SEA LEVEL RISE

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This is a second draft version of the knowledge synthesis product developed by the UNFCC Slow Onset Event (SoE) expert group, the subgroup focused on **sea level rise and coastal risks**.

Contributing authors

– (JM) Jaroslav Mysiak, Euro-Mediterranean Centre on Climate Change (CMCC), Venice, Italy
– (MA) Mariya Aleksandrova, German Institute of Development and Sustainability (IDOS), Bonn, Germany
– (AS) Albert Salamanca, Stockholm Environment Institute (SEI), Bangkok, Thailand
– (EC) Elisa Calliari, International Institute for Applied Systems Analysis (IIASA), Vienna, Austria

The case studies have been built based on the countries' submission to UNFCCC

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Procedural introduction

Background (title tbd)

COP 19 (2013) established the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts to address loss and damage associated with the impacts of climate change in developing countries that are particularly vulnerable to the adverse effects of climate change.[1] The Mechanism fulfills this role by undertaking, inter alia, the following functions:[2]

- Enhancing knowledge and understanding of comprehensive risk management approaches to address loss and damage associated with the adverse effects of climate change;
- Strengthening dialogue, coordination, coherence and synergies among relevant stakeholders;
- Enhancing action and support, including finance, technology and capacity-building, to address loss and damage associated with the adverse effects of climate change so as to enable countries to undertake actions.[3]

The Executive Committee, which comprises 20 representatives from Parties, guides the implementation of the Mechanism through a rolling workplan across five thematic workstreams. The Committee is assisted by five thematic expert groups established under these strategic workstreams. The thematic expert groups co-create knowledge products and undertake activities jointly with the Committee to promote integrated and coherent approaches to loss and damage associated with climate change impacts.

The Expert Group on Slow Onset Events was launched in 2021. Its current Plan of Action, endorsed in 2024, contributes to implementing one of the strategic workstreams that aims to enhance cooperation and facilitation in relation to slow onset events by strengthening the understanding and enhancing the capacity to address associated loss and damage, in particular at regional and national levels.

At COP 25, Parties mandated the Executive Committee and its thematic expert groups to develop technical guides within their work in their respective thematic area, covering:[4]

- Risk assessment, including long-term risk assessment of climate change impacts;
- Approaches to averting, minimizing and addressing loss and damage associated with such risk assessment;
- Resources available for supporting such approaches;
- Monitoring systems for assessing the effectiveness of the approaches

Accordingly, the relevant activities to develop thematic technical guides are incorporated into the workplan of the Committee and plans of action of respective groups. In the areas of slow onset events, an initial series of products will focus on glacial retreat, sea level rise and desertification.

[1] Decision 2/CP.19, paragraph 1.

[2] Decision 2/CP.19, paragraph 5.

[3] Pursuant to decision 3/CP.18, paragraph 6.

[4] Decision 2/CMA 2, paragraph 26.

The Executive Committee hopes that they provide information to assist developing countries to integrate relevant responses to loss and damage associated with these climate hazards into national planning and policymaking processes.

Scope of this document

The impacts of climate change include those associated with slow onset events. Slow onset events, as initially introduced by the Cancun Agreement (COP16),[5] refer to increasing temperatures, desertification, loss of biodiversity, land and forest degradation, glacial retreat, ocean acidification, sea level rise, and salinisation. These hazards lead to compounded and cascading impacts, which unfold gradually and, in some cases, may result in far-reaching or irreversible losses on society, culture, and the environment over an extended period that affect livelihoods in the varying contexts of particularly vulnerable developing countries. The interplay and scales of these intricate processes often add to the complexity of developing effective long-term risk management strategies for given territories or connected landscapes.

This set of technical guides aims to provide a shared understanding of how to manage the impacts and anticipate risks from slow onset events in a systemic manner through examples of projected risks and impacts, and steps that stakeholders can take to respond to these risks in a timely manner, taking into account regional particularities, traditional knowledge and local practices. The guides provide information on policy options, user-friendly tools and approaches to respond to these types of slow onset events in a manner that can be tailored to the needs of policymakers, governments, implementing agencies and other relevant stakeholders at various levels. In this context, the guides also shed light on key challenges in the specific regional context and ecosystems resulting from the focal slow onset events and showcases a wide range of examples. Presented approaches and solutions do not intend to be fully exhaustive.

This guide is structured as follows:

(a) X…. placeholder to be filled
(b) …..
(c) …..

1 Introduction (JM)

Sea level changes result from variations in ocean volume or the shape of ocean basins, shifts in Earth's gravitational or rotational fields, and local land uplift or subsidence[1]. Anthropogenic climate change causes **sea level rise** (SLR) by increasing ocean water volumes due to melting glaciers and ice sheets (land ice) and changes in ocean water density, such as thermal expansion under warmer conditions[2]. Compared to Global Mean Sea Level (GMSL) change, which is the increase or decrease in the ocean's volume divided by its surface area, regional and local sea level change is measured relative to the current mean sea level at spatial scales around 100 km (regional sea level changes)

[5] Decision 1/CP.16, paragraph 25.

and smaller than 10 km (local sea level changes). Relative sea level (RSL) change is the elevation difference between the land and the sea surface at a specific time and location[2].

Sea level rise poses substantial hazards to coastal communities worldwide, including increased flooding, erosion, saltwater intrusion into freshwater resources, and the loss of critical habitats[3,4]. As sea levels rise, causing significant land loss, the frequency and severity of coastal floods are expected to increase, damaging buildings, transportation networks, and energy systems. This disproportionately affects vulnerable communities in low-lying coastal regions, contributing to displacement, loss of livelihoods, and health risks. Coastal ecosystems, including wetlands, mangroves, and salt marshes, are particularly vulnerable to coastal inundation and erosion. Understanding and adapting to these risks is essential for building resilience of coastal communities. Effective adaptation strategies build on recent scientific knowledge, community engagement, and innovative solutions to address multifaceted challenges.

Although landward and seaward limits of the coastal zone are not consistently defined, the **low elevation coastal zones** (LECZ) are stretches of land hydrologically connected to the sea and less than 10 meters above sea level[2,5]. Gradually developed to become home to millions of people and host to large coastal cities and critical industrial and transportation infrastructure, LECZs are among the hotspots of multiple risks driven by sea level rise. Because of their low elevation, even small increases in sea level can significantly impact them. Low elevation coastal zones are by various geomorphological and land use aspects, which influence how coastal risks are propagated and what adaptation measures may be effective.

