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Coastlines in crisis: key risks from rising oceans

Key take aways

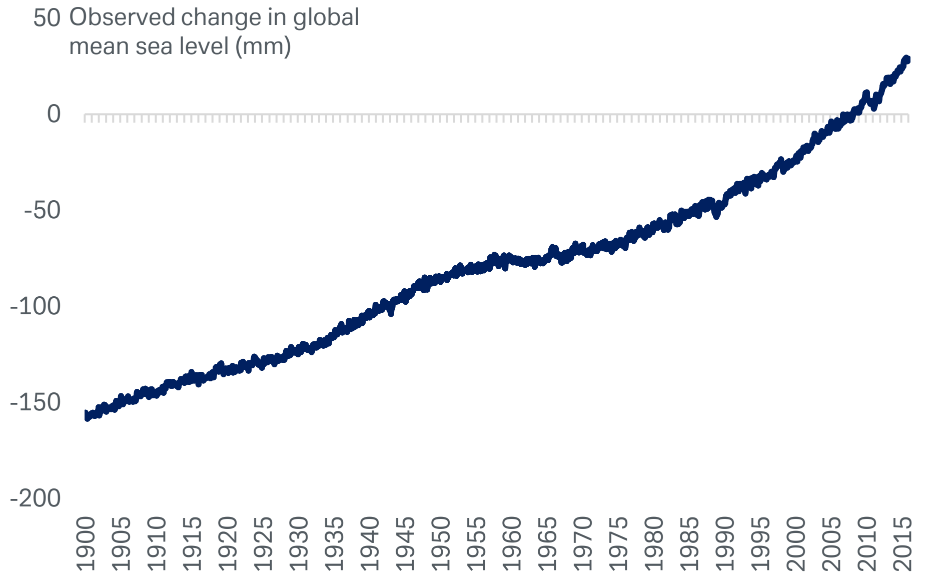
- Rising sea levels will put coastal populations and critical economic assets under increasing stress, in addition to the impact of climate change and ocean degradation on marine ecosystems.
- Substantial population displacement is not an unlikely scenario. This and the impact of rising seas on food supply, tourism, transport and energy infrastructure could markedly reduce global GDP.
- Adaptation strategies have the potential to reduce the impact of rising seas but substantial and coordinated investment will be needed, as well as financial transfers from developed to developing economies.

01 Introduction and investment implications

Average sea levels have increased over 21 cm since the start of the 20th century, with about one third of this rise being experienced in the last 25 years alone. Every year, the sea rises another 3.4mm mainly because of the thermal expansion of ocean water and the melting of land-based snow and ice reserves.[1]

Rising seas will put ecosystems, marine biodiversity, coastal populations and critical economic assets under increasing stress. The implications are not limited to coastal areas.

Figure 1: Sea level changes since 1900 according to satellite and other observations



Source: Nature climate change. Data as of August 2021.

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The **economic risks** are substantial. It is estimated that 20% of global GDP could be threatened by coastal flooding by 2100 if no action is taken.[2] Effects on sectors like agriculture and tourism will be especially disruptive for developing countries most reliant on them. Infrastructure and real estate assets will be put at risk if no adaptation is undertaken.

There are some encouraging historical precedents. We know (from the examples of Venice and the Netherlands) that **adaptation strategies** (including both nature-based and technology-based solutions) can help mitigate the risks.

However, the costs will be high and strategies may need to be revised as new challenges come ahead and our understanding of the ocean gets more complete. Policymakers will need to create the right framework for decision-making processes. International coordination and financial transfers between countries will be necessary to avoid development imbalances across the world. Indeed, coastal protection has so far often been very effective and cost-efficient for cities – but will involve a degree of subsidy for less densely populated rural areas.[3]

Judging exactly what is needed is a complex process. There are cognitive obstacles involved with assessing risks, exacerbated by the fact that sea-level threats are comparatively unquantified and may run over very lengthy time periods. Moreover, communities may feel threatened by some adaptation methods, given the threats to private assets (e.g. homes).

Planning for rising seas levels involves creating a far-sighted **planning framework** that is robust and versatile – in that it can adjust to changing circumstances, always looking for creative solutions. The decision making process needs to create a common awareness of risk, involving all stakeholders but also addressing the incentives and limitations that these stakeholders have to change their approach.

