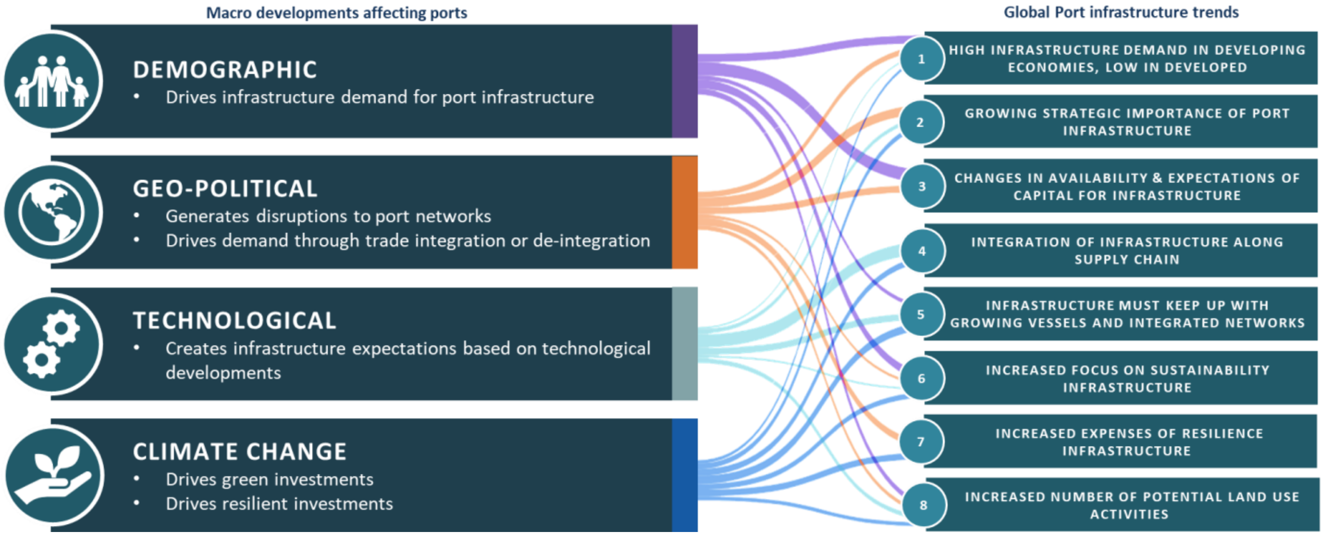
Geopolitics is the fastest moving driver by far, potentially affecting the maritime industry overnight. The recent Red Sea Attacks[7] are a prime example, diverging trade flows around the Cape. The effects of these disruptions on actual port infrastructure are rather limited; the problem suddenly arose due to their fast-moving nature, and once the conflict in the Middle East is resolved, they will disappear just as suddenly. However, 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 more important, which is a major trend currently developing in Europe, Asia, and the US. The additional effects of this unrest are a higher instability of the financial markets, leading to different expectations of capital, directly affecting debt and equity port infrastructure investments.

Digitalisation or technological developments impact infrastructure at its core. Whereas 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 focus of this study - stands out among the various disruption drivers 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 funding sources, such as public investment schemes and grants.

Trends impacting port infrastructure



Source: MTBS

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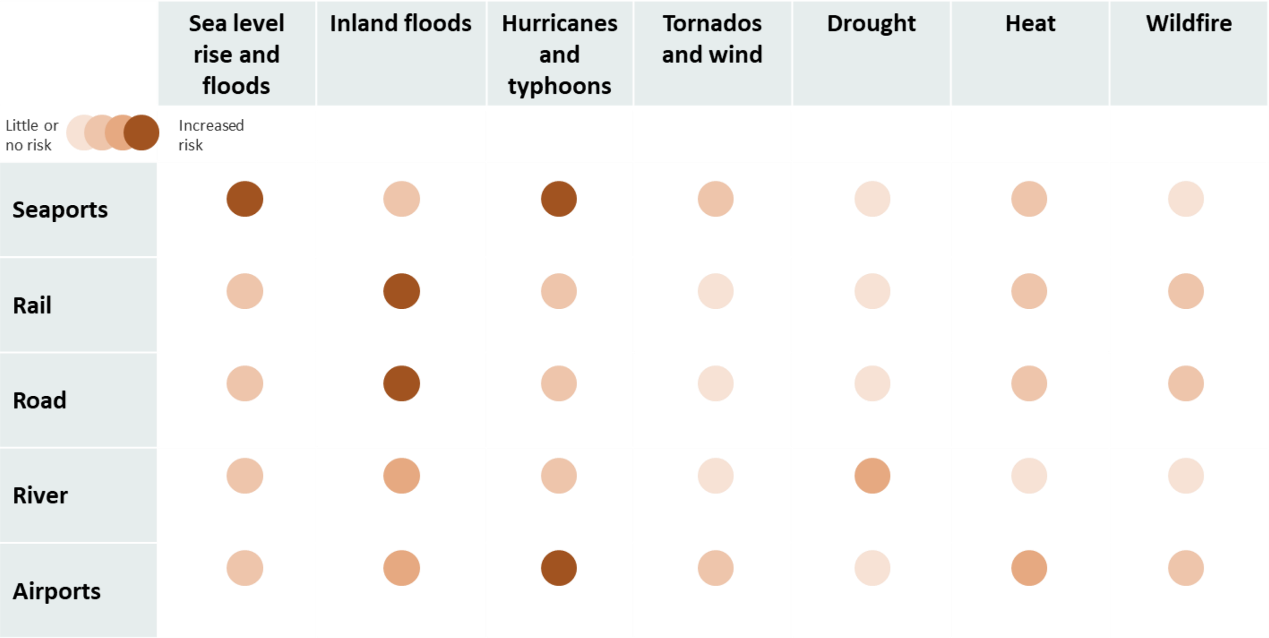
Fast-Moving Disruptions of Climate Change

Climate change is increasingly manifesting through fast-moving, large-scale local disruptions. Extreme weather phenomena, 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:

Disruptions across the maritime transport chain



- **Storm Surges and Flooding**: Ports are highly vulnerable to storm surges and flooding, due to their coastal location. These phenomena can lead to flooding of 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.

- **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**: they indirectly affect port operations, resulting in lower efficiency or the complete shut-down of the port, if certain thresholds are reached.

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

Slow-moving Effects of Climate Change

In contrast, climate change also has 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, the polar ice cap melts, which leads to the thermal expansion of seawater, which in turn results in higher sea levels. The implications for ports include:

- **Flooding and Submerged Areas:** Over time, rising sea levels can lead to the permanent flooding of low-lying port areas, which requires the relocation of facilities or the construction of protective barriers.
- **Increased Salinity:** Higher sea levels can result in salt water 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 access channels and berths. Due to this slow-moving effect, more frequent dredging and maintenance works are required, 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 demonstrated remarkable resilience 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

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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 its 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 shipping-related GHG emission is an urgent, but complex and challenging task. The energy use on vessels can be optimised in different ways. There are many options with regards to alternative propulsion power, each with its 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 of investing in technology that may not be (widely) adopted, eventually. This risk is inconvenient for large major ports and unbearable for smaller ports.

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

GHG reduction solutions[18]

Source: 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 goal 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 instrument 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 decarbonisation initiatives or infrastructure.

To facilitate the transfer to zero and near-zero fuels infrastructural challenges need to be overcome. The conversion of 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 adopted 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; these are mostly dredging and construction vessels.

Moreover, contractors notice that there is a need for sustainable fuel supply outside of Europe, based on their own bunkering needs and on the development 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 ambitious solutions.

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 renewable energy infrastructure, that is scalable, 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

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

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Both cause and effect

This duality of resilience and vulnerability is even more pronounced when we take into account that **in terms of climate change, ports provide both a cause and an effect.** Ports in developed countries 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 GHG and air emissions due to the sheer volume of global trade. Major ports handle thousands of vessels annually, each emitting CO2, sulphur 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 countries are often located in regions that are highly vulnerable to the effects of climate change (tropical storms, sea level rise, and coastal erosion). Often, they also have less developed infrastructure. These ports have historically benefited less from maritime trade and are only now starting to reap the benefits (or in some cases they do not reap any benefits at all).

Adaptation vs mitigation in port infrastructure

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

Case study – Low sulphur emissions: doing bad by doing good

According to a research study published in the journal *Nature*, a major reduction in emissions of sulphur dioxide in 2020, following the enforcement of new international shipping fuel regulations, led to a “termination shock” that could heat up the world's oceans by 0.16 degrees Celsius over seven years, greatly accelerating global warming.

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Why ports are needed

Ports located in developing countries have a significant impact on the economic activity and welfare of the country 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 country 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 countries depend on ports for:

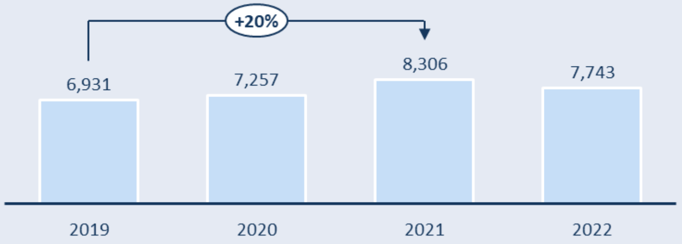
1. **Food Security:** a high dependence on imported food
2. **Disaster Readiness**: A resilient port-based supply chain enables the efficient distribution of emergency supplies
3. **Economic Balance**: resilient supply chain nodes to uphold business continuity and safeguard growth
4. **Tourism Support**: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

Case study – COVID impact

The correlation between ports and 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

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Seaports as drivers of decarbonisation

Traditionally, high-volume fossil fuel cargo has 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 industry, where alternative fuels play a crucial role. This shift presents both opportunities and challenges.

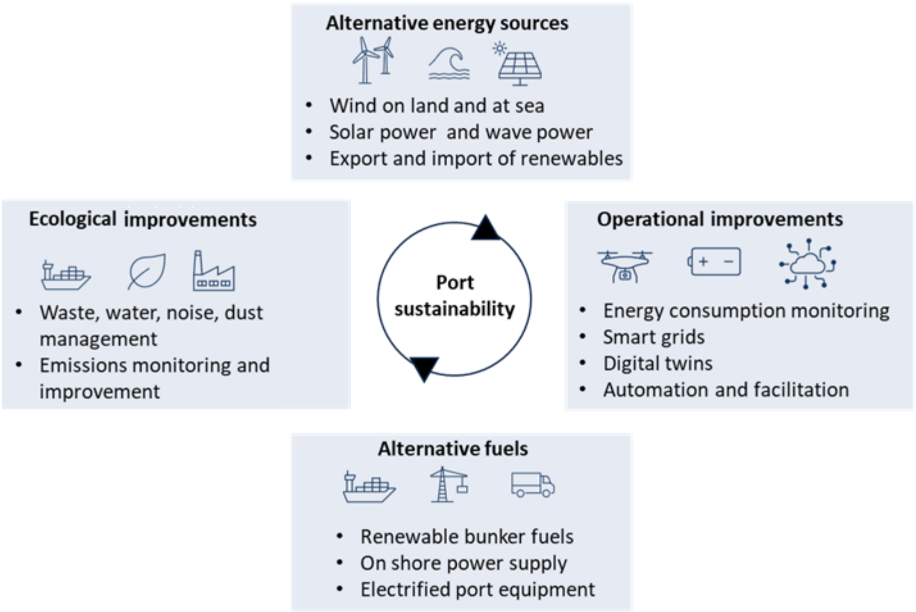
On one hand, **port authorities can capitalise on this transition by preparing their facilities for new cargo types.** This involves enhancing circular economy synergies, investing in new infrastructure such as offshore energy projects, and redeveloping existing port areas to accommodate the space requirements of these new types of cargo. On the other, the traditional revenue model based on high-volume fossil fuels is under threat. Additionally, the generation and bunkering of renewable energy will require 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 obvious, 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 study – APMT co-investment in solar for zero emission terminals

Achieving decarbonised operations for terminal operators in developing countries can be a challenge due to the low capacities of local networks, the lack of green energy feedstock, poor energy infrastructure, etc. The strategy of APM Terminals consists of only building new decarbonised terminals. It 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



The Energy Transition and Renewables - a new opportunity for developing

As hubs of 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 cargo, but to continue to fulfil their role as economic engines for the wider hinterland that is transitioning to renewable sources.

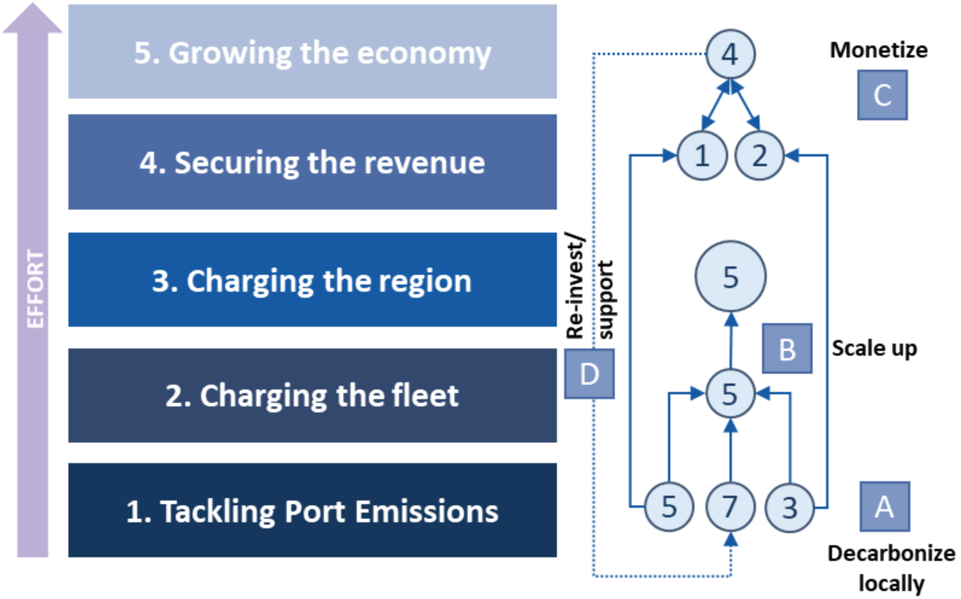
Leading ports, often in developed parts of the world, are already investing in offshore wind, marine, solar, and green hydrogen capabilities[1]. These investments cover both the local industry, energy infrastructure and supply fuel for the clean shipping fleets of tomorrow.

A. The first step in achieving a clean energy port is decarbonising the on-site "polluting" activities through expanding renewable power generation and on-site storage, in order to displace carbon-intensive grid electricity usage. Both the on-site industrial activities and resulting fleet movements (both sea and land) can be countered in such a way.

B. After its own operations have been decarbonised, the role of the port can be leveraged as an industrial and transport cluster, by installing shoreside charging infrastructure, offshore wind, solar power, green hydrogen electrolysis facilities, etc. The decarbonisation of the fleets is the first step, but these actions also strengthen the flexibility of regional electricity grids that are often affected by constraints. Ports with a strong grid connection can help balance local renewable energy supply and demand, both through on-site generation and by acting as hubs for fuel import and export.

C. Once on-site renewables are secured and supply chains start to take shape, ports can create significant new revenue streams for themselves and the wider region. This happens through the sale of electricity to users, lease fees charged to developers, and earnings from ancillary grid services. The export of decarbonised fuels will accelerate the global energy transition, through direct and indirect economic effects, as this supports local green jobs and industries.

A transition path towards a "decarbonised port"



FRAMING THE CHALLENGE

Developing countries hold just a tenth of the world's financial wealth and have only made a fifth of the clean energy investments 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 investments in developing countries, as the limited access to capital markets, high borrowing costs, and the real or perceived investment risks deter domestic and foreign investors[12]. This means that feasible solutions or solutions that are currently being implemented in developed countries, such as electric vehicles, carbon capture, utilisation and storage (CCUS), and hydrogen production or imports, may be financially inaccessible.

Economic growth emerges as the primary solution to bridge this gap, enabling developing countries to offer incentives and subsidies for energy transition and infrastructure development. However, access to cheap, affordable energy is crucial to achieving such economic growth, which puts developing countries 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 countries with a new opportunity to produce, use and/or export green energy to countries with high energy demands. 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, fertiliser and steel production. Locally generated renewable energy can be exported in the form of liquid hydrogen (LH), a chemical carrier such as ammonia (NH3), or other liquefied 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]. As a prerequisite for an effective export operation, the country should not be landlocked and it should have the ability to use or develop a seaport for this commodity.