Coastal areas, often dominated by rivers, estuaries, and wetlands, have a high-water table and limited drainage, making them prone to waterlogging and salinisation. Vegetation includes mangroves, marshes, and other coastal wetlands, crucial for stabilizing shorelines and providing habitats. Many low-lying areas are in tropical and subtropical regions with warm, humid climates. The soil in these regions is usually fertile due to sediment deposits from rivers, supporting intensive agriculture. Coastal areas also sustain fishing industries due to their proximity to water bodies and attract tourism driven by recreation and nature. These regions are often densely populated, with critical infrastructure such as ports, airports, and urban centres frequently located there.

Text box 1 Typologies and archetypes of coastal areas (JM)

Recognizing that coastal areas are not equal, adaptation strategies must consider their specific vulnerabilities and requirements to effectively address their diverse needs. Various archetypes have been proposed to identify the unique challenges and effective adaptation measures for each archetype. Simple typologies include open coasts, deltas, and estuaries, whether in rural or urban contexts[6]. More comprehensive typology[7] include urban atoll islands, Arctic communities, large tropical agricultural deltas, and resource-rich cities.

- **Urban Atoll Islands**, such as those in Tuvalu, Kiribati, and the Maldives, are low-lying, ring-shaped coral islands with central lagoons. They are highly vulnerable to sea level rise, storm surges, and coastal erosion. These islands face challenges like limited freshwater resources, high population densities, and an economy often reliant on tourism and fishing.

- **Arctic communities** in regions such as northern Russia, western Alaska (USA), and northern Canada, are situated in remote, cold regions with limited accessibility. The communities rely on subsistence hunting, fishing, and herding; and face challenges from thawing permafrost that leads to land subsidence and infrastructure damage, and changes in sea ice patterns that affect traditional activities.
- **Large Tropical Agricultural Deltas**, such as the Mekong Delta in Vietnam and the Ganges–Brahmaputra–Meghna Delta in Bangladesh and India, are fertile and densely populated regions crucial for agriculture. These deltas face high exposure to flooding, cyclones, and storm surges, with saltwater intrusion threatening agricultural productivity.
- **Resource-Rich Cities**, like Houston in the USA, Rotterdam in the Netherlands, and Shanghai in China, are economically significant hubs with substantial investments in infrastructure and industry, located in coastal areas exposed to sea level rise and extreme weather events. Challenges include flooding and storm surges disrupting industrial activities and infrastructure, and urbanization increasing runoff and flooding

3 Risk assessment, including long-term risk assessment, of sea level rise impacts [JM]

3.1 Global assessments

Sea level rise is driven by multiple factors, leading to a complex array of impacts. The melting of land ice sheets and glaciers increases the ocean's water mass, and as the ocean absorbs heat, its water warms and expands. A smaller contribution to sea level rise is the decrease in liquid water on land due to groundwater depletion and reduced land retention. The redistribution of water also affects Earth's rotation and gravitational field, causing regional variations in sea level changes. Tectonics, mantle dynamics, and glacial isostatic adjustment (the uplifting of land previously compressed by ice sheets and subsidence in peripheral regions) also influence sea levels by causing vertical land motion and changes in sea surface height along coastlines.

Relative sea level (RSL) is influenced by global sea level changes and local land movements. Coastal areas can experience subsidence from natural sediment compaction or human activities like groundwater extraction. Hydrological cycles, including river runoff and precipitation changes, affect local sea levels by altering freshwater input into oceans. Sedimentation and erosion, impacted by river damming or land use changes, also influence coastal stability. Regionally, ocean currents and wind patterns are critical as they redistribute water masses and can pile up water along coastlines, causing variations in sea levels.

Extreme sea level events are often driven by short-term climate phenomena. Storm surges from intense storms like hurricanes and typhoons can cause significant temporary sea level rises, leading to coastal flooding. Atmospheric pressure changes, such as those during El Niño and La Niña events, can also cause sea level fluctuations. Additionally, non-climate events like tsunamis, triggered by underwater earthquakes or volcanic eruptions, can result in sudden and extreme changes in sea level.

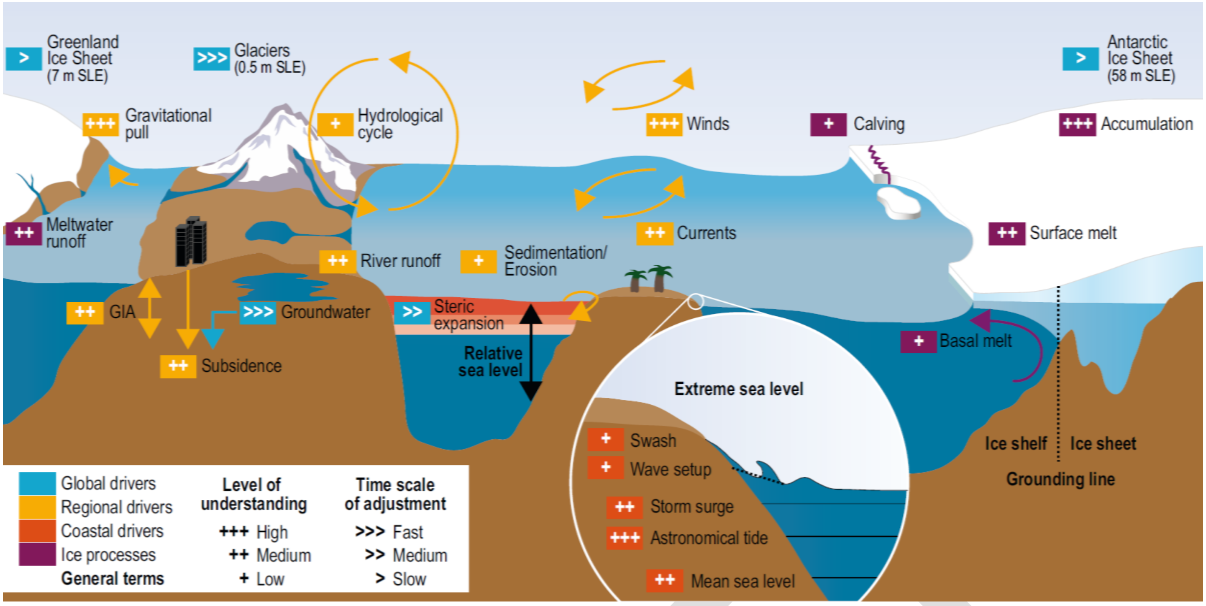


Figure 1: A schematic illustrating processes influencing sea levels along coasts.
Source: IPCC SROCC Report [1]

Figure 1 highlights the role of various feedback mechanisms and interactions between global, regional, and local processes in influencing sea level changes along coastlines. It illustrates how both climate and non-climate factors collectively impact sea levels. For instance, ice melt and calving contribute to sea level rise, which in turn affects ocean currents and wind patterns. Surface melt on ice sheets and the accumulation of meltwater impact ice dynamics and stability. Sedimentation processes, influenced by both climate and human activities, play a crucial role in shaping coastal landscapes and their resilience to sea level changes. Understanding these interactions is essential for developing effective strategies for coastal management, resilience, and adaptation to sea level changes and extreme events.