As part of this, policymakers will need to address **imbalances with less developed countries**. Protection is projected to be extremely cost efficient on a worldwide scale and in metropolitan and densely inhabited areas, but in disadvantaged and less heavily populated places, benefit-cost ratios are typically less than one.[4] As a result, without significant transfer payments to underdeveloped countries, poorer areas are likely to suffer.

For investors, three points are worth stressing:

- Rising sea levels pose threats to many different sorts of investment, and not just in physical assets. Sustainability ratings need to reflect this.
- Adaptation strategies will involve both technology and nature-based approaches – creating a wide range of interesting projects and opportunities.
- Rising sea levels will have major implications for the overall macroeconomic and policy outlook (e.g. around borrowing, inter-country transfers) which may impact the overall investment environment.

02 Warming oceans and ecosystems

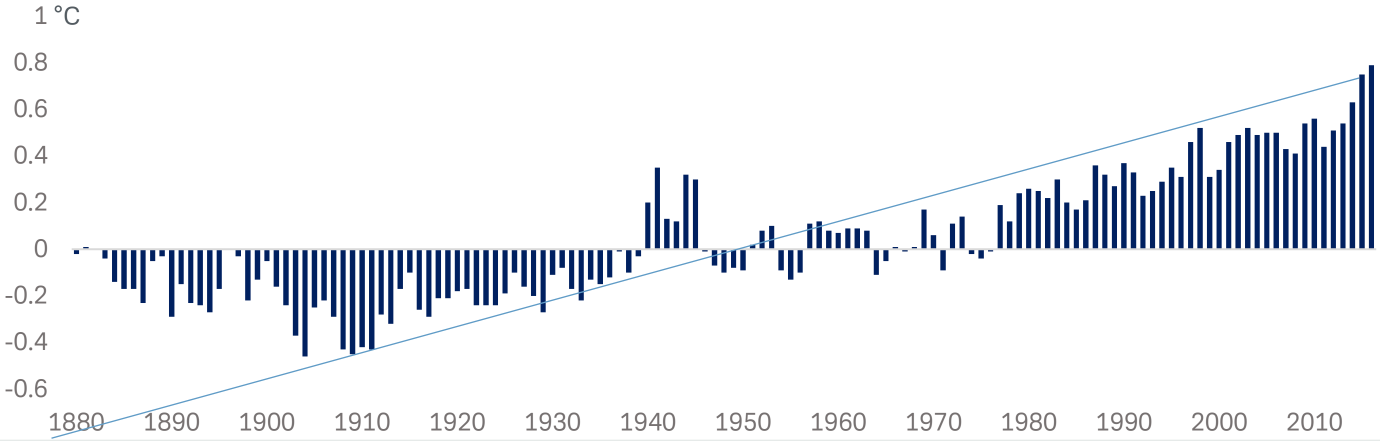
Oceans and coasts provide critical ecosystem services such as carbon storage, oxygen generation, food and income generation which are put at risk by climate change. Feedback loops mean that the loss of these ecosystem services will in turn further exacerbate **climate change.**

Every year, the ocean absorbs around a quarter of CO_2 emissions produced by human activities, making it one of the world's greatest "carbon sinks", as well as most of the trapped heat. But their ability to do this is not unlimited. Hotter and more acidic oceans, due to the effects of climate change, are already having an impact on marine ecosystems and biodiversity.

Increased greenhouse gas emissions (even under a limited carbon budget) will worsen the impact of already existing stress factors on coastal and marine environments from land-based activities (e.g. urban discharges, agricultural runoff and plastic waste) and ongoing exploitation of these systems (e.g. overfishing, biodiversity loss, deep-sea mining and coastal development).

These cumulative impacts weaken the ability of the ocean and coasts to continue to perform critical ecosystem services.[5] This in turn will affect populations living in coastal areas in a variety of ways, as for example forced migrations due to rising sea levels and depleted food supply due to warming oceans' impact on fish stocks.

Figure 2: Global sea surface temperature anomalies (deviations from expected levels) since 1880



Source: U.S. National Oceanic and Atmospheric Administration. Data as of August 17, 2021.