Case study: economic contribution of the hydrogen sector[14]

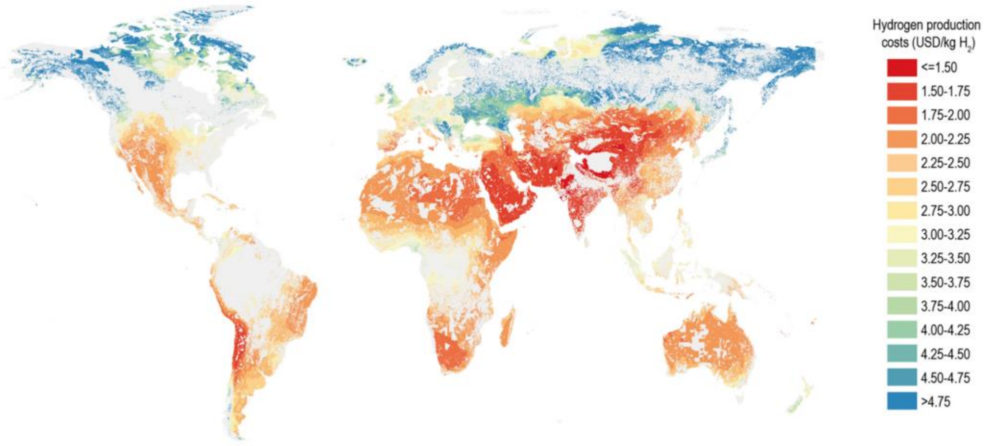
The UK government aims to develop up to 10 GW of low-carbon hydrogen production by 2030. Using multipliers and cost estimates in terms of employment and gross value added, this scenario suggests that the UK hydrogen sector could support approximately 30,000 direct jobs by 2030 and could contribute more 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, 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.

Kenya and India (see case studies on p.31 and p.54) 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 by 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]



The Middle East: Saudi Arabia, Yemen, Oman, Qatar, Bahrain, Jordan, Iraq, Syria, Kuwait, Iran, Pakistan
The Indian subcontinent: India, Sri Lanka
Southern Africa: Namibia, South Africa
Northern 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: Chile, 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

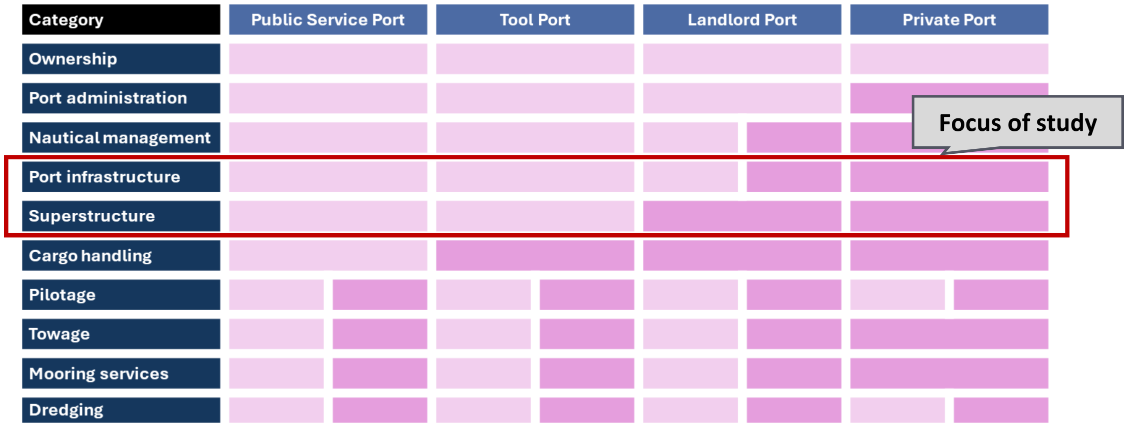
FRAMING THE CHALLENGE

Challenges in port financing

The trends summarised 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 pollute and do not necessarily create economic benefits for their own city.

Port ownership models[19]



Category	Public Service Port	Tool Port	Landlord Port	Private Port
Ownership	□	□	□	□
Port administration	□	□	□	■
Nautical management	□	□	□ ■	■
Port infrastructure	□	□	□ ■	■
Superstructure	□	□	■	■
Cargo handling	□	■	■	■
Pilotage	□ ■	□ ■	□ ■	□ ■
Towage	□ ■	□ ■	□ ■	■
Mooring services	□ ■	□ ■	□ ■	■
Dredging	□ ■	□ ■	□ ■	□ ■

The decisions regarding infrastructure investments are taken by different entities within each country and sometimes they diverge from one port to another, depending on the port ownership model (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, governments or utility providers. This trend is shifting where there is a clear divide between the centralised backbone energy infrastructure (e.g. a high-voltage power network, gas-related backbone, etc.) which is managed by the utility provider and governments, and the decentralised local energy infrastructure (e.g. a solar farm, onshore power supply, wind on land, etc.), where the investment decision is taken by 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

FRAMING THE CHALLENGE

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 made by equity funds. Whilst ports in developed countries usually have a relatively large investment capacity (depending on the size of the port in question), the nature of port investments makes it often impossible for the port authority to make the necessary investment without external financing. This is even more the case when we consider port infrastructure investments in developing countries.

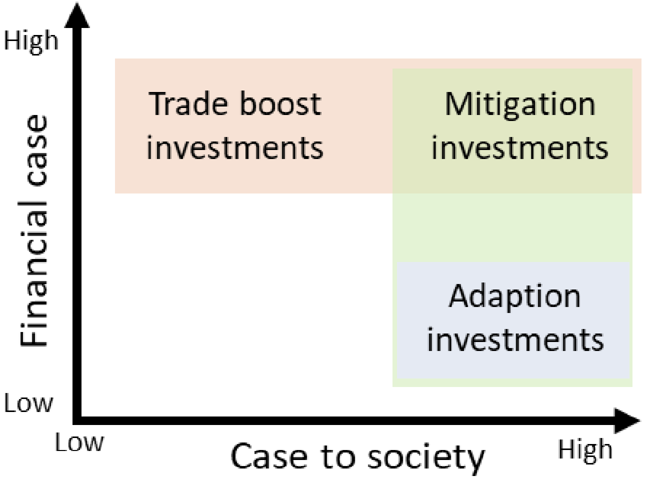
When it comes to mitigation and adaptation infrastructure investments, they often carry a high added value from a societal standpoint and wider economic returns beyond the port community, which cannot attract private financing because of a limited return on investment for the investing port authority.

Two approaches to green financing are commonly used. The first approach consists of finance products whose funds are only made available to green investments. The second approach consists of incorporating "Green KPIs" into a standard financing product. The question is whether this is enough to achieve decarbonisation by 2050.

New financing methods are being developed to facilitate decarbonisation. The International Maritime Organization (IMO) discussed green financing during the FIN-SMART round table discussions, where IMO's Head of Project Implementation, Gyogyi Gurban, described the role of the IMO in relation to the 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 decarbonisation. These round tables provide 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 investment requirements in sustainable and resilient seaports for vulnerable and developing countries. Given the diverse nature of countries and ports, the following metrics were used to identify the most optimal cases:

- A variety of national Port Governance structures
- 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 was gathered by **desk research** and **interviews**. The desk research phase is based on the analysis of the literature 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 need 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.

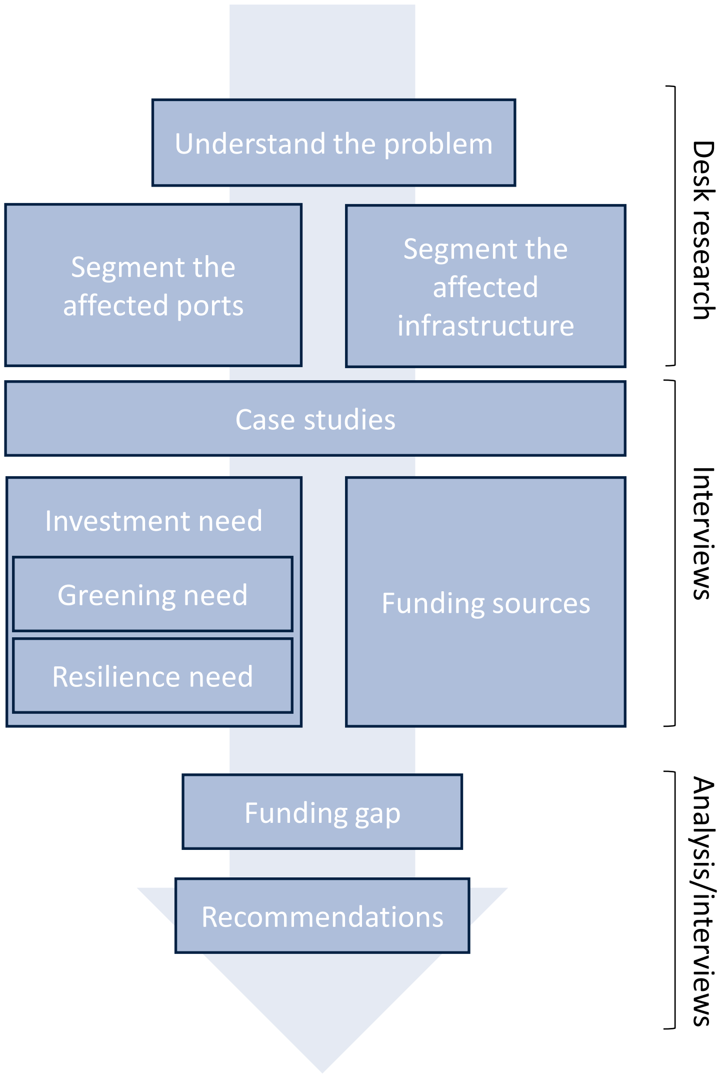
The goal of the **interviews** is to obtain specific information on the ports in the countries that are being considered. Multiple stakeholders are interviewed: port authorities, governmental organisations, bunker terminal owners, and port construction companies.

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

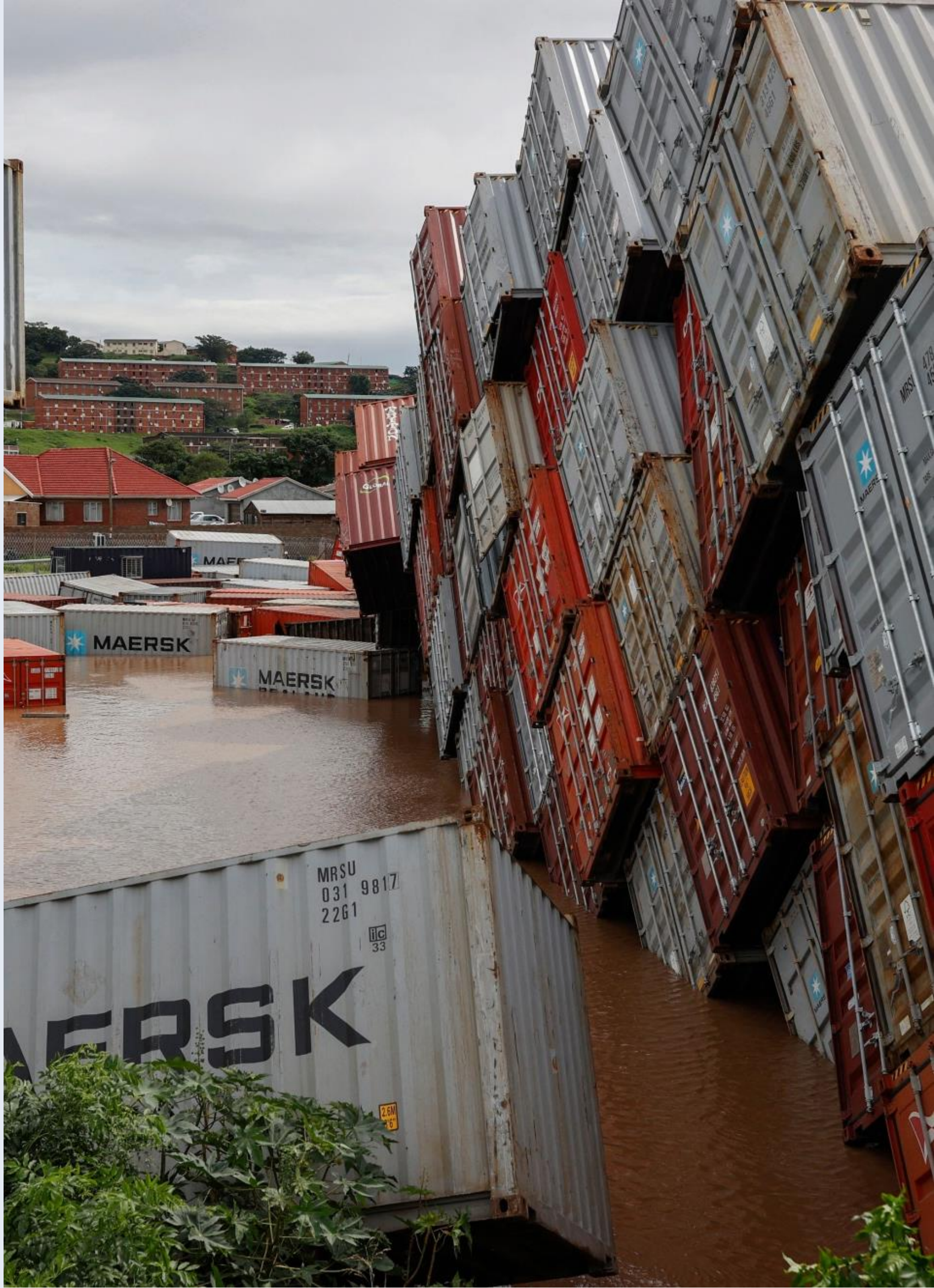
The research findings for each case study are discussed in separate sections. **Two main topics are covered: the impact of the energy transition and the impact of climate change in the form of climate resilience adaptation.**

The results obtained from the 5 case studies 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 case studies.

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



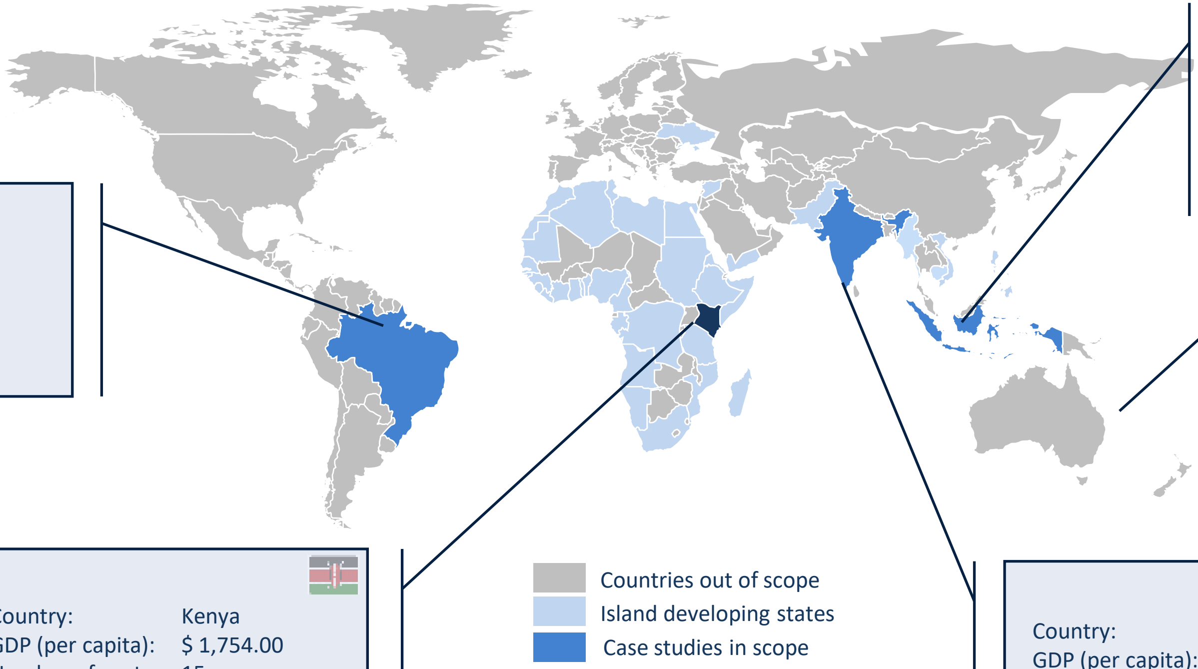
Case studies



The 5 case studies

The 5 selected countries are part of the group of island developing states (see annex p.83). They were selected due to their geographical features and high variety of ports, port models, vulnerability levels, trade and economic parameters. For each of the countries, multiple interviews were conducted with local representatives, followed up with interviews with international experts. Each of the case studies outlines the current challenges and developments for adaptation and mitigation infrastructure.