3.2 Observed and future sea level rise

Observed sea level rise has been extensively documented and updated in the IPCC reports (Special Report Ocean and Cryosphere in a Changing Climate SROCC[1] and Sixth Assessment Report AR6[3]) and ever since by the global and regional State of Climate Reports[8] produced by the World Meteorological Organization (WMO) and other regional partners, such as the Copernicus Climate Change Service (C3S). Common insights from across these reports indicate, with high confidence, that global mean sea level (GMSL) rose faster in the 20th century than in any prior century over the last three millennia, and this rise has accelerated since the 1960s. The largest contributor to the observed changes is the loss of land ice, accounting for over 40%, closely followed by ocean thermal expansion, which is slightly under 40%. Among the ocean basins, the largest increase was recorded in the Western Pacific, while the slowest increase was observed in the Eastern Pacific[3].

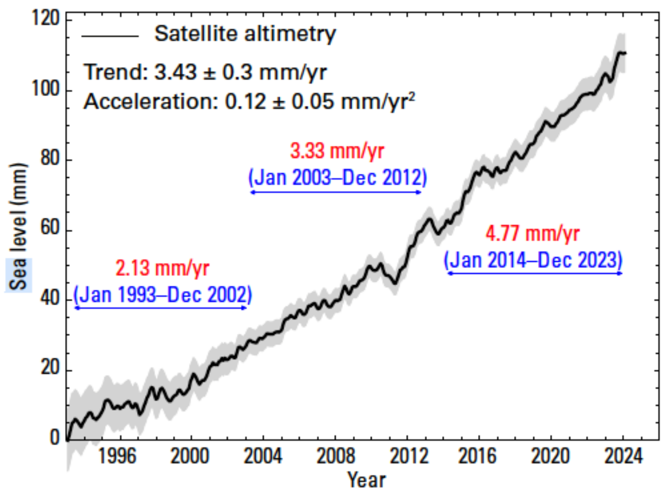


Figure 2 GMSL evolution from January 1993 to December 2023 based on satellite altimetry.

Explanation. WMO 2024[8]. The black line represents the best estimate, while the grey shaded area indicates the uncertainty.

Global sea levels have risen by over 10 cm over the past 30 years, and by about 21cm since records began in 1880. According to the most recent measurements (Figure 2), the long-term rate of sea-level rise increased to **4.77 mm per year** between 2014 and 2023, which is more than double the rate of 2.13 mm per year observed between 1993 and 2002[8]. Observed variations in relative sea levels indicate significant regional differences, influenced by factors such as land subsidence, glacial isostatic adjustment, and ocean circulation patterns, leading to areas experiencing sea level rise at different rates (Figure 3). Global sea level experienced a significant rise from 2022 to 2023, due to the transition between El Niño–Southern Oscillation (ENSO) effects. A mild La Niña in 2021-2022 led to a lower-than-expected sea level rise, while a strong El Niño in 2023 boosted the average sea surface height.

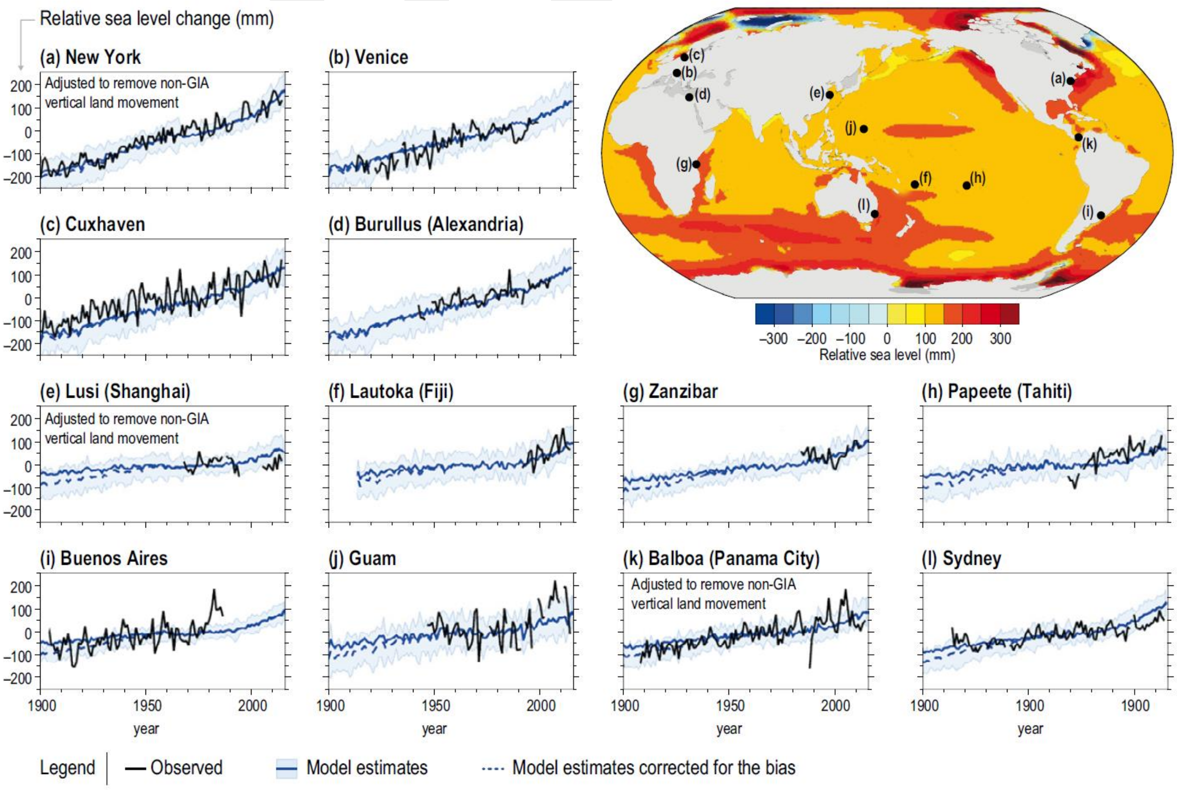


Figure 3: 20th-century regional sea level changes: model simulations vs. tide gauge data.