Prominent effects from warming oceans already include seasonal shifts in species, coral bleaching, coastal flooding, coastal erosion, toxic algal blooms, hypoxic (or dead) zones, novel marine illnesses, the extinction of marine animals, variations in precipitation levels, and fisheries losses.

These effects set up feedback loops. For example, **vulnerability from coastal flooding** has been exacerbated by the loss of biodiversity, ecosystem services and coastal vegetation due to increased ocean degradation. At present, 50% of salt marshes, 35% of mangroves, 30% of coral reefs and 29% of sea grasses have been either lost or are degraded worldwide.[6] These ecosystems together lower wave heights on average by 35%-71% and their degradation will magnify the already significant increase in storms' severity and coastal erosion and land loss from rising sea levels.[7]

The themes of climate change and **ocean acidification** are inseparable. As shown by Figure 3 (and discussed in in our previous [CIO Special report – Empowering the blue magic]) the ocean has absorbed much of global warming since the 1970s. This stabilizing function, though, comes at the cost of acidification and rising sea levels. Ocean acidity is estimated to have grown by about 30% since the beginning of the industrial age and has already caused significant changes to ocean ecosystems, with implications for food security.[8] In a high CO_2 business-as-usual emission scenario, the worldwide yearly costs of mollusc loss, to give an example, from ocean acidification might exceed USD100bn by 2100.[9, 10]

Deoxygenation is another problem. Hypoxic (dead) zones are defined by low or depleted levels of oxygen in water, which is frequently accompanied with algal overgrowth and can be associated with reductions in regional fish stocks. Globally, since the 1950s oceans' dissolved oxygen level has dropped by around 2% and is predicted to decrease another 3-4% by the year 2100 under a business-as-usual scenario.[11]

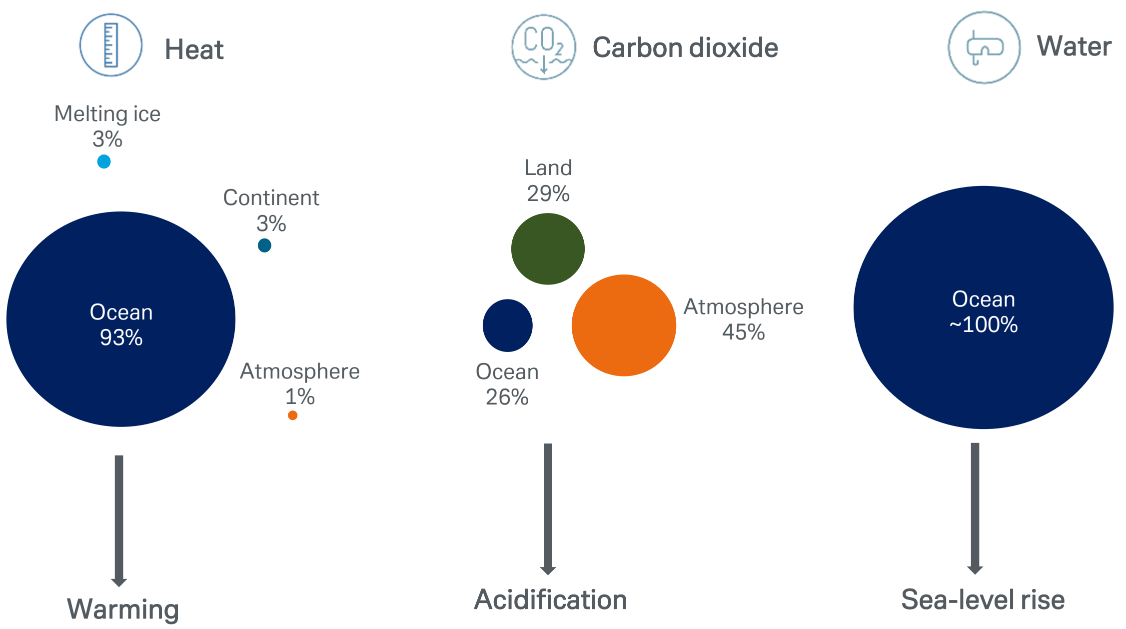
Rising ocean temperatures can also cause **coral bleaching** – when too warm water makes corals expel the algae that live in their tissues, leading the coral to turn totally white, bringing it under extreme stress and putting it at risk of death. Again, this has environmental and economic implications. According to one study, the overall net benefit of the world's coral reefs every year is USD29.8bn.[12]

Rising sea levels can cause saltwater intrusion into freshwater systems and groundwater, limiting the amount of water available for drinking and agriculture.