Case coverage of developing states



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

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

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

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

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

DEEPDIVE CASE – KENYA: PORT SYSTEM

General overview

Kenya is located on the eastern 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 indicated a GDP per capita (constant 2015 figures, US$) of $1,754; **this makes Kenya a relatively weak economy compared to the rest of the studied countries and the developing world.**

The Kenyan ports contribute significantly to the national economy, the estimated direct contribution of port operations making up 5% of the GDP and the indirect contribution making up 12% of the GDP.

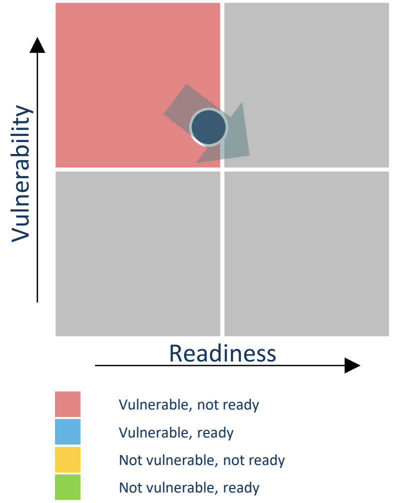
With respect to vulnerability[23], the country is ranked 150 out of 185 countries. Kenya is classified as having a **high vulnerability and low readiness**. According to the index, vulnerability is decreasing over time. The readiness score has recovered in the last few years from a relapse up to the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

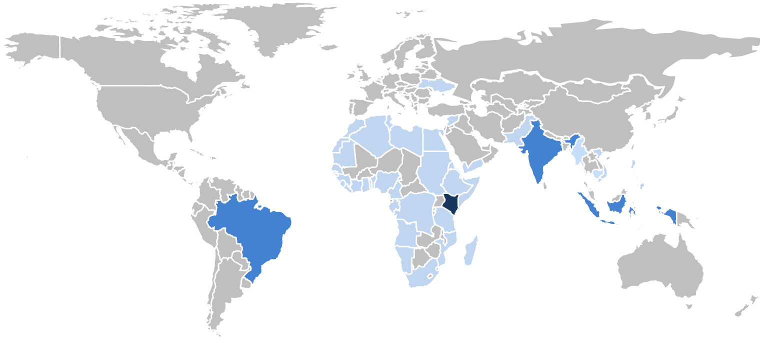
The high vulnerability score is mainly caused by the healthcare situation, the lack of medical staff being a major driver. The low readiness is mainly caused by the low level of social readiness stemming from the low level of education and innovation. **Infrastructure wise, Kenya is relatively resilient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

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]





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 **Kenya’s role as a transit hub from Asia to Europe and as 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 has a central location, acting as 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; among its notable trade partners are Uganda, Rwanda and Tanzania.

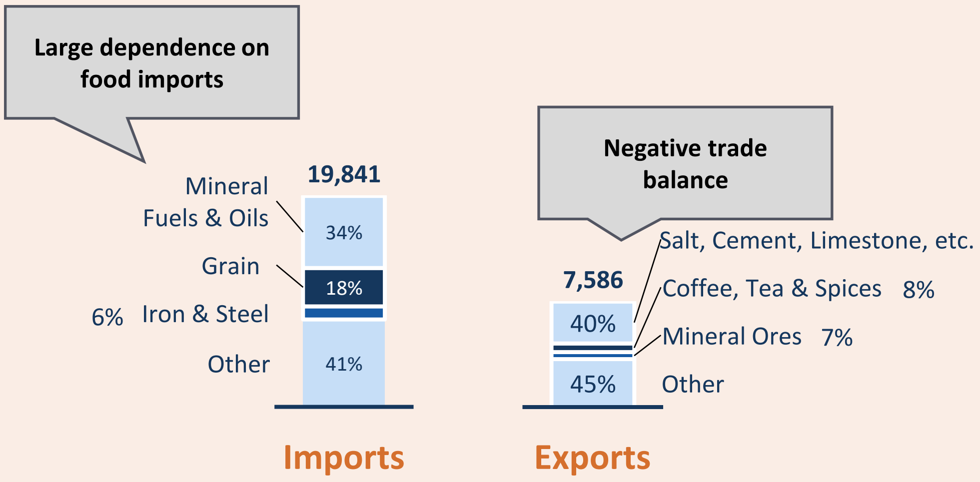
The two major seaports, eight smaller ports and two inland container depots are managed and **operated by the Kenya Ports Authority (KPA),** a state-owned organisation. The total cargo throughput of KPA is 35.96 Million MT and 1.62 Million TEU.

KPA manages ports of different sizes facing 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 landlocked African countries to the seaports on the eastern coast of Africa. The main goods transported via this route are staple goods.

Trade volumes 2023 (million tonnes)[24]



DEEPDIVE CASE – KENYA: PORTS ENERGY OVERVIEW

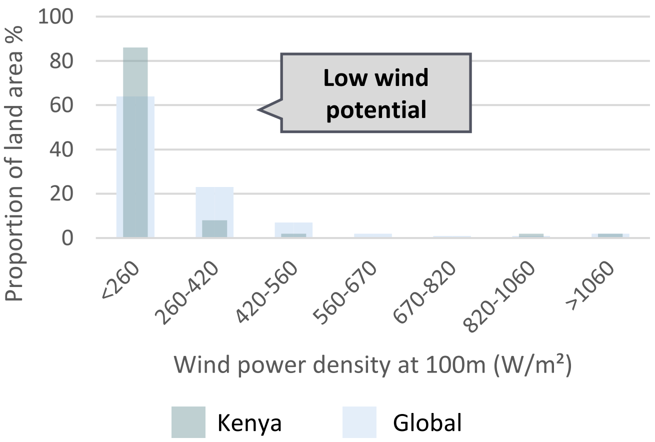
Most of the energy consumed in Kenya is already generated from renewable energy sources. 75% of the total energy supply is renewable, with geothermal energy as the biggest share in the renewable electricity production, followed by hydro power.

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

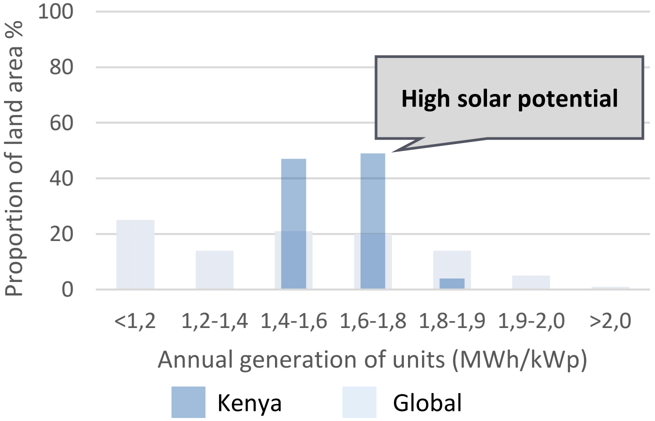
Around 5% of the surface of the country is located in an area with a wind power density of over 820 W/m², which exceeds the worldwide proportional area with this wind power density. In addition, the country has a high theoretical solar potential of 5,780 kWh/m² and is ranked as the 31st country having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

Overall, 75% of the energy used by the country is already renewable and the potential to produce a lot more renewable energy provides 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 the proposed alternate energy systems and the new shore power arrangements. In the future, the country expects to produce, export, and supply green hydrogen to ships, logistic companies and the manufacturing industry.**

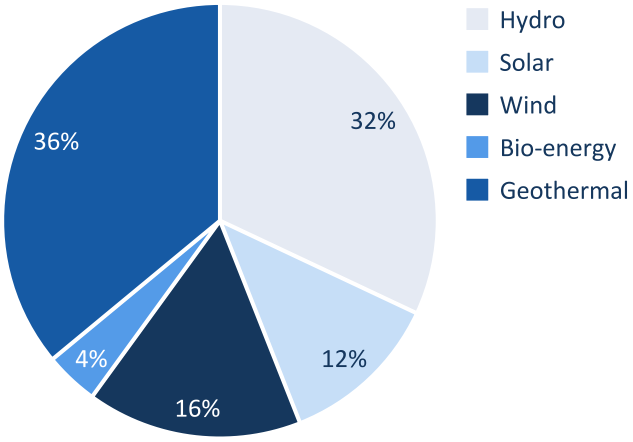
Distribution of wind potential[25]



Distribution of solar potential[25]



Renewable energy capacity in Kenya[25]



Share of renewables in final energy consumption[25]	Share of renewables in electricity generation[25]
75%	87.8%
LCOE[26]	Solar theoretical potential[26]
0.09	5,780 kWh/m²

DEEPDIVE CASE – KENYA: MAIN ISSUES

Main climate threats and the effects they have on Kenyan ports

There are four main climate threats that have been 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 consists of **extreme disruptions, in particular droughts and (rain related) floods**. The frequency and intensity of such events is likely to increase due to climate change. They also often have 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 and travel across the country.

Rain flooding

The effects of increased rainfall is most severe in the Lake Victoria region, where the water level rose to levels that **made (lake) ports inaccessible to ships**. Port facilities became permanently submerged and local infrastructure, such as buildings and access roads, were damaged. Seaports, including the port of Mombasa, located on a higher area, are also affected frequently by rain flooding. Heavy rainfall led to **flooded access roads and railways and the suspension of port operations**. Cargo needed 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 permanent.

Extreme heat

Heat induced stress affects roads and buildings and the port equipment in Kenya is affected by increased wear and tear. Heat stress is a concern for port employees, especially in what concerns equipment operators and employees working outside.

Storms

Kenyan ports are occasionally affected by tropical cyclones and these storms are more frequent, 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

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 their maintenance status, 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. Due to this circumstance, it is 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 maintained in operation until the new one is finished. **The Kenyan government started building 9km of new seawalls, which will protect the coastline and ports from storm surges and increased sea levels.**

Drainage

Improving the drainage of ports and their 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 that is not under the control of the KPA is the flooding of the access routes towards the ports, including railways.** There are no plans yet, as these need to be developed together with the (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 health risks due to extreme heat requires the construction of accessible heat shelters and the procurement of port equipment with sufficient cooling capacity. It is vital that the air-conditioning equipment in the port be properly maintained, to ensure that all staff in the port have access to heat shelters, particularly those working outside, without air conditioning. **This can, however, increase the maintenance costs of equipment and lead to new carbon emissions.**

Early Warning System

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

DEEPDIVE CASE – KENYA: DECARBONISATION NEED

Impact of the energy transition on Kenyan ports

The energy transition is topical and addressed by the KPA on a national and international level, with regulations 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, namely:**

- **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 mainly producing its own green energy, 1.5MW of installed solar power, with plans to increase the production to 5MW in the near future. The electricity produced by the solar power station is used to power the hybrid port equipment. During the night, KPA's own power supply is not generating enough energy to power 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 aims to transition from hybrid port equipment to full electric equipment.

However, this transition will not start unless a sufficient supply of green energy is secured to power the equipment around the clock. Until then, the port will continue operating 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 biofuels and green hydrogen in the country. Private parties are investigating investment opportunities in hydrogen production facilities, with the aim to set up a supply chain for local demand. Kenya aims to become a hydrogen hub within the East African region.

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

Port industry

To power the entire port, an estimated total of 6-7MW 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. Another option would be 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

Kenyan ports are investing in climate resilience and decarbonisation projects. **Most climate resilience investments are related to both rain and coastal flooding risks.** Flooding-related investments are capital intensive and can costs up to billions of USD dollars, such as 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 similar to those required to build a new port.

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

The country aims 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. Kenyan ports believe that a hybrid solution, involving both public and private parties, is needed to finance the investments. 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. Mobilising financing for adaptation is another key constraint. Despite these challenges, Kenya’s effort to adapt have led to improvement in recent years in the country’s climate vulnerability index, although it remains quite low, due to pre-existing social and economic vulnerabilities. To achieve that, not only should the Kenyan government be supported in further developing and updating its climate change action strategy, but also in focusing 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 in seaports and inland ports. Each of these ports have their own challenges that require investments of billions of USD to prevent flooding. Steps are taken to decarbonise the port sector, the port of Mombasa is a good example in this sense. Kenyan ports believe that the funding needed for investments should be a hybrid effort, involving both public and private parties.

Case study – Kenya: Lake Turkana Wind Power Project

Currently Africa’s largest wind farm, with a capacity of over 310 MW. The project also attracted the largest private investment in Kenya’s history, totalling $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 suffering significant impacts currently 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 the risk of flooding. The main ports are occasionally forced to cease their operations due to flooding disruptions. **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 of Lake Victoria, **smaller lake ports in the region have become (partly) inaccessible for ships.** Permanently flooded infrastructure should be considered a write-off and will need to be replaced. **The costs of rehabilitating these facilities are equivalent to their replacement value.** Additionally, a plan is under development to build seawalls that will protect the harbours and coastal areas.

Storms are also the cause of navigational hazards in the vicinity of Lake Victoria due to the floating islands of macrophytes. KPA plans to solve this using an early warning system; the costs of such a system are lower than those required to replace or build new infrastructure.

Port decarbonisation

The energy transition is addressed by KPA on a national and international level, with regulations 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, and (3) decarbonisation of the of the port industry. **Some of the more notable measures to transition to a fully decarbonised port include a (pilot) project providing shore power and switching from the use of fully diesel driven port equipment to hybrid equipment. In addition, the port installed a solar power plant, which will be expanded in the near future, according to plans.**

Overall, Kenya is a country with a lot of decarbonisation potential, due to its highly available solar power. The ports are actively investing in decarbonisation initiatives, with the notable exception of decarbonised fuels. The country aims 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 most significant challenge consists of the adaptation measures which need to be taken to keep the ports operational. The construction of new infrastructure- to replace the submerged infrastructure- and the replacement of destroyed hinterland networks are amongst the most significant challenges. When looking at the stages of the "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. A law introduced in 2008 pushed the ports in Indonesia to reform to the 'Landlord Port' model[38]. The Pelindo companies were directed to become terminal operators. New port authorities that should implement the landlord port model were created, however, all assets remained in the possession of the Pelindo companies[39].

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

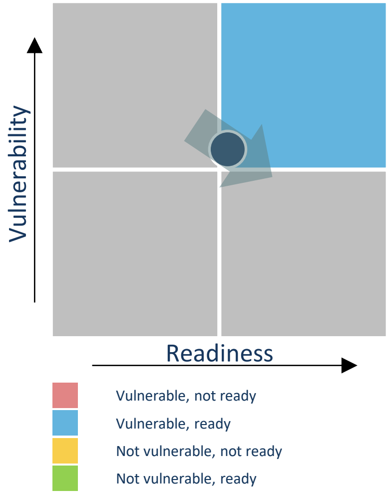
With respect to vulnerability[23], the country is ranked 98 out of 185 countries. Indonesia is classified as having high vulnerability and high readiness. The country is vulnerable with respect to food, with the projected change in grain yields and agriculture capacity as the main drivers of the vulnerability in terms of food. With regards to infrastructure, the country is vulnerable due to the number of people living below sea level.