Source: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, Chapter 4, based on Oppenheimer et al.[1].

Future projections of global sea level show high agreement for the mid-21st century across different climate scenarios. However, these projections diverge significantly for longer time scales, extending to the end of the century. This divergence is primarily due to varying projections of ice-sheet-related instability processes, which are associated with deep uncertainty, and is more pronounced in higher-emissions scenarios. Changes in climate system components have response times spanning multiple decades or longer. This means that even if **the increases in global surface temperatures is limited, with high confidence sea level rise will continue for centuries to millennia due to ongoing deep ocean warming and ice sheet melt, and it will remain elevated for thousands of years**[4]. However, rapid and sustained reductions in greenhouse gas (GHG) emissions would help limit further acceleration of sea level rise and the long-term commitment to rising sea levels.

Compared to 1995–2014 levels, global mean sea level is projected to rise 0.15–0.23 meters by 2050 and 0.28–0.55 meters by 2100 under the low-emission SSP1-1.9 scenario. Under the high-emission SSP5-8.5 scenario, the rise is expected to be 0.20–0.29 meters by 2050 and 0.63–1.01 meters by 2100. Over the next 2000 years, sea levels are anticipated to rise approximately 2–3 meters if warming is limited to 1.5°C, and 2–6 meters if limited to 2°C[4].

The IPCC also explores **low-likelihood, high-impact storylines** (high-end scenario) of 21st-century sea level rise, considering significant increases due to uncertain processes such as the disintegration of marine ice shelves, abrupt onset of marine ice cliff instability, and marine ice sheet instability in Antarctica, along with faster-than-expected ice loss in Greenland. This scenario is particularly relevant for stakeholders who are planning for coastal safety and long-term infrastructure investments. Understanding these high-end risks is crucial, despite the uncertainty, as they could lead to sea level rises as high as 2.4 meters by 2100 under RCP8.5, driven by factors like ice shelf breakup, enhanced surface melt, and oceanic feedback[9]. The significant uncertainties in ice sheet dynamics necessitate considering extreme scenarios to avoid underestimating potential impacts and ensure preparedness[10]. Incorporating high-end projections helps build robust coastal defences and sustainable urban planning to withstand future sea-level rise.

3.3 Risk and impact assessments at global levels (JM and MA)

The IPCC Sixth Assessment Report (AR6) provides the most authoritative summary of current knowledge about the risks and impacts of climate change, including the significant challenges faced by coastal communities[11]. Recent studies published after the literature cutoff date for AR6 continue to advance our understanding of these issues, underscoring the ongoing need for updated and comprehensive research to inform policy and adaptation.

Sea level rise leads to the loss of land to the sea, including the ecosystems and built environments located on it. It also exacerbates other, single or compound hazards such as coastal floods due to extreme sea levels, water quality degradation, and land degradation from saltwater intrusion. These hazards cause a range of impacts such as the failure of critical infrastructure systems; declined land productivity and values; damage to cultural heritage sites; loss of livelihoods; population displacement; disruption of social fabric, leading to cohesion and cultural losses; and damage to coastal ecosystems and their contributions to people.

Coastal risks have been amplified by non-climatic risk drivers, including population growth, demographic changes, continuous urbanization, land-use changes, and resource extraction; and mitigated by implemented adaptation and disaster risk reduction measures. Increased population densities, together with inadequate building codes and land use planning, have led to developing risk-prone areas. Land reclamation and ecosystem degradation with damage to and loss of ecosystem services with hazard mitigation potential[7].

Population and cities. An estimated 900 million people, or 12% of the global population, lived in low-elevation coastal zones (LECZ) in 2020, representing an increase of over 40% since 2000[12]. More than twice as many people (2.15 billion or almost a third of global population) live in the near-coastal zone, defined as land within 100 km of the coast at an elevation of up to 100 meters. The expected annual population affected by climate change impacts could rise dramatically, from 34 million people per year in 2015 to 246 million people per year by 2100.

Critical infrastructure. Sea level rise disrupts and destroys critical coastal infrastructure, including ports and essential nodes of marine transportation, leading to cascading effects through interconnected systems like electricity, roads, and telecommunications[13–17]. This disruption can spill over into financial systems and drive financial and economic instability. The elevated groundwater levels and saltwater intrusion can corrode underground utilities and compromise structural integrity. This hidden damage affects critical infrastructure such as water supply, sewage systems, and transportation networks, requiring extensive and costly repairs[18]

Ecosystems. Loss of ecosystem services and biodiversity from sea lever rise and associated risks can lead to a loss of habitability and consequent displacement (cross-ref here: technical guide NELD). Sea level rise leads to habitat loss and forces species to migrate, reducing biodiversity and disrupting food webs and breeding grounds. The effects vary by region: near the equator, saltwater intrusion threatens mangrove forests and local livelihoods; in temperate areas, beach erosion destroys marine breeding grounds; and in polar regions, melting sea ice displaces animal population and disrupts food sources. Rising sea levels increase ocean carbon dioxide levels, causing acidification that harms coral reefs, shellfish, and phytoplankton. Coastal ecosystems face higher salinity and acidification, leading to habitat loss and species displacement, which further decreases biodiversity and erodes coastal features[19–22].