Food security in terms of production, access, usage, and price stability – will also be affected. According to one piece of research, the total impact of a warmer ocean from 1930 to 2010 was a 4% reduction in food provisioning potential throughout the planet. Food provisioning potential losses have been significantly higher in certain locations, such as the East China Sea and the North Sea, ranging from 15% to 35%.[13]

Finally, warming oceans may also pose increased dangers to **human health.** Evidence shows that observed warming might influence numerous vector-borne illnesses through a variety of processes, such as changing diseases, vector, or reservoir distributions, or increasing outbreak likelihoods and risk of disease spread.[14]

Figure 3: The ocean's contribution to excess heat and carbon dioxide absorption



Source: Magnan, Cooley, Billé, Kelly: Intertwined ocean and climate: implications for international climate negotiations, 2015.

03 Economic impacts

Rising sea levels will have global macroeconomic effects (for example on agriculture and tourism) but also damage existing infrastructure – including ports, airports, sewage systems, transportation and energy networks – and real estate assets, from residential to commercial properties.

Population displacement. Over two-thirds of the world's major cities, with over a quarter of a billion people population, are positioned on the coast.[15] Now and in the near future these communities will have to face the very real threat of rising sea levels and an increase in both frequency and strength of storm surges. In terms of exposed populations, most of these cities are in Asia: at present, Kolkata probably leads the list, followed by Mumbai, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai and Bangkok.

Currently, 680 million people are estimated to reside in low-lying coastal areas, with this figure expected to rise to over one billion by 2050.[16] It is projected that if global mean sea levels rise by 2 metres by 2100, up to 187 million people will be forced to relocate.[17]

Lost assets. Sea level rise and floods are expected to cost the world's economy USD14.2tn in lost or stranded assets by the end of the century.[18] The expected annual cost to the economy would be equal to 4% of global GDP, with significant differences among regions. The northeastern coast of the United States, northwestern Europe, and significant sections of Asia, particularly nations surrounding the Bay of Bengal, Indonesia, China, and northern Australia, are the most vulnerable to extensive floods.[19]

Agricultural sector. The rise in sea levels will primarily affect the agricultural sector through land inundation, salinization of soil and fresh aquifers, and land loss brought by irreversible coastal erosion, with implications for production, livelihood diversification, and food safety, particularly in coastal countries strongly dependent on agriculture.[20] Recent research on rice cultivation emphasises the importance of coupled surface elevation and soil salinity. In a 1.8 m sea level rise scenario, the rice production index in the Ebro delta (Spain), for example, is expected to fall from 61.2 percent in 2010 to 33.8 percent by 2100, almost half of its value today.[21]

Fisheries and aquaculture sectors. As we note above, a rising sea level has a negative indirect influence on fisheries and aquaculture by negatively impacting ecosystems (e.g. coral reef degradation, decreased water quality in deltas and estuary settings, soil salinization, and so on) as well as infrastructure (e.g. damage to small and large harbours).

Tourism and recreation. A substantial danger can also be foreseen for tourism and recreation through impacts on landscapes (e.g. beaches), cultural features, and critical transportation infrastructures. Nearly half of all overseas tourists visit seaside locations. Tourism is responsible for more than 25% of GDP in several developing nations, especially Small Island Developing States.[22] More than a million square kilometres of shoreline – an area roughly three times the size of Germany – may be jeopardised by 2100 under a high-temperature scenario with no adaptation.[23] Countries heavily dependent on tourism will have to bear the damages of eroding coastlines and the consequent economic damages. Coastal erosion and sea level rise will impact infrastructure including energy plants, water treatment facilities, underground communications cables and transportation networks, as ports and railways.