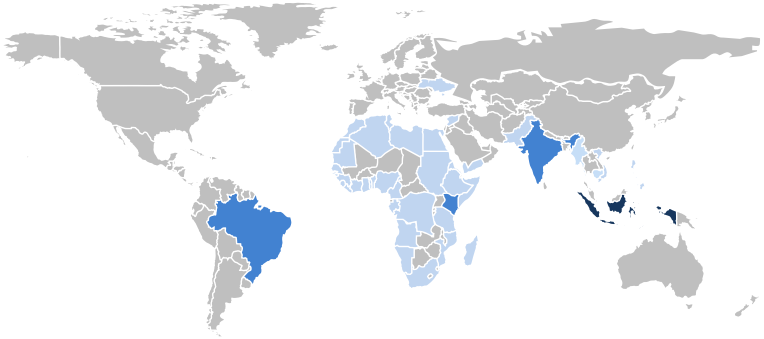
Indonesia needs reliable ports to provide sufficient food in case yields and agriculture capacity are not sufficient for the provision of food to the country's inhabitants. As the country is an archipelago, all inhabited islands need their own port facilities. In Indonesia, climate change is likely to impact water availability, health and food sources, the ability to manage disaster risk, and urban development, particularly in coastal areas, which could result in 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]





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

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.

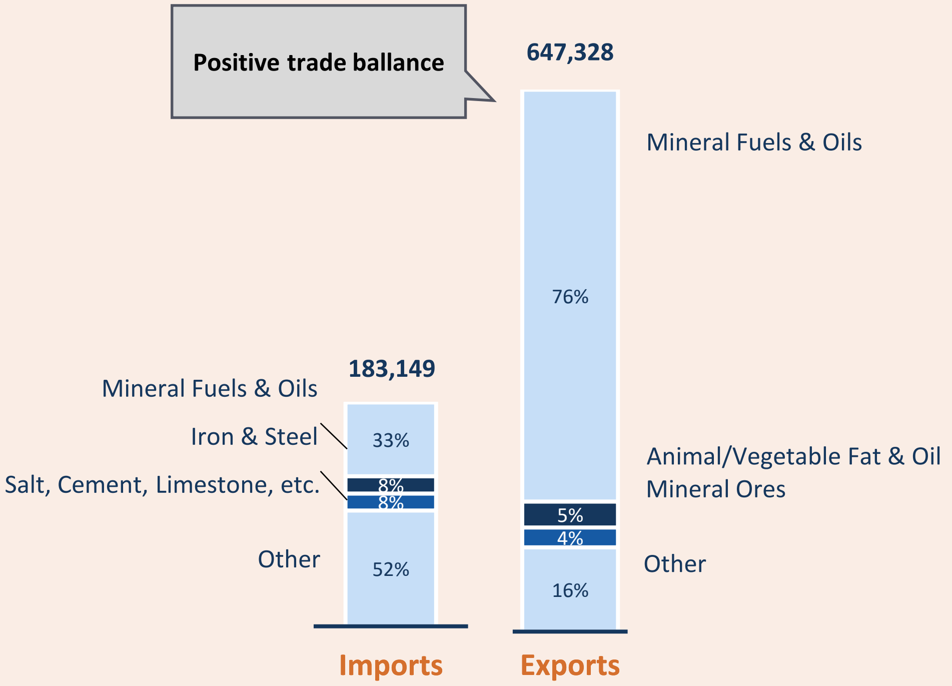
Imports[24]		Exports[24]	
China	18%	China	35%
Australia	14%	India	19%
Singapore	8%	Japan	6%
Malaysia	6%	Rep. of Korea	6%
USA	6%	Philippines	6%

In 2021, Indonesia had 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 annual average growth of 9.6 percent of the Asia Pacific region during the same period. Indonesia’s GHG emissions from shipping in 2018 are estimated to represent about 3.7 percent of the 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 western region of Indonesia.

In contrast with western ports, eastern ports are located on small islands that facilitate local trade and are vital for the food supply of the local communities. Their hinterlands are small, they have no industrial activity or large volumes of exportable resources. **As a consequence, the ports in the east struggle in terms of 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 tonnes)[24]



DEEPDIVE CASE – INDONESIA: ENERGY OVERVIEW

In Indonesia, 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 has committed to raise the share of renewables in its power generation mix, from its current level of 19 percent to 34 percent by 2030.

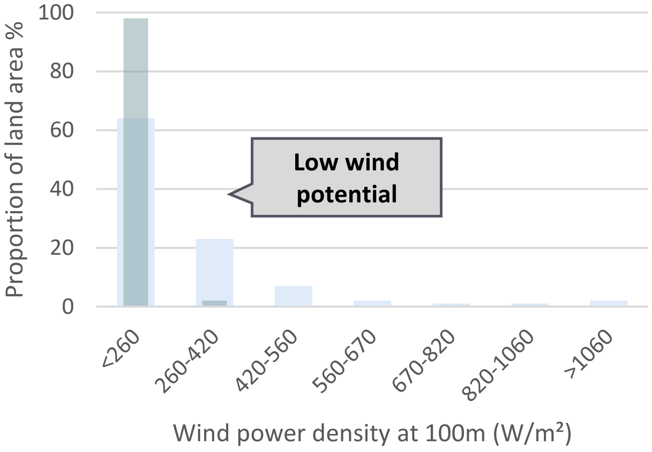
Solar represents 21%, the contribution of wind (1%) and bioenergy (2%) are negligible.

The Indonesian government has made progress in 2023 on renewable energies, by creating a national budget, reducing the VAT on electric vehicles with batteries and introducing subsidies.

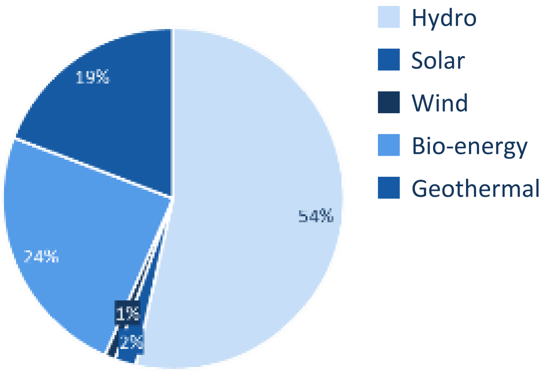
The potential for wind energy in Indonesia is low, with 98% of the area of the country having a wind power density of less than 260 W/m². **The potential for solar is average but constant year round,** and the country is ranked 136 in terms of solar potential.

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 significant. 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 decarbonisation by 2050, according to the Global Maritime Forum.

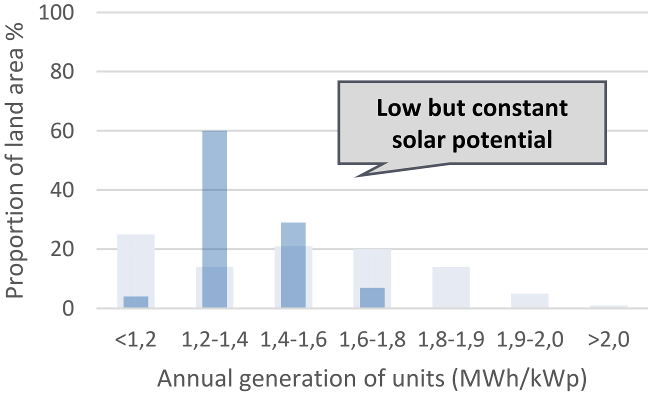
Distribution of wind potential[27]



Renewable energy capacity in Indonesia[27]



Distribution of solar potential[27]



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

Main climate threats and the effects they have on Indonesian ports

Indonesia faces several issues in terms of climate change. Indonesia is highly vulnerable to climate change impacts, including extreme events such as floods and droughts, and long-term changes due to sea level rise, shifts in rainfall patterns and increasing temperatures. These 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 eastern region 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 eastern region of Indonesia need to suspend 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 an increasing number of severe storms with lots of rainfall and high wind speeds. These storms mostly affect the western ports. This leads 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 phenomena that occur in other areas may have a significant impact (in the form of massive high waves and storm surges) on vulnerable coastal areas.

Rain flooding

Local storms are accompanied by heavy rainfall and are the cause of severe flooding. Indonesia is not unfamiliar to floods; in the past they have occurred regularly in January. Due to climate change, such phenomena now happen 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

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 experience continuity issues when it comes to port operations**. **The small island ports in the east are affected the most 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 that have sufficient budget resources are developing construction plans or have even completed the works on their infrastructure, as their facilities had already become inoperable. Some of the infrastructure is replaced by new infrastructure with higher deck levels, while other is completely replaced.

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; here, replacement or relocation seems like the only option.

Seawalls and Breakwaters

Seawalls and breakwaters will protect the harbours from waves and current minimising 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 for the flooding of jetties and quays, in addition, the installation of seawalls or breakwaters in these ports is not financially feasible. There is a plan under development to protect the city of Jakarta and its seaport with a 32-kilometre seawall which should be finished by 2030, with an estimated cost of $60 billion.

DEEPDIVE CASE – INDONESIA: DECARBONISATION NEED

Impact of the energy transition on Indonesian ports

The government in Indonesia is not confident it can reach decarbonisation by 2050 and states that 2060 is 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 advancing at a slow pace in Indonesia.

Port operations

The large ports in the western region of Indonesia are implementing **shore power connections to provide electricity to moored vessels,** which renders the use of auxiliary engines in the port unnecessary. For smaller ports in the east, these kinds of investments are not realistic. These ports are already struggling to finance port resilience investments that are needed to continue operations in the present, and are not 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 **electricity is still sourced from coal powered electricity plants.**

Bunker supply

Indonesian ports are still very much fossil fuel oriented, except for a few carbon reduction initiatives in the bigger ports focusing 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 situation**. 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. 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 as such they experience trouble financing the needed port resilience investments.** Investments related to energy transition are therefore not a priority and, more importantly, they are 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 decarbonisation and requires a high-level of certainty from the 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, and they depend on private investments.**

Port Resilience

Indonesia's small islands in the eastern part of the country face the biggest challenge when it comes to adaptation measures. These small island ports are vital for the food supply of 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, **and the costs involved are similar to those required to build a completely new small port.**

The larger ports in Indonesia are more profitable, and therefore able to invest in adaptation 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 will 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 in terms of port decarbonisation. Whereas the smaller ports are struggling to finance the much-needed resilience investments and do not have any money to spend on decarbonisation, the bigger ports 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 decarbonisation has been developed, the government deems decarbonisation by 2050 as an unrealistic goal and maintains that 2060 would be a realistic deadline in terms of decarbonisation.

Without a central vision from the government, Indonesia will struggle in terms of both adaptation and mitigation measures for ports. 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 adaptation measures. Given its large export volume of mineral fuels & oils, and its location close to the main shipping lanes, the country could try to pivot to a decarbonised fuelling strategy, but this would require a centralised strategy and international support.

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, with the exception of Ecuador and Chile. **Due to this, Brazilian ports have a contribution of over 90% in 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 regulated by ANTAQ (National Agency For Waterway Transportation) and MTPAC (the Ministry of Transport, Ports and Civil Aviation). A port authority oversees each port, whereas activities undertaken in Brazil´s territorial waters are under control of the Brazilian Maritime Authority.

The World Bank indicated a GDP per capita of $8,830, which places Brazil in the strongest position in the investigated group.

The indirect contribution of the Brazilian transport sector, which includes ports, is estimated at 12%.

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

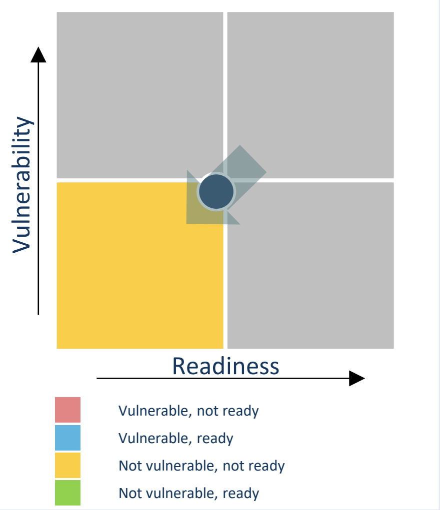
The main vulnerability score driver is the status of the human habitat, influenced by the condition of the paved roads, urban concentrations and the **projected change of flood hazards, which is directly related to the ports.**

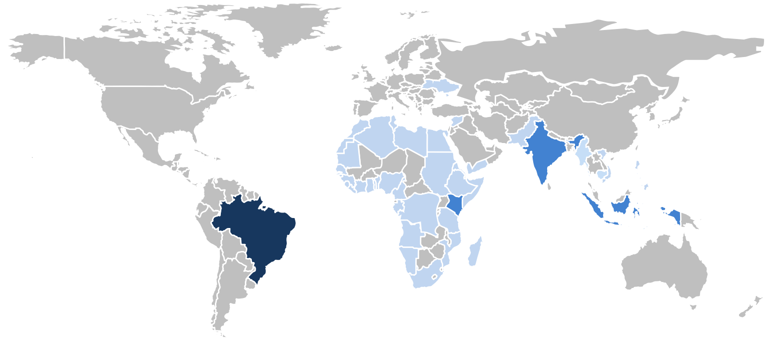
In terms of readiness, Brazil could improve on its economic and social readiness, the most significant areas of improvement being innovation and social inequality.

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]





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, grains and sugars.

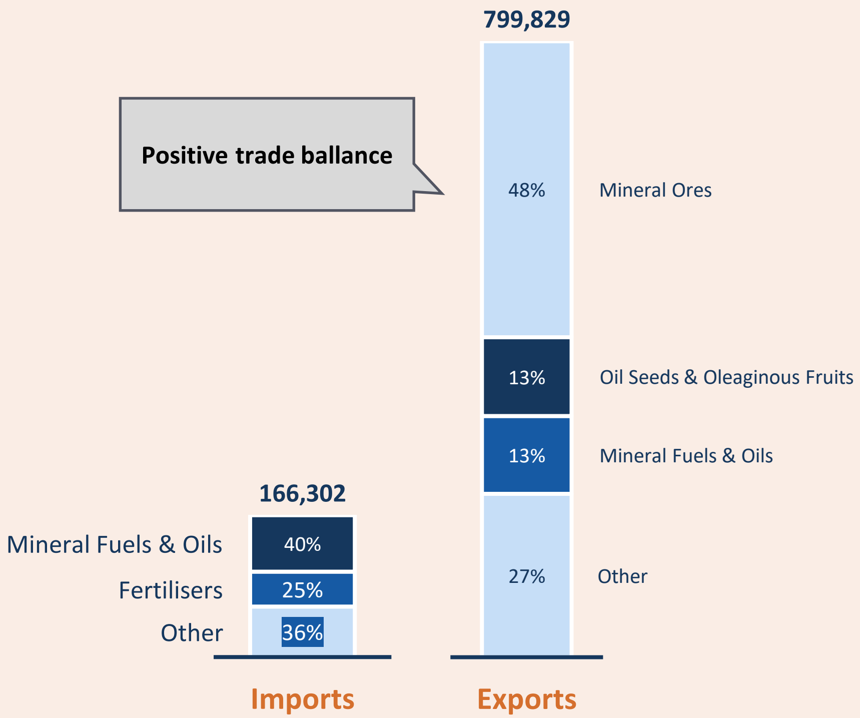
Imports[24]		Exports[24]	
USA	18%	China	54%
China	15%	USA	5%
Russian Federation	14%	Malaysia	3%
Argentina	6%	The Netherlands	3%
Australia	4%	Japan	3%

The top 5 main trade partners with respect to imports and exports are located on 5 continents. China stands out as trade partner with respect to exported goods, primarily attributable to the trade in commodities, which is 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 portion of the port traffic is coastal, with Brazil serving as a hub for neighbouring countries – making it a key port economy in the region.**

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

Trade volumes 2023 (million tonnes)[24]



DEEPDIVE CASE – BRAZIL: PORTS ENERGY OVERVIEW

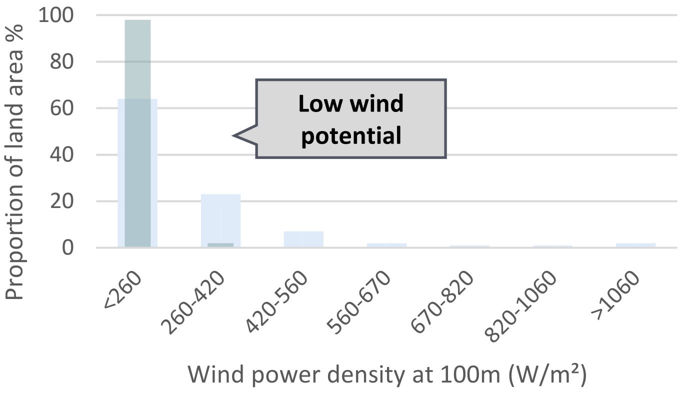
In Brazil, 48% of the total energy consumption is made up of renewable energy – the Northeast accounts for almost 83% of renewable energy generation capacity thanks to the solar and wind energy generation capacity, of 27.8 gigawatts (GW). Most of the renewable electricity originates from hydro power 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 prepare 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 for 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 significant focus on renewables in the country.