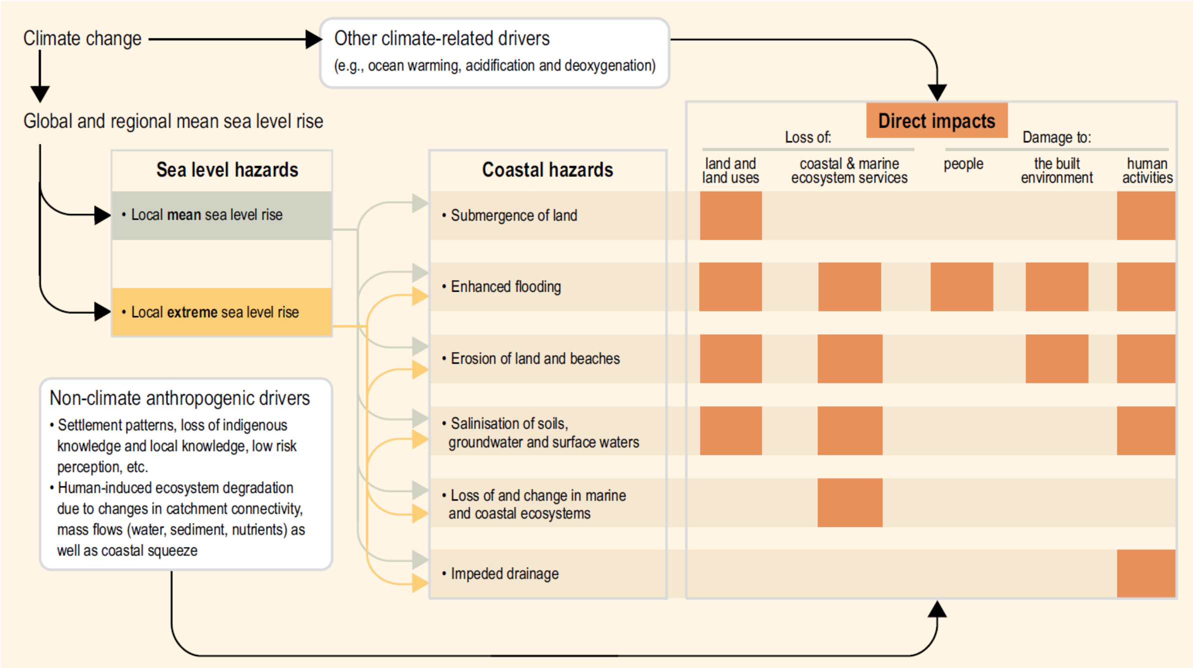
Human health. The salinization of coastal freshwater and land resources attributed to SLR along with other climate-induced drivers (like storm surges) and non-climate factors (such as water extraction and land-use changes) will continue to threaten coastal water and soil quality in the future, endangering human health[23]. In addition, SLR-related impacts significantly increase the risk of marine-borne pathogen outbreaks in ocean and coastal regions, affecting also seafood quality and safety (ibid). Relocation of marine-dependent communities, shifts in traditional diets, and loss of territory and traditional roles due to SLR and related impacts, could have profound implications for the physical and mental health of affected coastal communities[23–25].

Loss of cultural heritage and Indigenous knowledge. SLR threatens coastal archaeological and heritage sites, as well as marine and coastal cultural ecosystem services. Long-term loss of marine ecosystems would result in irreversible loss of local knowledge, culture and well-being in some locations[23]. Potential decrease in seafood consumption due to food safety concerns or shift in fishing patterns, and loss of biocultural heritage, could increase the risk of loss of cultural practices, especially for Indigenous Peoples[23,25]. In the Pacific islands' region, Indigenous knowledge including understanding weather, coping with climate extremes, resource use and management, and social values and networks, plays a critical role for enhancing local adaptive capacity[25]. Losses to cultural heritage can further manifest in diminished cultural diversity, the loss historical evidence for future generations, and diminished cultural rights and right of access to culture (/**cross-ref here**: technical guide NELD).

Loss of territory, social cohesion and societal/cultural identity. Loss of land affects the cultural, psychological and spiritual well-being of coastal and island communities. For instance, displacement, planned relocation and migration due to reduced habitability of low-lying coastal areas of small islands across the Pacific can result in shortages of skilled labour, loss of sense of place and social cohesion, and traditional adaptive mechanisms, which in turn can decrease the overall resilience of affected populations[25]. Loss of burial sites and changes to traditional burial practices due to SLR and coastal inundation with implications for mental well-being, social cohesion and cultural identity have been observed in Small islands[24,26].

Women's well-being and security. Climate-induced coastal risks can erode women's and children's wellbeing through shifts in gender roles (e.g. climate-induced female migrant factory work affecting physical and mental health), increased risk to life, exposure to violence and gendered dependency[27]. For instance, women in Bangladesh face gendered cyclone risks due to social norms such as inability to swim during floods because of clothing or immobility to relocate to shelters related to concerns over possible alleged or actual sexual assaults (ibid). In the aftermath of coastal natural disasters, women in Fiji have been exposed to risk of violence (e.g., domestic abuse, exploitation, and trafficking), while in Vanuatu, women have lost their ability of self-subsistence from small sales at local markets (ibid).

Cascading effects. In a world of ever-increasing supply chain, trade, and financial interdependencies, understanding the wider systemic impacts of coastal risks. Impact chains[28] trace the cascading effects of SLR impacts scarcity through different sectors and risk storylines[29] provide context and narrative to these impacts, tracing dynamic interdependencies and feedback loops among risk drivers, and their propagation through risk pathways and helping to identify critical intervention points. Storytelling of climate risks considers how climate hazards may compound, cascade, or spill over across geographic or functional boundaries, and how the interplay of risk drivers unfolds in specific situations[30]. A single loss can lead to multiple losses experienced by individuals differently, such as loss of opportunities, habitability, security, dignity and identity (/**cross-ref here**: technical guide NELD). For example, loss of cultural heritage can have cascading effects such as breakdown in the traditional governance of culture, resulting in weakened social cohesion and increased risk of conflict, in particular for Indigenous Peoples[27].

339 

340 *Figure 4: Overview of the main cascading effects of sea level rise (SLR).*

341 Legend. Colours of lines (light green and light orange) and boxes are used only for the readability
342 of the figure. Source: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate,
343 Chapter 4, based on Oppenheimer et al., 2019.

344 [/further to be added an overview of coastal climate risk indices]

4 Approaches to averting, minimising and addressing loss and damage associated with the assessed risk of sea level rise

4.1 Introduction (JM, MA)

A spectrum of adaptation approaches can be used in the long term to **avert, minimise, and address** loss and damage (L&D). These approaches are grouped into ever-expanding categories of solutions. Each strategy involves different measures and considerations and can be applied individually or in combination, depending on the specific needs and conditions of the coastal areas. As early as in the 1990s[31] and still referred to in recent works[6], solutions have been organised in three categories: protect, accommodate and retreat.