Port infrastructure. Port cities have high population densities, with 13 of the world's 20 most populated cities being port cities in 2005.[24] Additionally, with the volume of seaborne trade globally doubling in the last 30 years, coastal cities are an important component of national and global economies, particularly in poor nations.[25] Damage to ports and harbours, as a result of sea level rise, may cost as much as USD111.6bn by 2050 and USD367.2bn by the end of the century, placing severe pressure on trade dependent developed and developing economies.[26]

Airport infrastructure. As the majority of the world's largest cities have developed around coasts, consequently, their main international airports have usually been built either extremely close to sea level or on filled shallow coastal waters. Sea-level rise was not a factor nor reason for concern when most of the world's major coastal airports were designed. Due to the combination of exceptionally high tides, storm surges, hurricanes, typhoons, and a progressively increasing sea level, these airports are currently experiencing unprecedented problems that will influence their operations for decades to come.[27] In 2012, the Federal Aviation Administration (FAA) of the United States warned that more than a dozen of the country's 50 major terminals had low-lying infrastructure that is vulnerable to rising seas and storm surge induced flooding.[28]

Sewerage infrastructure. Rising sea levels and more frequent floods will also create major problems for sewage treatment. Sewage overflow has severe health and environmental consequences. While storm water drainage systems are designed for draining surface runoff, groundwater inundation caused by sea level rise reduces the drainage capacity of storm water systems, and thus, could affect drainage and runoff infiltration. For illustration, during Hurricane Sandy in 2012, sewage congestion caused a spill of over 40 billion litres of untreated sewage into the streets, rivers, and coastal seas.[29]

Energy infrastructure. Likewise, rising sea levels endanger energy infrastructure systems and put energy assets in coastal areas at risk. Changes in sea level, as well as the periodicity and severity of storm occurrences, will almost certainly have an impact on how energy is generated, distributed and utilized. A high proportion of coastal energy facilities in the United States are located in regions sensitive to a 120 cm sea-level rise. Under a rapid sea-level rise scenario, the number of US energy facilities vulnerable to storm surge threats might grow by 15% to 67%.[30] Natural gas infrastructure, electric power plants, and oil and gas refineries are examples of these facilities.

Transportation infrastructure. Modifications in weather patterns, together with rising global warming and sea levels, have a considerable influence on transportation infrastructure systems too (e.g. roads, railways, and ports). With persistent sea-level rise, transportation infrastructure will require more regular and substantial maintenance and restoration. With enhanced rainfall frequency and severity, transportation networks will be flooded more regularly, increasing the degradation rate of transportation systems and causing interruptions in these networks.

Real estate. Sea level rises also create risks to real estate. The number of extreme weather events increased by over 250% between 1980 and 2013 globally, and insured losses in 2020 as a result of weather-related events were the fourth highest on record.[31, 32] Flooding due to sea level rise and overflowing rivers can cause severe damage to residential properties and real estate, as well as slower future price appreciation.[33] Insurance has been the main tool for mitigating these risks, but if flood events increase in frequency or severity, certain assets may become uninsurable, causing permanent loss of value. For example in the UK, an estimated 70,000 homes are at risk of becoming uninsurable due to flood risk.[34]

Potential damage to U.S. real estate is substantial. A 2018 report by the Union of Concerned Scientists argued that by 2045, sea levels are expected to go up sufficiently to put over 300,000 of today's residential homes in the **United States** at danger of chronic inundation. The total market value of these coastal houses at risk of chronic flooding is estimated roughly at USD117.5bn today; nearly 14,000 coastal commercial properties, valued at approximately USD18.5bn at present, are also at risk.[35]

04 Adaption strategies

As demonstrated historically by Venice and Dutch cities, coastal adaptation, focused on human populations and economically significant locations along the shoreline, may mitigate a large proportion of the anticipated economic losses.[36] However, measures to counter climate change also represent a significant investment – estimated at USD140-300bn by 2030 and increased to USD280-500bn by 2050.[37]

Several studies have also found that the **relative benefits and costs of coastal adaptation** are allocated unequally among nations and areas.[38] For instance, while the median cost of defence and retreat in 2050 is predicted to be less than 0.1 percent of national GDP, small island governments such as the Marshall Islands or the Maldives may have to spend the equivalent of 7.6 percent and 7.5 percent of GDP respectively.[39]

Within the OECD, implementation of measures is lagging. Only five nations have budgeted specifically for coastal adaptation. In one of them, **Germany**, a special instrument (Sonderrahmenplan) was founded in 2009 to accelerate the development of coastal protection owing to climate change concerns, which gives additional combined funding of EUR25mn per year for all coastal federal states until 2025 (EUR550mn total).[40]

Adaptation strategies can be artificially divided among two categories: nature and technology-based solutions. (Although, in reality, solutions are likely be implemented together and in a complementary way via hybrid models.)