The potential of wind energy in Brazil is low, with most of the country being classified as having a wind power density of less than 260W/m^2.

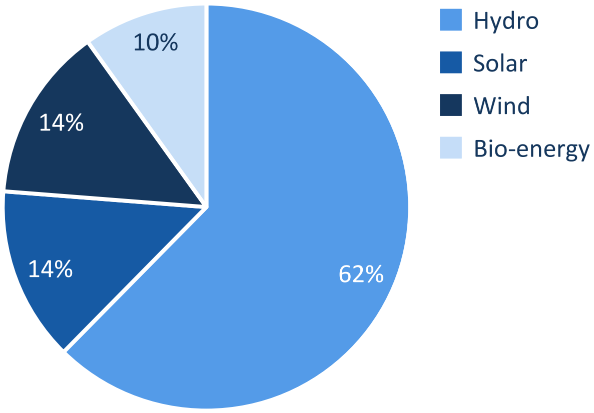
The country has an average theoretical potential of 5,276 kWh/m^2 of solar energy production and is ranked 89th in terms of Global Photovoltaic Power Potential.

Distribution of wind potential[28]

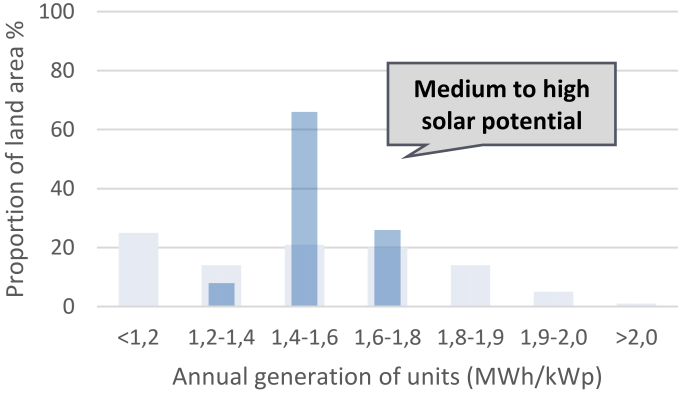


Low wind potential

Renewable energy capacity in Brazil[28]



Distribution of solar potential[28]



Medium to high solar potential

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/m^2

DEEPDIVE CASE – BRAZIL: MAIN ISSUES

Main climate threats and their effects on Brazilian ports

The Brazilian government presented a study[31] that identified the main climate threats for the Brazilian ports. These types of studies and the simcosta system are the basic building blocks used by the Brazilian public ports to develop 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 increasing number of storms and their increasing intensity threatens port operations. Ports need to cease operations temporarily due to high wind speeds during storms, which disrupt the supply chain. The effects of storms are taken into account by the ports and they are identified as a major threat in the study prepared by the government[31].

Rain flooding

Rain flooding is a major threat and an already relevant cause of the disruption of the supply chain. **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 are occasionally flooded due to extreme rainfall.

Coastal flooding

Sea level rise or coastal flooding has been 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 ports, for instance Porto Itaqui, which has been in operation for over 50 years, will, in time, have to deal with sea level rise issues.

Heat

As the country is close to the Equator, heat is an issue for the ports in Brazil. The main issue is the health and safety of the operators. Port equipment needs to be properly cooled and maintained, and 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

Mitigating measures against the main climate threats

At this stage, Brazilian ports are aware of the threats, but **have not implemented adaptation measures yet**. Plans and roadmaps are being developed based on findings of studies conducted by the government and Brazilian universities. Porto do Açu is a relatively new port that does not require adaptation yet, as current expected 100-year extreme weather conditions were taken into account during its design.

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 **strict public procurement standards**.

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 ports.

Status of RESILIENT infrastructure development in Brazil

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

Source: interviews

Drainage

Due to the increased amount of rainfall caused by 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 Porto Sudeste wells 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 facilities to protect from the heat are needed for port employees.

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 separates clean rainwater from water that flows through the yards. Used sanitary water is treated and reused was well. The resulting sludge is used as a fertiliser.

DEEPDIVE CASE – BRAZIL: DECARBONISATION NEED

Impact of the energy transition on Brazilian ports

Brazilian ports 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 related activities.

National and international partnerships were established to investigate the issue and develop action plans.

Three objectives can be identified for the port: (1) prevent further damage to climate, (2) comply with upcoming regulations and legislation, and (3) develop new business opportunities.

In concrete terms, the impact is especially noticeable in the investments in decarbonised port equipment and in the infrastructure needed for decarbonised energy supply. **Brazil plays a leading role 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.** LNG, a transition fuel, is used in certain ports as energy source for electricity generation and as a fuel for trucks.

The progress made in terms of decarbonisation and the investments related to decarbonisation varies from one port to another. Porto do Açu, for instance, has already installed shore power and developed an action plan to invest in decarbonised port equipment. Porto do Itagui has not taken any measures in this field, as they are still being analysed.

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

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

Efficiency

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

Green energies

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

Green solutions for the logistics chains

The green solutions for the logistics chains are closely related to green energy, it however is specifically focused on the logistics 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 entered into a partnership with Valencia Port Foundation. The know-how obtained from the partnership is used as basis for the development of the port's road maps and actions plans 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 adaptation measures for climate change in Brazil, information on the actual costs was not provided. **Overall, we have found that the most capital-intensive investments related to climate resilience and adaptation in this region consist of raising the quaysides and installing seawalls**. Investments in green bunker fuel production and supply infrastructure are the most capital-intensive investments related to energy transition. While 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 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. The intended early warning systems 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 on-site electricity and generation of renewables in the long run is amongst the cheapest options.** Investments related to profitable business models, such as decarbonised energy and fuel production or shore power can be financed using traditional financing methods. Investments needed from a resilience perspective that do not create or improve 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 trade within their ports. Both privately managed and operated ports as well as 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 through the port. Priority is given to port resilience investments, decarbonising investments following suit once there is a solid business case or if the ports are forced to implement them due to regulations.

Port Resilience

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 seawalls. 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-year 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 markedly from one port to another.

(continued on next page)

DEEPDIVE CASE – BRAZIL: CONCLUSION

(Contd.) The port sector indicates that the government should facilitate the investments not only by providing funds, 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 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 the 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 prepare 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 significant. The newer ports will be able to cope with adaptation investments, whilst new greenfields will need to keep the increasing storm frequency and intensity in mind. Of all the investigated cases, Brazil has taken the largest steps in using its strong global export position combined with its strong potential renewable energy generation as a lever to develop an export-oriented hydrogen/renewables economy. The progress made in terms of decarbonisation and the investments related to decarbonisation vary from one port to another, with some ports still focusing on phase 1- Tackling Port Emissions, whilst others are actively looking at securing revenue and economic growth (phases 4 to 5). The major challenges to be overcome to speed up this development are related to the local procurement regulations.

DEEPDIVE CASE – INDIA: PORT SYSTEM

General overview

India is located in South Asia, on the Indian subcontinent, and has the largest population in the world. The World Bank indicated 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 contribute significantly to the economy of the country, the estimated direct contribution of port operations making up 5% of the GDP and the indirect up 12% of the GDP.

As of 2022, there are 12 major ports and 217 non-major ports (not related 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 the respective state governments—this also includes private ports.**

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

India's most vulnerable aspects are healthcare and food supply. The most important issues are the availability of medical staff and the projected change in terms of grain yields. **The country is also vulnerable to in terms of the projected change of flood hazards, which have 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

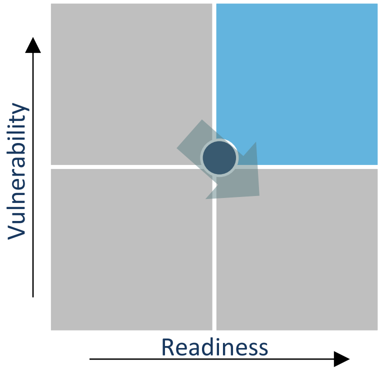
GDP contribution agriculture
16%

GDP contribution services
48%

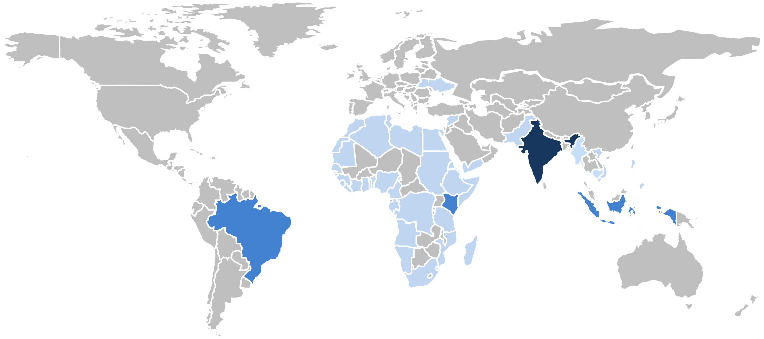
GDP contribution industry
25%

GDP contribution manufacturing
13%

ND-GAIN Country Index[23]



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



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 by 6.9%[22] from 2022 to 2023.

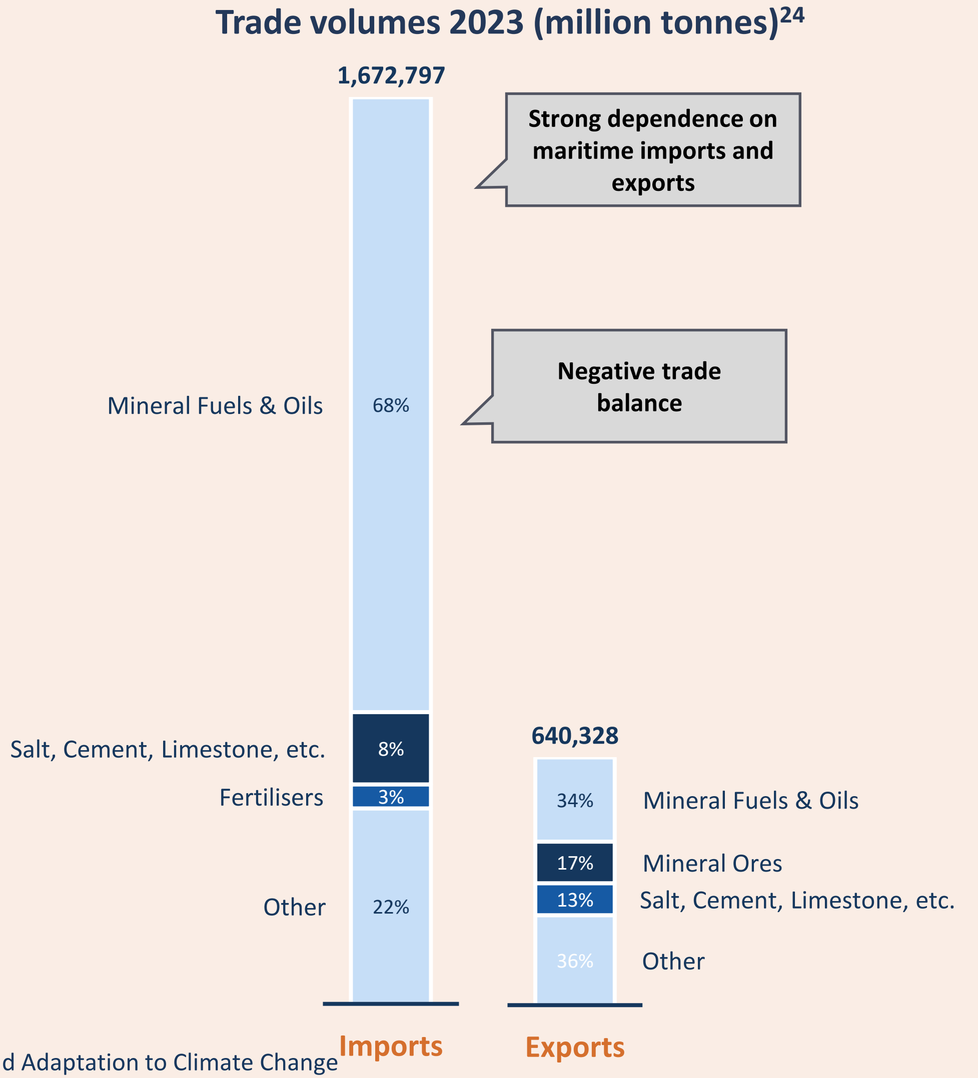
Imports[24]		Exports[24]	
Russian Federation	17%	China	19%
Indonesia	15%	Bangladesh	9%
United Arab Emirates	8%	The Netherlands	6%
Australia	7%	USA	6%
USA	7%	United Arab Emirates	5%

As India is a peninsula, its maritime connections have historically involved trade, religion, and culture; these early associations, however, were severed over time. Especially after gaining its 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. Its 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 continents. **The Indian ports both increasingly serve as a gateway to the vast subcontinent, as well as a transshipment hub for 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 tonnes)[24]

Strong dependence on maritime imports and exports

Negative trade balance

DEEPDIVE CASE – INDIA: PORTS ENERGY OVERVIEW

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% is bioenergy).

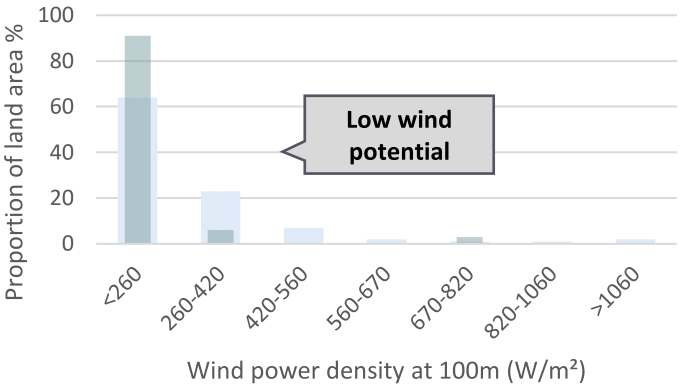
The average levelised cost of energy in India is 0.07, which is the lowest LCOE of all 5 cases studies included in this analysis.

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

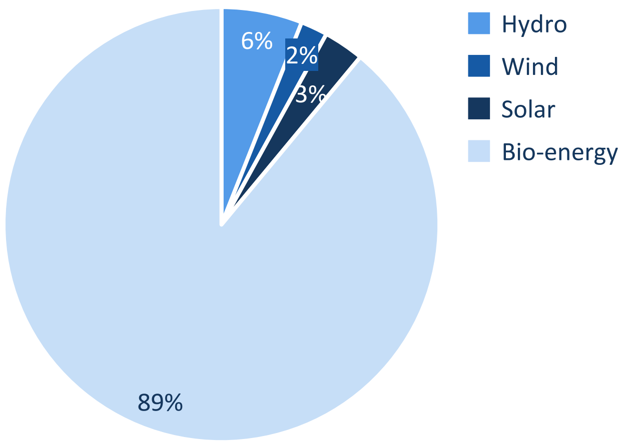
With respect to solar, the country has a potential of 5,098 kWh/m^2, and the country ranks 104th in terms of solar energy production potential.