- **Protect**. This category includes defensive measures to safeguard areas from inundation, tidal flooding, wave effects, shore erosion, salinity intrusion, and the loss of natural resources. These measures include both "hard" and "soft" structural solutions, such as dikes, levees, floodwalls, seawalls, revetments, bulkheads, groins, detached breakwaters, and infrastructure modifications like raising piers and installing floodgates or tidal barriers. Hard structures aim to physically block or redirect water, whereas soft structures, like beach nourishment and dune building, enhance the natural defences of coastal areas. The protective measures aim to ensure that protection can be incrementally improved to accommodate future sea level rise.

- **Accommodate**: These strategies involve measures that enable continued occupancy and use of vulnerable areas. This includes elevating buildings on pilings, modifying drainage systems, and implementing storm preparedness plans. Accommodation may also involve changing agricultural practices, such as switching to salt-tolerant crops or converting agricultural lands to aquaculture. Managing groundwater resources to prevent saltwater intrusion, encouraging insurance subscription to cover potential damages, and protecting coastal ecosystems are also part of this category. Institutional accommodation constitutes another important element of response strategies. Related activities include EWS, insurance mechanisms, and social policies, among others.

- **Retreat** entails abandoning land and structures in vulnerable areas and resettling inhabitants. This strategy may involve preventing new developments in at-risk areas, allowing development with the condition of eventual abandonment, or relying on market mechanisms to discourage development in vulnerable zones. Retreat is often considered for areas where long-term protection and accommodation are not feasible or economically viable. Retreats can help preserve natural coastal ecosystems by allowing them to migrate inland as sea levels rise.

IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) included another category of solutions, referred to as accommodate:

- **Advance**. This category includes measures to advance the coastline, which involves creating new land by building out into the sea, reducing coastal risks for both inland and newly created land. This process includes land reclamation, where sand or other fill materials are added to raise the land above sea level. Additionally, vegetation is planted with the specific intention of supporting natural land accumulation. Another technique, known as polderization, involves surrounding low-lying areas with dikes to keep water out, requiring effective drainage and often using pumping systems to manage water levels.

The SROCC report also identified ecosystem-based adaptation as a distinct category, while acknowledging that many interventions overlap with other categories. [/In this report we include ecosystem-based adaptation under the accommodate category]

Transformative adaptation policies embrace systemic changes in response to climate risks, recognizing that detrimental global environmental change was not merely a side effect, but a characterizing trait of modern societal development[32]. Transformative change involves changes in social structures and power relations[33], as well as norms and institutions that shape behaviour of people and organizations[34], and structural reforms that reduce people's and system's exposure to shocks[35], while addressing the root causes of vulnerability.

Transformative adaptation encompasses innovation, reorganization, expansion, and reorientation[36,37]. Transformative policies involve changes in existing practices, governance, and market structures, for which social learning, community engagement, and a deep understanding of socio-ecological impacts are prerequisites[38]. Implementing transformative adaptation faces institutional inertia, resource constraints, and socio-political resistance. However, it also presents opportunities for co-benefits like improved social equity, resilience, and environmental sustainability[37]. Fostering change means promoting inclusive governance, social cohesion and culturally appropriate strategies incorporating Indigenous knowledge and local knowledge in early-warning systems, sustainable resource management, social policies, and planned relocation, which stand at the core of just transformation. However, practical guidance on induce, design, and implement transformative adaptation is rare.

*Table 1: List of solutions [/**to be completed**]*

Land use type	Main impacts of SLR	Main types of loss	Solutions by types of SLR		
			High SLR	Medium SLR	Low SLR
A1. Open urbanized coasts	- Increased erosion of beaches and dunes - Increased flooding - Submergence	Loss of tourism and recreational activities	- Coastal retreat and resettlement	- Internal planned relocation - Hard-engineered coastal technologies - Structural elevation	- Beach nourishment - Nature based protection
		Port infrastructure damage	…	…	- Hard-engineered coastal technologies: dikes, sea walls, polders - Hazard proof infrastructure
		…	…	…	…
A2. Open rural coasts	- Increased flooding - Submergence - Soil and water salinization - Change/loss of mangrove/wetlands /sandy ecosystems	Loss of agricultural production	- Social protection tools - Livelihood diversification - Insurance mechanisms	…	…
		Loss of ecosystem services	…	…	- Dune building/rehabilitation - Increase natural accretion
		…	…	…	…

4.2 Protect (AS)

Protective measures aim to defend vulnerable areas from the direct impacts of sea level rise. These strategies typically involve the construction of **physical barriers and infrastructure** to shield coastal regions from flooding and erosion. Examples include seawalls, levees, storm surge barriers, and breakwaters. Additionally, natural or hybrid solutions, such as restoring or creating wetlands, mangroves, and dune systems, can buffer against storm surges and wave action. The primary goal of protective measures is to maintain the current land use and protect human activities and assets from the encroaching sea.

There are many and varied engineering or hard infrastructure approaches to protecting coastal communities, economies, and livelihoods from the impacts of sea level rise. This means several sources of insight guide how localities need to respond to the challenges they face. These approaches are described below. Some examples are also provided to guide how to implement them. Depending on the situation and complexity of impacts, multiple lines of defence may be necessary to respond to the effects of SLR[39].

4.2.1 Coastal Armouring

Several approaches to coastal armouring include seawalls, levees, breakwaters, coastal revetments, piles, and groins, and several studies have been conducted on these approaches. Many countries also have experiences with their use. These protect coastal areas from rising tides and storm surges by absorbing and deflecting wave energy.

- **Seawalls** absorb and reflect wave energy as vertical or near-vertical structures. Levees or dikes are embankments or raised barriers built to prevent coastal inundation and erosion. A notable example of these solutions is the Galveston Seawall in Texas[40]. These approaches are, however, considered divisive due to their visual impacts, impoundment or placement losses, beach access reduction, sand supply loss from eroding bluffs/cliffs, and passive and active erosion[41]. In Maldives, building seawalls 0.5, 1.0, and 1.5 m high could delay flooding for 0.2, 0.4, and 0.6 m of sea-level rise, respectively. However, land raising could simultaneously reduce flood risk while also addressing development needs.

- **Breakwaters** are submerged and emerged structures that manage wave impacts. The Maeslantkering in the Netherlands is an example of a breakwater and storm gate system. Bamboo is used as a breakwater in the Mekong Delta as it is readily available and cheaper[42].