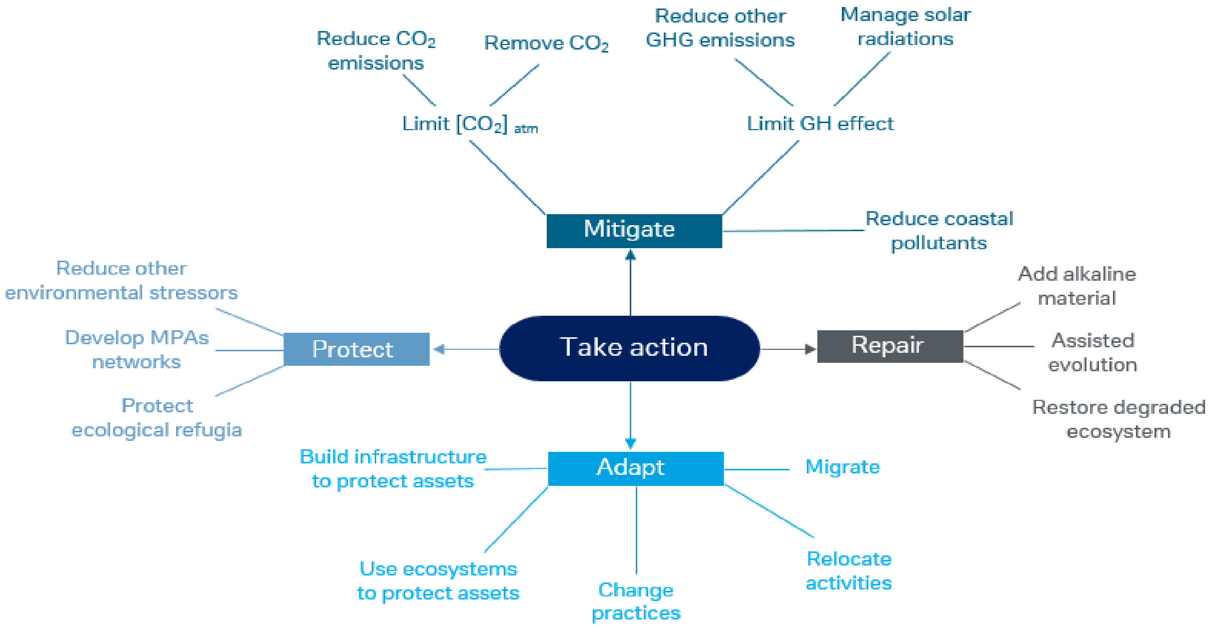
Nature-based solutions (e.g. coastal protection via developing wetlands, oyster reefs or sustainable drainage solutions) are progressively being employed as supplements or replacements for "grey" infrastructure (e.g. human-engineered water management infrastructure). They provide several advantages in addition to flood protection, including carbon sequestration, biodiversity restoration, and recreational activities.

Figure 4: Port areas with high exposure to climate extremes

Rank	Country	Urban agglomeration	Exposed assets - current (USD bn)	Exposed assets - future (USD bn)
1	USA	Miami	416.29	3513.04
2	China	Guangzhou	84.17	3357.72
3	USA	New York-Newark	320.2	2147.35
4	India	Kolkatta	31.99	1961.44
5	China	Shanghai	72.86	1771.17
6	India	Mumbai	46.2	1598.05
7	China	Tianjin	29.62	1231.48
8	Japan	Tokyo	174.29	1207.07
9	China	Hong Kong	35.94	1163.89
10	Thailand	Bangkok	38.72	1117.54
11	China	Ningbo	9.26	1073.93
12	USA	New Orleans	233.69	1013.45
13	Japan	Osaka-Kobe	215.62	968.96
14	Netherlands	Amsterdam	128.33	843.7
15	Netherlands	Rotterdam	114.89	825.68
16	Vietnam	Ho Chi Minh City	26.86	652.82
17	Japan	Nagoya	109.22	623.42
18	China	Qingdao	2.72	601.59
19	USA	Virginia Beach	84.64	581.69
20	Egypt	Alexandria	28.46	563.28

Source: OECD, RMS, University of Southampton: Ranking of port cities most exposed to coastal flooding today and in the future, 2007. "Exposed assets – future" column projects forward to 2070.