Given the potential for renewables and the 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 has already been initiated in many of the major ports. **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.**

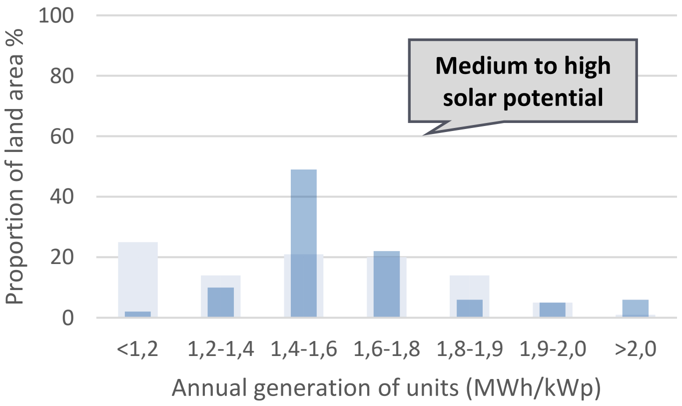
Distribution of wind potential[29]



Renewable energy capacity in India[29]



Distribution of solar potential[29]



Share of renewables in final energy consumption[29]

24%

Share of renewables in electricity generation[29]

22.4%

LCOE[26]

0.07

Solar potential[26]

5,098 kWh/m^2

DEEPDIVE CASE – INDIA: MAIN ISSUES

Main climate threats and the effects they have on Indian ports

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

Storms

Cyclones can have an effect on the port for 12 to 48 hours, depending on the intensity of the storm. The storms affect both the port and the continuity of the maritime operations. Most harbours in India are well protected natural harbours, and as a result **the damage to the infrastructure due to storms is minimal.** The main issue are high wind speeds and heavy rainfall, causing disruptions to the maritime and port operations. Most of the infrastructure in 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, which makes cyclones one of the most important climate-related 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 the past, only ports located on the east coast had to deal with heavy rainfall due to the monsoon season. With the increase in the number of 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. The 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 that causes stress for personnel, negatively impacting the work efficiency and health of the port employees. The impact on equipment is rather limited. Sufficient cooling capacity is required for operators working with harbour equipment, as well as heat shelters for the 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

Mitigating measures against the main climate threats

Depending on the ports, mitigating measures are necessary. The port of Chennai plans to modernise its infrastructure. Most other ports do not have any plans to modernise their infrastructure at the moment.

Drainage

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

Weather predictions and port capacity increase

Weather predictions are used to anticipate incoming storms. In combination with capacity increase, this could prevent supply disruptions. 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 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 from heat; sufficient cooling facilities and shelter from heat are required. There are no specific initiatives to improve the current heat shelters or cooling facilities.

Heat Action Plans

The Indian government has implemented Heat Action Plans at various levels (state, district and city). The plans include early warning systems, public awareness campaigns, cool roof initiatives and urban planning. During heat waves, working hours are rescheduled, if possible. Workers can avoid doing their job during the hottest part of the day, and this reduces extreme heat exposure.

Hinterland connections

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

DEEPDIVE CASE – INDIA: DECARBONISATION NEED

Impact of the energy transition on Indian ports

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

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 or 6 are already powered by renewable energy. For example, the port of Mumbai is 75%-80% powered by renewables.

Port operations

Ports in India are implementing shore power connections for vessels to reduce the use of auxiliary engines while in port. The port of Chennai already has shore power connections available. The difficulties encountered are non-standard electricity supply 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 aims 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 the related regulations. 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, whereas 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 areas around the existing ports for the development of green industries. Most investments are coming from private parties and they need to navigate an evolving situation, where new investments with increasing CapEx are needed, while the concession agreements stay unchanged. This applies increasing pressure in terms of 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 do not have plans yet to upgrade port infrastructure in terms of 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 prepared by private parties. **The Indian port sector is in favour of a viability gap funding, especially in terms of green bunker fuels. The market for these fuels is not mature 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, given the evolving regulations and technologies.**

Port Resilience

Indian Ports are mostly threatened by storm disruptions. Heavy rainfall caused by storms affects 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.

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

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

Port Decarbonisation

India keeps track of the developments occurring in Europe to minimise the risk of investing in technologies that would not mature. The Indian port industry is already investing in decarbonised port equipment and the installation of shore power.

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

Indian Ports are struggling mostly with the available land for the development of renewable infrastructure and the inflexibility of old school concession agreements, when it comes to the new climate change investment needs. The ports face disruptions caused by extreme weather events which have increased in frequency, but for the moment these remain mostly operational. When it comes to mitigation, private parties are driving the initiatives and they are trying to turn ports into the decarbonised bunkering hubs of the future. The focus here is on hydrogen, although fast-paced development is hindered by a lot of uncertainty regarding the most prominent fuel type. India is in a prime position to leverage its large renewable energy generation capacity and has a 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 are a geographically dispersed country, consisting of 9 provinces across 6 major islands and over 900 smaller islands, a third of which are inhabited. The World Bank indicated a GDP per capita of $2,084, and this places the Solomon Islands in the weaker economic segment of the investigated group.

The ports of the Solomon Islands contribute significantly to the country's economy, as 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 148th out of 185 countries. The Solomon Islands are classified as having high vulnerability and high readiness. According to the index, vulnerability is decreasing overtime. The readiness score increased from 2012 to 2020.

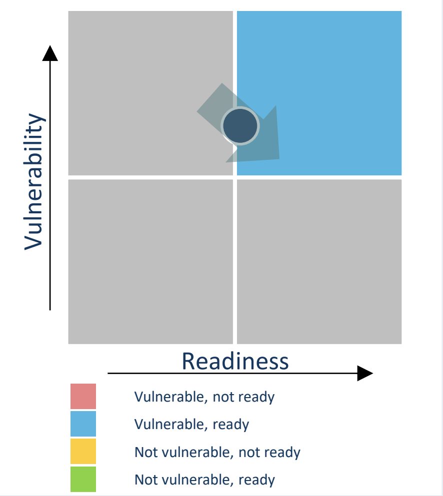
The Solomon Islands are most vulnerable in terms of human habitat and infrastructure. Flood hazards, the change of warm periods and the projected change of sea level rise are the most critical vulnerability categories, with the impact of the projected change in sea level rise being amongst the worst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

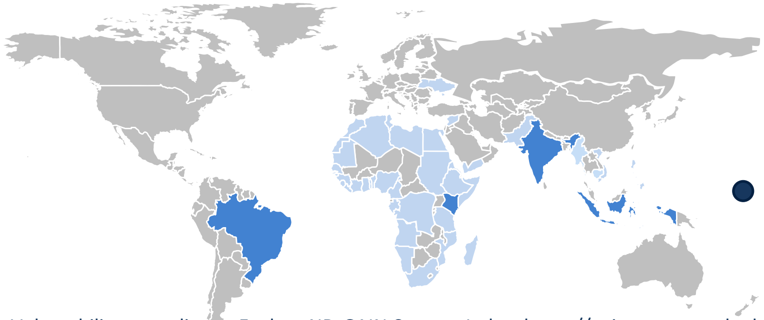
On a readiness level, categories that need improvement are economic readiness and the ICT infrastructure.

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]





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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

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%

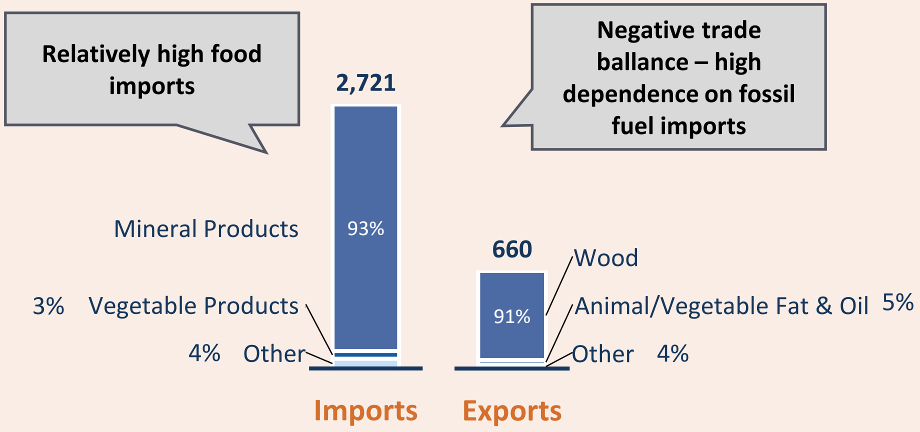
The total exports of the Solomon Islands amount to US$569m and the total imports to Us$601m, therefore the country is a net importer. The electricity of the Islands is produced using fossil fuel powered energy stations, hence the mineral products are the largest category of imported goods.

The second largest category of imported goods are vegetable products; the third largest is foodstuffs, which indicates that most of the food consumed on the islands is imported.

The Solomon Islands have two international ports, port Honiara and port Noro, which act as a 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 and 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 tonnes)[24]


Relatively high food imports

Negative trade ballance – high dependence on fossil fuel imports

DEEPDIVE CASE – SOLOMON ISLANDS: PORTS ENERGY OVERVIEW

According to the statistics, 44% of the total energy supply is made up of renewables in the Solomon Islands. However, only 7% of the country's electricity is generated using renewables as a source of energy. 80% of the renewable energy in the country originates from solar power, followed by bioenergy and hydro power. As of 2020, close to 45 percent of the electricity in SIPA's ports was obtained from renewable sources

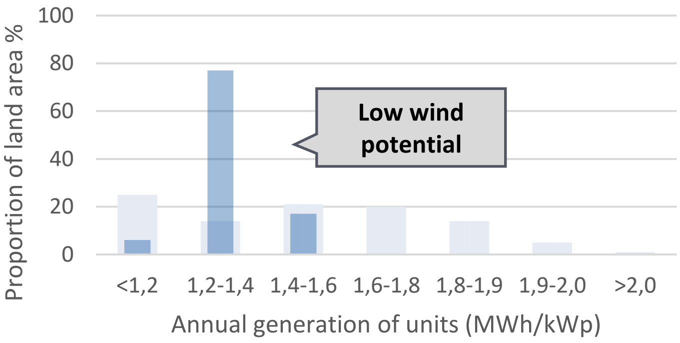
The levelised cost of energy for the Solomon Islands is 0.12, the same as Brazil.

The Solomon islands are located in a region where more than 95% of the area has a wind power density of less than 260W/m², the lowest ranking. As a consequence, there is not a significant potential for wind power.

With respect to solar, the country's average potential is 4,402 kWh/m², which ranks the country at number 152 in terms of solar energy potential. The country has a lower score than the other case studies, but does have the advantage of a small seasonality impact, making it a year-round generator.

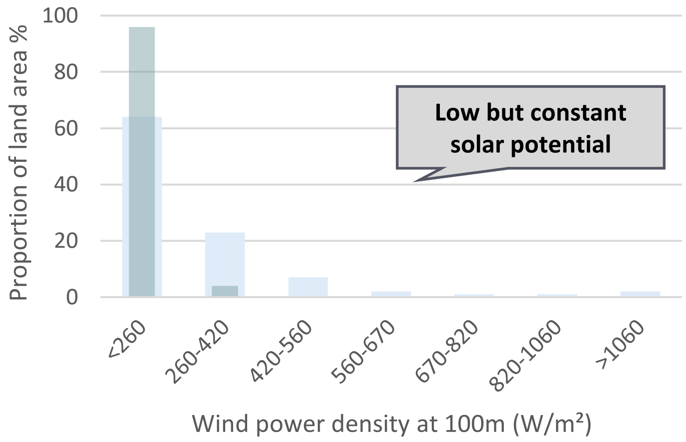
With support from the World Bank, the Solomon Islands Port Authority has also undertaken the Green Ports initiative in order to support rural communities, by providing decarbonised power to those who previously had no access to any form of energy.

Distribution of solar potential[30]



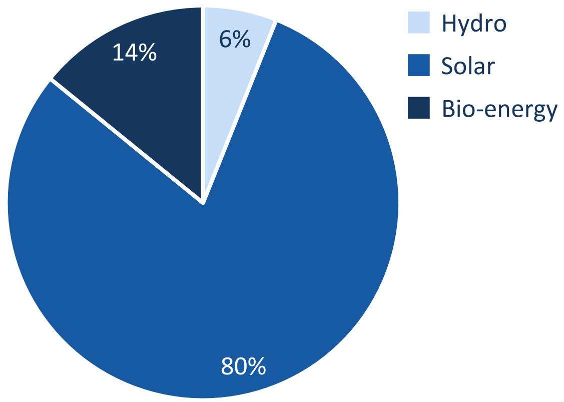
Low wind potential

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/m²

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: sea level rise, increase in the number of storms/cyclones and even earthquakes. Storms are accompanied by high wind speeds, waves and rainfall. In addition, earthquakes in the region, caused by climate-induced land submergence, may 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 usable 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 are not affected by rain flooding. However, during storms, the flooding of the hinterland connections is an issue due to the lack of sufficient drainage. The change in the weather patterns intensifies the problem.

Storms

Climate change has led to an increase in the number and intensity of the storms that pass through the Solomon Islands. These storms are accompanied by heavy rainfall, as we have already mentioned. They are also accompanied by strong winds, which affect lifting operations and thus the loading/unloading of vessels. The yearly occurrence of storms is quite unpredictable, historically the Solomon Islands experience a storm 2 times a year, on average.

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 is increasing. The Solomon Islands experience more earthquakes which have become more violent as well; the last earthquake occurred 1,5 years ago and had a magnitude of 7.1. When occurring offshore, earthquakes can cause tsunamis, which can be the cause of serious damage and loss of life, as illustrated by the tsunami that occurred in 2013, when 5 people 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

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 needs 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 built 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 jetties increase the capacity of the port, as well as its resilience.**

Status of RESILIENT infrastructure development in the Solomon Islands

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

Source: interviews

Drainage

Additional drainage is needed for the transport routes connecting the port to its hinterland. 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 as a result the water depths near the islands increase rapidly to over 100m. **Due to the water depth, seawalls and breakwaters are not a realistic option, neither from a construction, nor from a financial perspective.** Fortunately, the ports on the Solomon Islands tend to be naturally sheltered.

Earthquake protection

The Solomon Islands 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 in the Solomon Islands

The Solomon islands still are, for the most part, powered by fossil fuels. The cost 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 in 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. At the time of the study, smaller buildings, perimeter lights and boom gates were powered 100% by renewable energy. The power for the perimeter lights is saved using 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-powered port equipment to electric equipment is investigated, but will not lead to decarbonised operations, as almost all electricity on the Solomon Islands is generated using fossil fuel power stations. The same applies to 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, shore power will not be provided to all ships. The power consumption of cruise ships, for instance, which consume 10 to 15MW of power, demands too 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 for a solid business case.**

Port industry

The decarbonisation of the port industry will follow the pace of the country transitioning from fossil fuel powered electricity plants. Further steps can be taken by installing solar power on the buildings in the port, however this will not be sufficient to provide decarbonised energy 24/7.

Status of GREEN infrastructure development in the 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 related to climate resilience. Green energy related investments are considered if they can lead to cost reductions and the capital investments are within the reasonable budget of the port authority or government. Private investments are needed to finance the climate resilient assets and the 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 risks, **harbour infrastructure needs to be replaced**, and the required investments can run up 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, both 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 port activities and most of the food supply is imported through the ports.

An area where action is needed is the replacement of existing jetties with jetties that have a higher deck level by 1m. The connection to the hinterland needs to be improved as well, by installing better water management systems, as the access routes may flood in case of 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. In terms of decarbonisation, 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 the GreenVoyage2050 project, are not feasible at the moment.

Of all the investigated case studies, the urgency of climate adaptation is the highest for the Solomon Islands. Surprisingly, this does not mean that port decarbonisation initiatives are discouraged. The ports are actually in phase 3 in terms of providing power to 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 lead to some form of export economy, limiting any future business case driven investments.

Discussion

DISCUSSION

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

Survival comes first

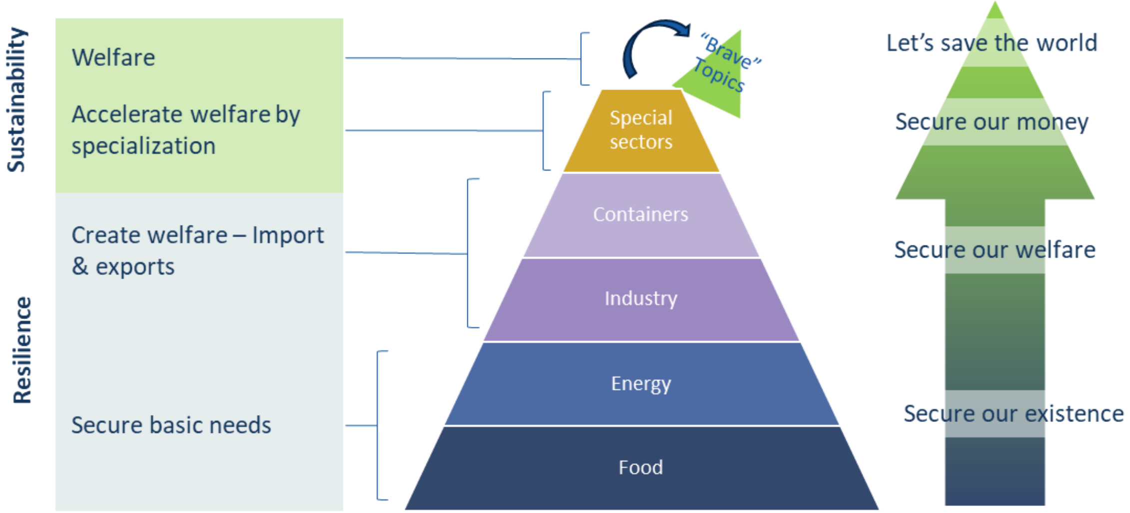
From the interviews, it became apparent that ports tend to prioritise resilience investments over decarbonisation investments, the higher the vulnerability and the smaller the port, the more prominent this development. The small island ports in Indonesia and on the Solomon Islands have the strongest opinions in this regard.