- **Coastal revetments** are built perpendicular to the shoreline to trap sediments, enable their accumulation, and prevent erosion[43]. From 2016 to 2020}, revetments have armoured 45.7 km of Thailand's shoreline[44]. Piles are also being used for coastal protection but with varying success. They transfer the load to deeper soil layers to achieve stability[45]. Piling is a common technique to achieve stability of coastal structures and is used in seawalls, bulkheads, breakwaters, and the construction of piers and docks. Groins are placed perpendicular to the shore to prevent soil movement[43]. They feature prominently in coastal engineering management, such as on Coney Island (USA) and the Gold Coast of Australia.

- **Polder systems** combine the above approaches, notably dikes, sea walls, water storage, and pumps, to protect an area from intruding seawater. However, they can only protect those areas affected by tidal floods at specific heights. They are also expensive to build and require long-term planning, long construction, and high maintenance costs[46].

The approaches described above have environmental and biodiversity consequences on surrounding ecosystems as they "hardened" shorelines[47]. As such, they should be carefully planned. Seawalls are a popular engineering response to flooding and coastal erosion due to SLR, especially for island coasts, but are considered maladaptive because they give a false sense of security[48,49]. Removing shoreline armours has been shown to restore the viability of intertidal ecosystems[50]. Thus, thoughtful considerations must be made when deciding on coastal armouring to address SLR. Other options suitable to the geographical, social and developmental context of the location should be explored.

Case Study 1 Tuvalu Coastal Adaptation Project

The Tuvalu Coastal Adaptation Project (TCAP) is a comprehensive and innovative climate change adaptation intervention for one of the world's most vulnerable nations, particularly to SLR. TCAP focuses on capacity training, infrastructure protection, and sustainable financing to enable Tuvalu's coastal communities to survive a changing climate. The initiative aims to strengthen Tuvalu's coastal towns against rising sea levels and storm surges using US$36 million from the Green Climate Fund and $2.9 million from the Government of Tuvalu.

TCAP will boost the resilience of Tuvalu's coastal communities. The project aims to improve Tuvalu's human resource capacity by training and transferring knowledge to create qualified professionals to manage and implement climate change adaptation projects. TCAP reduces storm surge and erosion susceptibility by building and repairing coastal infrastructure. Homes, public buildings, and vital infrastructure like highways and airports will be protected from climate hazards. The project aims to integrate climate risk management into national and local planning. This implies future development projects will include climate change, making infrastructure and communities more robust. TCAP will establish sustainable financing mechanisms to ensure a steady flow of resources for continuing adaptation initiatives. This will assist Tuvalu in continuing to develop its climate resilience measures and preserve and build on TCAP's accomplishments.

TCAP was launched in August 2017 and is expected to wrap up in 2024. The evaluation and impact assessment of the outcomes of this project will provide insights and examples for others on how to reduce coastal and infrastructure vulnerability through a comprehensive and sustainable approach.

4.2.2 Flood Barriers and Gates

This approach involves constructing storm surge barriers and tidal gates in harbours and estuaries to prevent storm surges during high tides and storms and minimise flooding, particularly in low-lying areas, effectively protect harbours, reduce property damage, and avoid loss of life during large storms[51]. The opening or closing of the barriers and gates depends on the incoming water flow, including its height. Surge barriers are costly, so their utility and role in risk management should be carefully planned[52]. Aside from the cost, its use should also be thoroughly vetted, particularly when applied to estuaries, as they can lead to several impacts, including blocking exchange in estuary-ocean exchange, stratification and salt intrusion, changing sedimentary systems, and impeding animal migration and ecosystem connectivity. Their impacts are amplified with increasing gate closures. In light of SLR, the frequency and length of gate closures will grow exponentially[53]. However, prolonged closure can also affect municipal water supplies and the estuary environment due to salt intrusion and stratification[51]. This means this solution is complicated, and its benefits should be weighed against the costs.

4.2.3 Elevating Structures and lands

This approach involves raising buildings or structures and introducing innovative designs that enable them to float during high water levels. This is particularly useful in flood-prone areas. In many parts of Asia, traditional houses along water bodies and flood-prone regions were built on stilts to adapt to seasonal flooding and protect inhabitants from wild animals. However, these are no longer possible with SLR, as are the wider impacts of climate change and the decline of this form of architecture. That said, there are efforts to revive them for resilience.

This revival sees a responsive or adaptive form of architecture responding to new challenges due to SLR. Latest innovations and design principles are pursued, of which aquatic or amphibious architecture, or the so-called “aquatecture”, is a promising practice. It is architecture that is shaped and informed by the environment, aquatic, on which the building is located and through which some needs have to be met due to being in that environment. Floating and amphibious architecture are aspects of this type of architecture. Floating houses enable the structure to adjust to the vertical shifting of water levels. Existing designs are modular in construction[54].

In Can Gio District in Ho Chi Minh City, Vietnam, elevated and floating floors were proposed to help residents cope with the impacts of SLR so that houses become amphibious or floating. This mechanism allows people to live with nature rather than build a hard infrastructure to fight it[55].

While still experimental, biomimetic or biologically inspired design offers ways through which nature inspires a place's architecture. The giant kelp, floating water fern, Venus flower basket, red mangrove, lotus leaf, cicada, and pitcher plant have been used to provide insights on addressing buoyancy, stability from lateral movement, and structural integrity of floating houses[56].

In Maldives, island raising has been pursued as a structural adaptation intervention to the impacts of SLR. This involves raising, expanding and connecting ‘urban’ islands to provide multiple benefits, particularly tourism and protecting residents. However, this is a costly intervention and should only be pursued alongside a proper cost-benefit analysis.