Figure 5: Possible action against climate and CO_2 ocean changes



Source: IUCN, "Explaining Ocean Warming; causes, scale, effects and consequences", adapted from Billé et al. (2013) and Gattuso et al. (2015)

Barrier islands, vegetated dunes, coastal wetlands, mangrove forests, and reefs are examples of natural barriers that augment shorelines' protection, e.g. through reducing wave heights.[41] These may also be very dynamic in their responsiveness to changes in the physical environment and may heal and regenerate after being damaged. But such replanting and recovery efforts can often fail due to the different criticalities in their implementation.[42]

Technology-based solutions involve a direct intervention, often through hard protection measures, to increase coastlines' resilience but they also include models and monitoring systems able to prevent disasters' occurrence through preparation and prevention.

Such solutions may involve the **construction of new infrastructure**, like flood barriers, to protect in turn other critical infrastructures, like ports and harbours. Other **"hard shoreline" maintenance** systems include breakwaters, bulkheads, and revetments (protecting the sloping shoreline). When these measures are not effective, relocating utility infrastructure, may be the only option: as this reminds us, climate-related risks need be integrated into capital improvement plans.

Another dimension in coastline protection is more accurate and precise **modelling for climate risk** to help predict future flood occurrences. Simulating sea-level rise and storm surge phenomena will aid in the positioning and protection of vital infrastructure. Understanding and modelling groundwater conditions will help to guide aquifer management and predicted water quantity and quality changes. Sewerage models can predict the influence of wet weather infiltration on the wastewater collecting system, as well as the capacity and operations of treatment plants. Infiltration reduction techniques, increased collection system capacity and offline storage are among the possible responses.

Coastal towns throughout the world are already progressively implementing adaptation measures. **Dutch** coastal communities' efforts are well known, including a 3,700-kilometer network of dikes, dams, and seawalls. In this regard, cities such as Rotterdam provide a blueprint for dealing with sea-level rise.

Shanghai has built 520 kilometres of defensive seawalls to lessen its vulnerability to rising sea levels.[43] **South East Asian cities** are also constructing sea-level rise defences. Jakarta, for example, is building a large sea wall and plans to move 400,000 people off endangered shorelines and reservoirs.[44] Bangkok has built a 2,600-kilometer canal network and a central park where 4 million litres can be absorbed by subterranean reservoirs.[45]

U.S. cities are industriously investing billions of dollars to strengthen their tolerance to rising sea levels. The New Orleans initiative (after Hurricane Katrina killed over 1,600 people and left 80 percent of the city flooded in 2005) is the most costly flood-control system on earth and one of the biggest public works projects in U.S. history.[46] Boston, Houston, Miami, New York City, and dozens of other cities are doing the same, though on a smaller scale.

Despite the increased focus on adaptation, it is clear that mitigation efforts must be scaled up even further to avoid irremediable damages. Past emissions will cause major sea level rise in the centuries to come, irrespective of our actions. Even if and when global warming is curbed, societies will still need to keep adapting to better protect for increasing environmental risks.

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Glossary

CO_2 is a natural gas that is also emitted as a byproduct of the combustion of fossil fuels (such as oil, gas, and coal), the combustion of biomass, land-use changes (LUC), and industrial activities (e.g., cement production). It is the most significant human greenhouse gas (GHG) affecting the Earth's radiative balance.

Greenhouse gases (GHG) are natural and manmade gaseous components of the atmosphere that absorb and emit radiation emitted by the Earth's surface, the atmosphere, and clouds. This property is responsible for the greenhouse effect and the consequent global warming.

Gross domestic product (GDP) is the monetary value of all the finished goods and services produced within a country's borders in a specific time period.

Nature-based Solutions (NbS) are classified by IUCN as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits".

The Organisation for Economic Co-operation and Development (OECD) has 35 member countries and has the objective of encouraging economic progress and world trade.

USD is the currency code for the U.S. Dollar.

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