Ports are vital to the economy of the region they serve; the first goal of a society is to meet basic needs, such as food, energy and housing, to a sufficient degree. Once basic needs are met, 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 met before investments at the level above are considered. Resilience investments ensure trade can resume; they directly affect the availability of basic needs and the creation of welfare.

Decarbonisation investments can be considered as brave topics, the effects are noticed in the long term and not always in the geographical location where the investments are performed. 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 prioritised over decarbonisation investments.

Investment Priority Pyramid



DISCUSSION

Vulnerability and size go hand in hand

Small ports, both in terms of 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 prioritise resilience over decarbonisation, the larger ports are often considered less "vulnerable". Major ports in Indonesia do have the size and leverage required to adopt mitigation measures, as well as make decarbonisation investments.

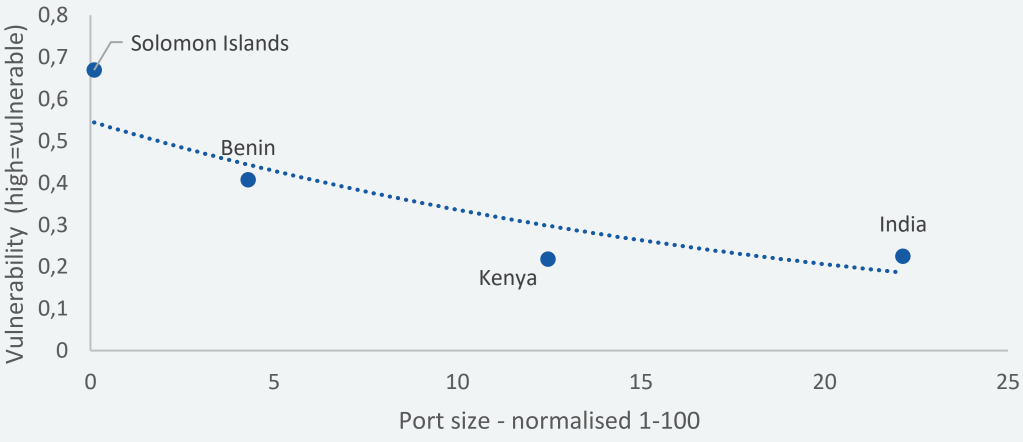
Even though the small ports are often extremely important for the survival of the local communities, they are the ones struggling the most for their continued existence. The following reasons were identified:

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

Whether or not ports have the budget to make the necessary investments is not just related to the country in which the port is located, but also to the size of the port itself. 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 the port is located in.

Vulnerability vs port size



Chasing the business case

Throughout the study, we have seen that often investments are not made due to low budgets, stringent regulations, lack of a national strategy or lack of available space. The most prominent reason for placing fleet decarbonisation initiatives in stand-by is the market uncertainty in terms of final fuel selection and the high prices 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, albeit often with a bankable business case - solar, for example, is already competitive with grey power in certain cases.

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

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

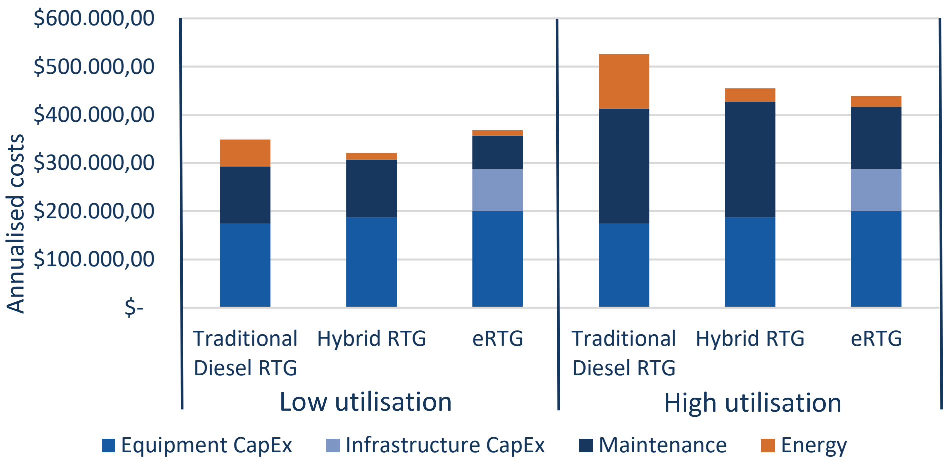
The costs of electrical equipment with a low usage rate is on par with traditional (diesel-powered) equipment. The costs of electric equipment with a high usage rate is lower than for hybrid electric equipment or traditional diesel-powered equipment with a high usage rate. When automated stacking solutions 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 in air quality and the positive effects on the health of the local people in cities located in the vicinity of the port and in terms of 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 on who will finance these upgrades, which can even lead to the renegotiation of concession agreements.

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



DISCUSSION

Allocation of funds remains a risk

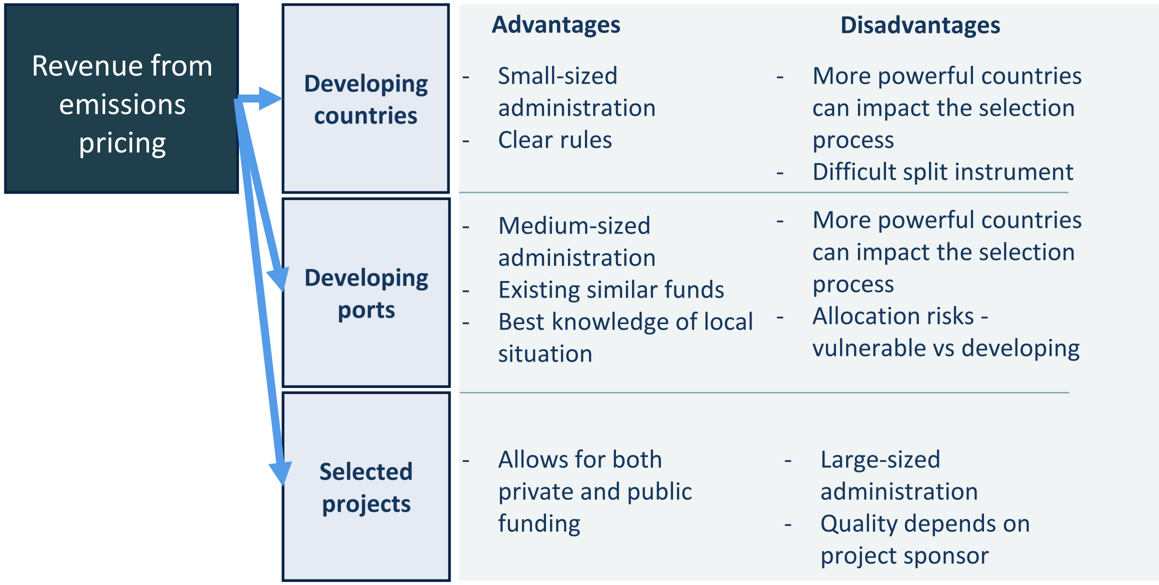
The core challenge regarding funding decisions is how to identify which investments require support and **how to assess not just the societal indirect and direct value, but also which countries need help the most**. Large maritime economies (such as India and Indonesia in this study) often have a larger budget at their disposal. However, it is often distributed unevenly amongst all ports, with the larger ones getting a larger share. The main risk when looking at support mechanisms for developing countries is the poor allocation of investments, i.e. Investing public funds 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 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, eliminating the need for local ports). **The effects of decarbonisation and resilience are also still in an early level of development themselves, both in terms of concession pricing and investment business case development.** This leads to the risk of an inefficient use of public funds.

Assuming that the GHG levies, as described in the first chapter, come into effect, the allocation of the revenue from the pricing instruments will be key. Parameters from literature and findings from 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 pricing 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



Revenue from emissions pricing

	Advantages	Disadvantages
Developing countries	- Small-sized administration - Clear rules	- More powerful countries can impact the selection process - Difficult split instrument
Developing ports	- Medium-sized administration - Existing similar funds - Best knowledge of local situation	- More powerful countries can impact the selection process - Allocation risks - vulnerable vs developing
Selected projects	- Allows for both private and public funding	- Large-sized administration - Quality depends on project sponsor

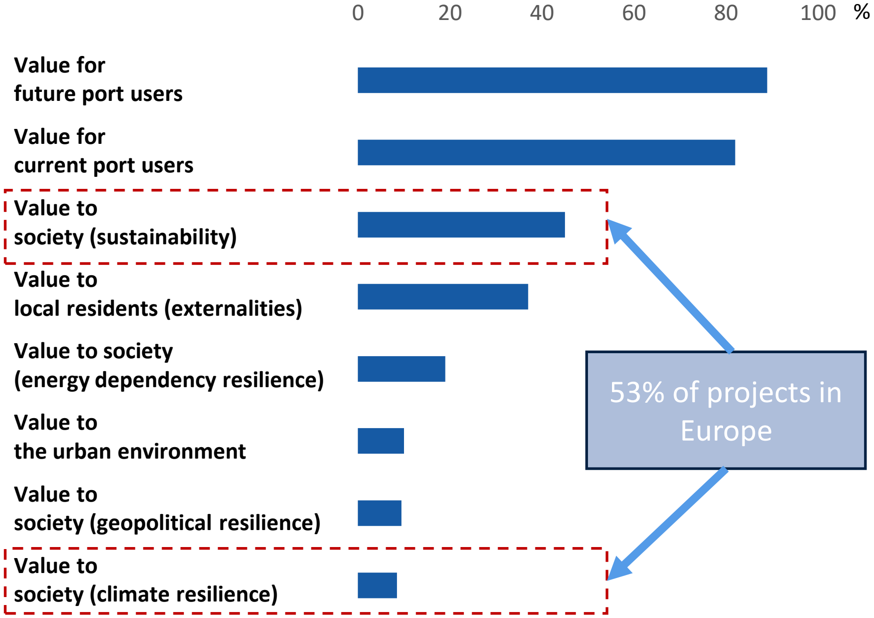
“Wait and see” regarding alternative fuels

As we have outlined in Section 1, usually port investments only make sense if they create “value.” This value is, traditionally, economic or societal in nature. 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 management body captures the value they create for the users.** This type of economic added value is, as explained in the previous sections, less prevalent in developing countries, both in terms of the pyramid of sustainability and due to the fact explained in Chapter 1, i.e. that many ports in developing countries lack good connections to the network and generate low value for the users. The creation of societal value is based on externalities, i.e., effects of the investments that reach beyond the boundaries of traditional economic activity. They are harder to monetise and traditionally include direct and indirect economic benefits, increased efficiency of transport infrastructure, increased safety, and security.

This reasoning for developed nations can be seen in the figure “Value creation of European port infrastructure investments” where we see that the majority of infrastructure investments is aimed creating value for current and future port users, who often bring in direct revenue. In addition, since a lot of European Ports are actively pursuing environmental goals and ‘value for society’ investments are on the rise, reducing the environmental footprint of the activities in the port and creating value for local communities through reduced local negative externalities.

Viable and financeable infrastructure investments are expected to generate value for society and the market, relative to their costs, e.g. be a bankable business case. However, not all viable investments generate the necessary financial returns to make them attractive from a commercial (private) perspective. The overall uncertainty of future fuel that needs to be used, coupled with the limited private interest in the business cases in these regions, led to a “wait and see” approach with most interviewees. **Hard figures on the necessary investment were not provided, however, in the 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]



DISCUSSION

Financing the green potential

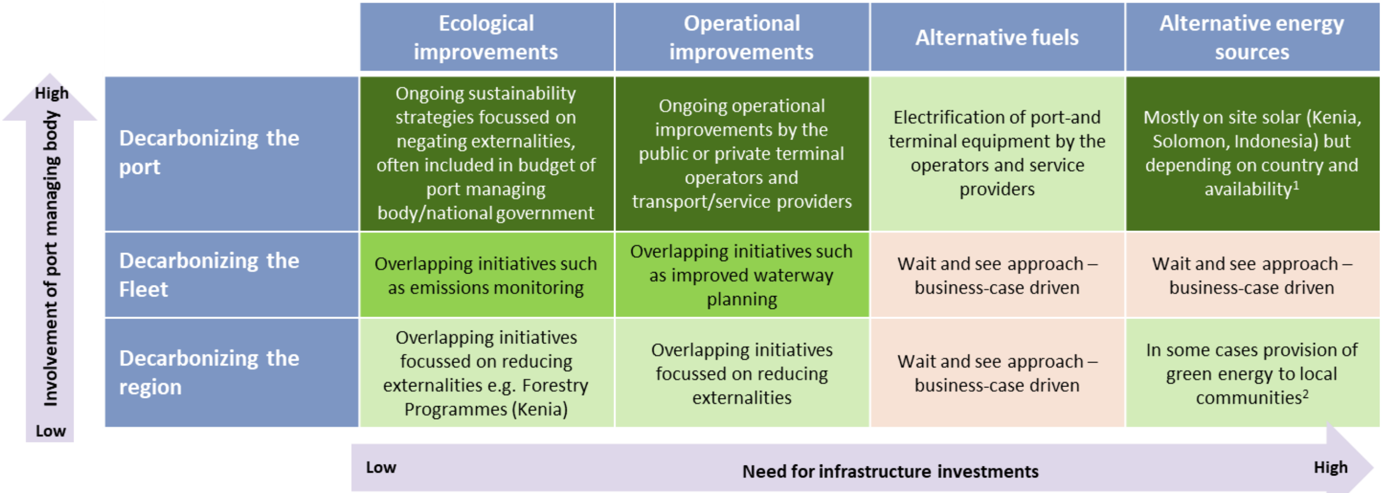
During the interviews, we focused on the potential benefits and costs of (1) decarbonising the port and using the port to (2) decarbonise the region. Many of the ports interviewed were included in national sustainability plans and road maps or had plans of their own (e.g., India National, Kenya National Ports, etc.). Following a simplified model as the one introduced in Section 1, we can map the current initiatives and gaps with fully decarbonised ports in the figure below. The Y-axis shows that the involvement and decision power of port management bodies decreases the more decarbonisation investments become regional in nature. 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 a complex PPP arrangement, with supply and offtake agreements.

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

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

In this segment, we can see a larger role for specialised agencies such as the IMO and regulators, accompanied by more certainty and therefore lower-risk investments.

Decarbonisation investments by 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 p.29, most countries are focused 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

Where to draw the line

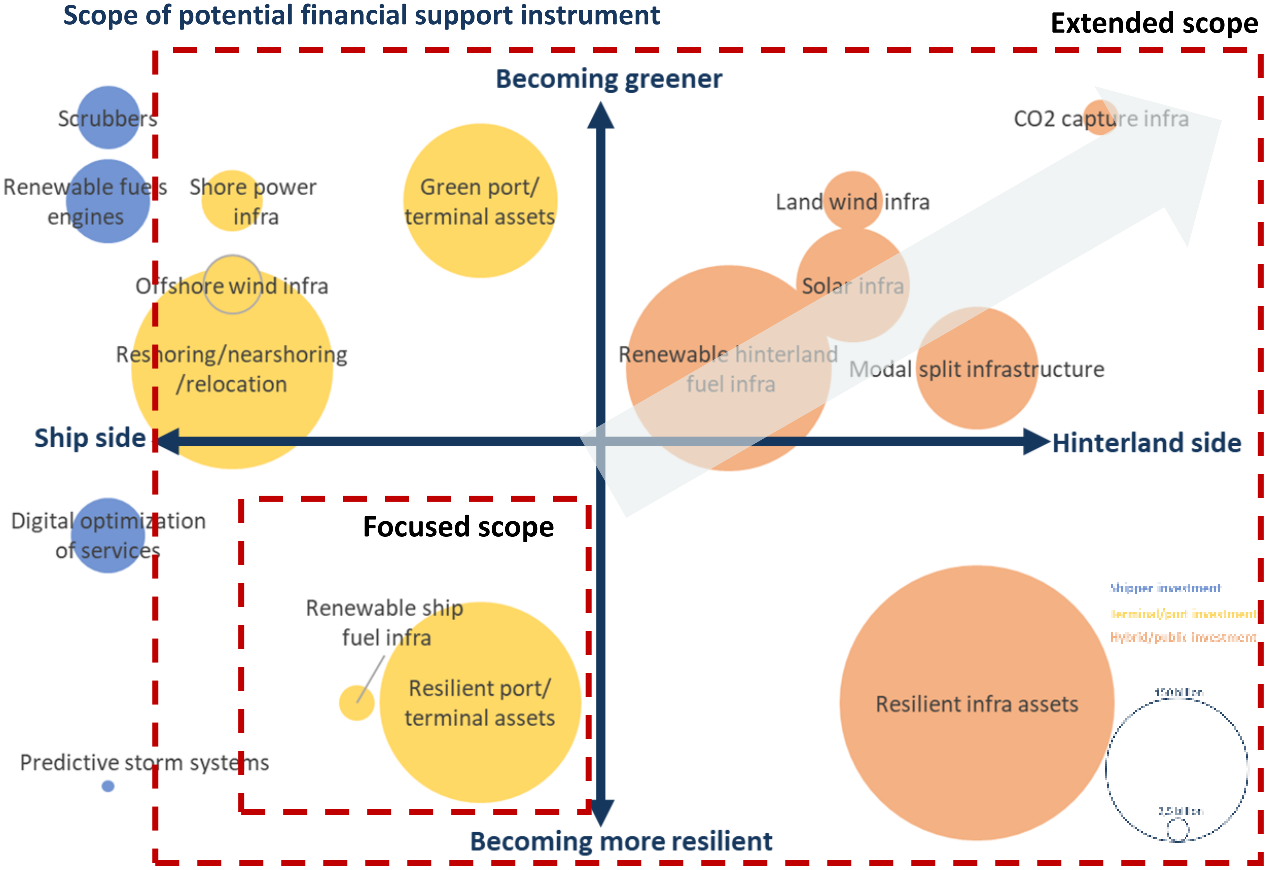
The interviews outlined a large number of examples both in what concerns the climate issue and the ongoing development projects. These projects and issues range from local flooding of terminals to flooding of the entire coastal-bound intermodal links (see case chapter p.29).

Given the complexity of both the port industry and the effects of climate change, it will be of the utmost importance to clearly define the allocation of potential funding. If the results from the prior assessment studies made by the IMO hold up and a potential revenue of about 100 billion USD is generated , choices will have to be made when it comes to which projects are included in the 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 mean the end of the port.

Scope of potential financial support instrument

Scope of potential financial support instrument



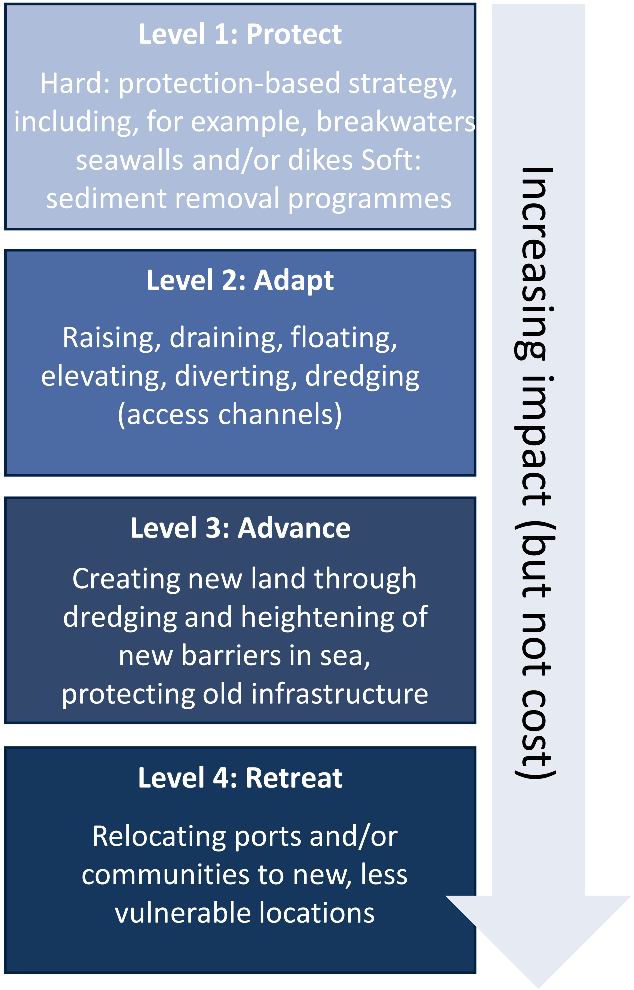
DISCUSSION

Pathways to resilience

Capital for infrastructure investments is becoming more scarce and protective measures are very costly. Hence, strategies to support the most vulnerable ports should also be considered in terms of effectiveness over 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 number and adversity of weather phenomena, be it flooding, storm surges, or other disruptions, infrastructure like additional breakwaters is needed and existing infrastructure needs to be adjusted or raised.

Where coastal flooding is an issue, it is, from the perspective of contractors (engineers, dredging firms), often more cost-effective 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 total impact of the downtime of a terminal on the supply chain and on the costs of the terminal operator for redevelopment often exceeds the impact related to the relocation of 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 by becoming completely submerged due to sea-level rise, such as the Maldives and Tuvalu. In the Maldives, the inside of atolls is being filled with sand to create new land that is protected by the outer area 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, including, for example, breakwaters seawalls and/or dikes Soft: sediment removal programmes

Level 2: Adapt

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

Level 3: Advance

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

Level 4: Retreat

Relocating ports and/or communities to new, less vulnerable locations

Increasing impact (but not cost)

Case study: 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 pace and influence of climate change. Climate is changing rapidly, there are projects that were completed less than 10 years ago and which have already experienced multiple times weather conditions that should only occur once every 100 years.

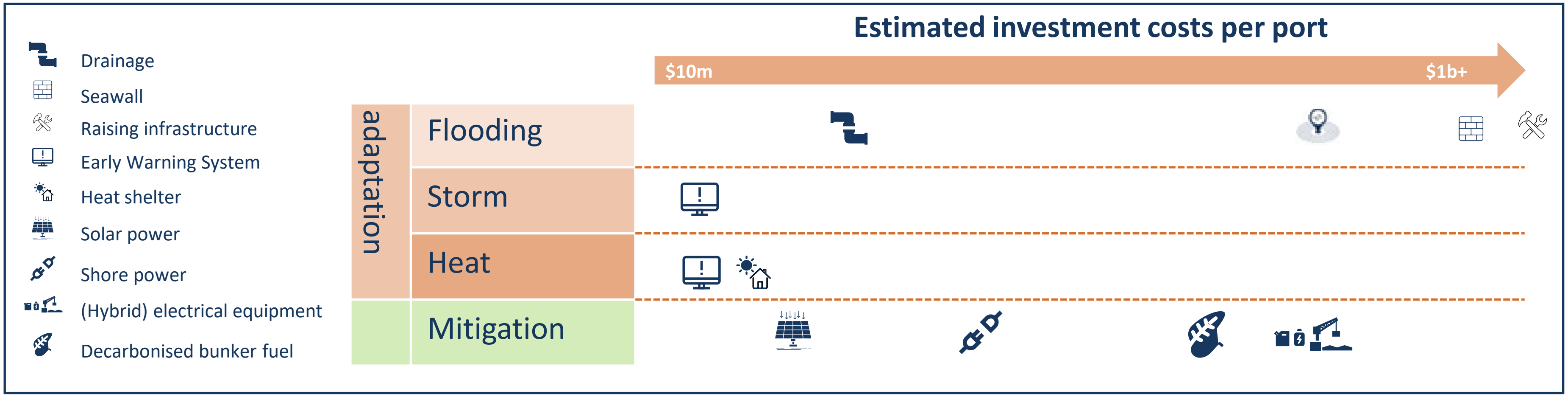
DISCUSSION

One size does not fit all (1/2)

The original intent of this study was to fully quantify the investment needs across the ports in all the developing countries, by extrapolating the infrastructure developments identified. This proved to be a nearly 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 interviews. None of the interviewees wanted to give firm figures in terms of the price of the required investments. However, a couple of interesting facts stand out:

1. The adaptation investments were estimated to be 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 adaptation and mitigation investment costs for ports, identified in interviews



DISCUSSION

One size does not fit all (2/2)

The figure to the right illustrates the challenge when trying to quantify the required infrastructure investments across many 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.

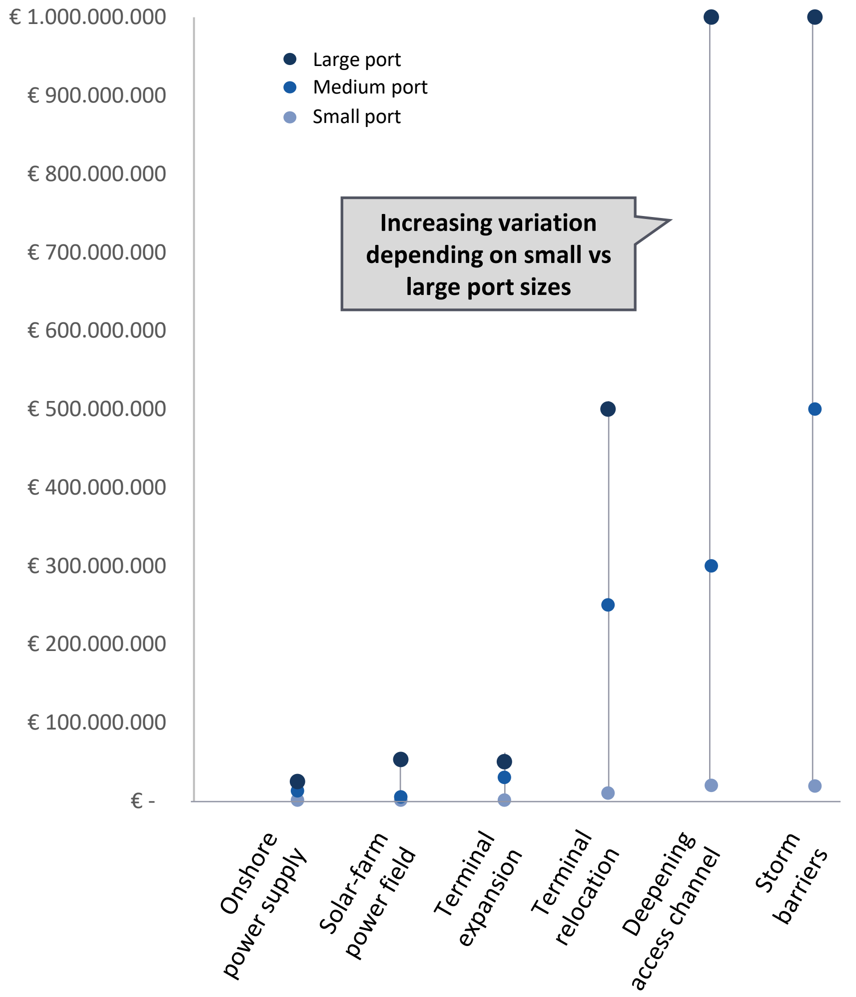
We have identified 51 developing countries, which include a total of 126 commercial ports. They have been classified as small to large based on estimated throughput and the CIA World Factbook. We have created a couple of very basic scenarios:

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

According to these scenarios, the estimated investment needs amount to a total of 55 to 83 billion USD for mitigating and adaptive port infrastructure, in the 51 developing countries identified.

Please note that this is a very rough calculation and only intended to be used as indication of the size of the issue of mitigating and adaptive port investments; it excludes many adjacent costs and only focuses on the costs identified in this study. A full quantification is only possible if a full bottom-up assessment based on a peer review climate model of each of the ports is 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 cannot be denied.** However, whereas ports in developed countries are industrial clusters and welfare generators, **ports in developing countries are literal lifelines for the local communities.** In addition, they often have less access to funds and capital for further development, in terms of both 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 support of the shipping industry.
- Port infrastructure is a complex matter with **many levels of infrastructure, often controlled and managed by different entities**. Due to this aspect, investment decisions in adaptation and mitigation infrastructure are especially complex. Due to the high importance of energy transition investments, from a social standpoint, we expect public authorities to become 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 on 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 more and more phenomena occurring in a shorter timespan, which puts pressure on the infrastructure**
- **Developing countries 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 investment priorities, etc.
- **Tackling climate change in the maritime industry means tackling both adaptation and mitigation for ports (and ships).** Adaptation is focused on maintaining trade through ports and making sure that they are protected against the onslaught of climate change disruptions. Mitigation entails trying to get the port to become 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 carbon pricing instruments suggested by the IMO present both promise and risk for developing countries**. 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 decarbonisation to succeed and help prevent dangerous levels of global warming, **the sector must reach a 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 of investing in technology that may not be (widely) adopted, eventually.**
- 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 payback requirements, this is even more the case for **adaptation measures like building storm barriers, where there is no underlying economic business case, except the potential protection from future economic loss due to the disruption of activities.**
- The five cases investigated focused on varied developing countries, from large to small port economies, countries with many and few ports, some having a mix of small and large ports, etc. **The results showed that these ports mostly deal with similar issues when it comes to investment needs for mitigation and adaptation. The types of required infrastructure may vary but overall, the need and findings were relatively similar. What was vastly diverging was the actual estimation of costs and feasibility of the investments, depending on the port size and the country in question.**
- From the 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 have the strongest opinions in this regard.
- **The costs of climate adaptation are a magnitude higher than those associated with mitigation**. The construction of storm barriers, the 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 the adaptation measures. For example, 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 *ad hoc***, e.g. upon request of a terminal operator (sometimes with joint investments) or driven by regulations. This is partly due to the high level of uncertainty in terms of fuel selection in the future and in terms of future supply and demand networks linked to renewables.

CONCLUSIONS

- Developing countries hold just a tenth of the world's financial wealth and have only made a fifth of the clean energy investments committed by developed countries. **Economic growth emerges as the primary solution to bridge this gap,** enabling developing countries to offer incentives and subsidies for energy transition and infrastructure development.
- **Green energy from solar and wind will provide several developing countries with a new opportunity to produce, use and/or export green energy** to countries with high energy demands. 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 measures**. A carbon tax that goes beyond the shipping sector and that also targets the companies in the ports could therefore be a strong incentive for both public and private port entities to achieve "greener" operations. This will however result in higher transport costs over time
- **Smaller ports are more vulnerable than large ports**, underlying factors are (1) Lower availability of budget resources from the national government, (2) Lower availability of budget resources from the income of port services, (3) Lower quality of existing infrastructure both for climate protection and trade, (4) Smaller port management organisation, 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 countries are to be supported through **revenue from carbon tax instruments applied to shipping, it is important that the funds be allocated as efficiently, justly and transparently as possible**. This means that decisions need to be made on the 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.
- Where coastal flooding is an issue, it is, from the perspective of contractors (engineers, dredging firms), **often more cost-effective 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 total impact of the downtime of a terminal on the supply chain and on the costs of the terminal operator for redevelopment often exceeds the impact related to the relocation of 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 the new external conditions.**
- The costs of port decarbonisation infrastructure vary widely depending on port size, location, existing infrastructure, existing activities, prior adaptation and mitigation plans etc. We **estimated that the total investment needs for port adaptation and mitigation in developing countries roughly amounts to 55 to 83 billion 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	25%	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.

Any calculations and assumptions presented in this study are based on expert opinion and publicly available data. No due diligence has been conducted to verify the accuracy of the information provided. This report is intended solely to provide insight into the estimated size of the investment amount and should not be relied upon for making financial decisions without further independent verification.

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