Case study 1 Coastal Protection in Senegal

Senegal's coastline, extending over 700 kilometers, is housing 60% of the population and is source of livelihood form fishing, tourism, and agriculture. This includes the capital city, Dakar, situated on the Cape Verde Peninsula, the westernmost point of mainland Africa, and home to over 1 million people. The coastal system of Senegal is subject to various risks from sea level rise and recession of the coastline, coastal erosion, and increase storm surges and floods. Estuarine areas, due to their characteristics, are also exposed to other types of risks, particularly fluvial flooding (where maritime conditions influence the flow and evacuation capacities of floods) and water salinization. To address these risks, the Senegalese government, with international support, has implemented several coastal protection initiatives. With support from Adaptation Fund[57], the government has constructed a 730-meter coastal protection dike to shield populations and infrastructure from heavy swells and storms. The project involved rehabilitating fish processing areas, protecting a fishing wharf, and constructing a 3300-meter anti-salt dyke to protect rice-growing areas from saltwater intrusion. The project actively involved local communities from conception to implementation, resulting in significant community ownership and ongoing maintenance of the interventions. Another example is aiming at restoring the beach of the seaside resort of Saly in the Petite Côte region. Beach erosion had suspended activities in several hotels, significantly impacting tourism, which contributes up to 7% of Senegal's GDP. In partnership with the World Bank, Senegal has invested over USD 41 million to address coastal erosion and restore the beach. The project includes constructing 12 breakwaters and 7 groynes to retain waves, restoring 7 kilometers of beach with a width of 50 meters. Furthermore, to cope with high flood losses – estimated to over USD 100 million over the recent past, the Green Fund financed a 15 million Euro project focusing on national flood risk mapping, detailed urban area mapping, infrastructure design tools, rainfall-runoff models, real-time hazard monitoring, groundwater knowledge improvement, optimized drainage management, and enhanced warning systems. This is important as the National Adaptation Plan projects that demographic growth and urban development may lead to increased impacts in the future.

Source. Government of Senegal[58]

4.3 Accommodate

Accommodation strategies focus on adjusting existing infrastructure and practices to live with the changing conditions rather than trying to prevent sea level rise impacts entirely. These measures aim to reduce vulnerability and increase resilience by adapting buildings, infrastructure, and communities to cope with periodic flooding and other sea level rise effects. Examples include elevating buildings and infrastructure, improving drainage systems, designing flood-proof buildings, and implementing zoning regulations that restrict development in high-risk areas. Accommodation measures also encompass policies and practices that promote sustainable land use and water management, ensuring that communities can continue to thrive despite the changing environment. Accommodation strategies focus on adjusting existing green and grey infrastructure, practices, economic sectors and social systems to live with the changing conditions rather than trying to prevent sea level rise impacts entirely. These measures aim to reduce vulnerability, increase resilience, and retain residual risk. In human settlements, examples include elevating buildings and infrastructure, improving drainage systems, designing flood-proof buildings, and implementing zoning regulations that restrict development in high-risk areas. Accommodation measures also encompass policies and practices that promote sustainable land use and water management, ensuring that communities can continue to thrive despite the changing environment. Other strategies that fall under the scope of this category relate to economic and social measures such as transforming food production systems, economic diversification, adapting health systems and strengthening social protection mechanisms. For instance, in the health sector, concrete actions include investment in technology and infrastructure to improve ocean and coastal water quality monitoring and forecasting to inform planned responses; strengthening policies and institutions to plan and implement preventive public health and seafood safety measures; and public awareness[23].

The following sections provide an overview of two key areas of action: (1) ecosystem-based approaches; and (2) social protection policies and measures.

4.3.1 Ecosystem-based adaptation (JM)

Ecosystems constitute components of the natural and semi-natural environment, and they are a source of vital services, benefits, and goods to mankind. Ecosystems can mitigate natural hazard risks and boost societal resilience, locally or regionally. Restoration of ecosystems and their services, where these have been degraded or otherwise altered, provides solutions to societal challenges such as the climate and biodiversity crises. These are commonly referred to as **Nature-Based Solutions** (NbS)[59]. NbS can provide means to mitigating climate risks - through mass stabilisation, water flow regulation, wind dissipation, and temperature regulation - remove particle pollution and improve air quality, protect soil and biodiversity, and enhance climate resilience. NbS provide over one-third of the cost-effective climate mitigation[60] needed to stabilise warming to below 2°C. The 2020 IUCN Global Standard for Nature-based Solutions[61] defined NbS along with criteria and indicators supporting purposeful design, implementation, monitoring and continuous improvements of NbS interventions[6].

The concept of NbS has been embedded in policy agreements to enhance resilience and sustainability across various global policy frameworks; essentially recognizing the role of NbS in addressing interconnected challenges of climate change, biodiversity loss, disaster risk and Sustainable Development Goals. The **Sharm el-Sheikh Implementation Plan**, resulting from the 2022 United Nations Climate Change Conference (UNFCCC-COP27), marks the first inclusion of NbS in climate negotiations. It stressed the need to address the interconnected crises of climate change and biodiversity loss comprehensively and synergistically, within the broader context of achieving the Sustainable Development Goals (SDGs). NbS are also central to the Kunming-Montreal Global Biodiversity Framework (GBF), an ambitious plan to halt and reverse biodiversity loss, under the **UN Convention on Biological Diversity**. NbS are integral to the GBF's targets, promoting the sustainable use and management of ecosystems to enhance resilience and connectivity, restore degraded areas, and support biodiversity conservation. In the context of the UN **Sendai Framework for Disaster Risk Reduction** (SFDRR) 2015-2030, NbS are pivotal for enhancing resilience and reducing disaster risks. The Framework promotes the integration of NbS to mitigate impacts from natural hazards, leveraging the protective functions of ecosystems such as wetlands, forests, and mangroves.

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[6] "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 NbS can be implemented, for instance, at the buildings scale, through green rooftops, green walls, and the re-greening of communal spaces; within public spaces, by enhancing urban parks and forests, creating water squares, greening streets and depaving urban land; and at the level of water bodies and drainage systems, through the renaturation of streams and rainwater harvesting. NbS for coastal protection use natural processes and ecosystem services to mitigate sea-level rise and coastal erosion, providing sustainable alternatives to engineered infrastructure like seawalls and breakwaters.

- **Coastal wetlands**, such as saltmarshes and mangroves, can trap sediments and build elevation[62]. Salt marshes in intertidal zones between land and brackish water are composed of salt-tolerant plants like grasses, sedges, and shrubs. They form in areas protected from high-energy waves, such as estuaries and bays, and develop in zones with fine sediment deposition, assisted by tidal flows. Mangrove forests are formed by salt-tolerant trees and shrubs in intertidal zones, stabilizing coastlines with their complex root systems. Mangroves protect coasts by reducing erosion, buffering storm surges, filtering water, supporting diverse species, serving as nurseries, and acting as efficient carbon sinks.
- **Coral and oyster reefs** also play a vital role in protecting shorelines. Coral reefs, formed by the accumulation of calcium carbonate skeletons from coral polyps, and oyster reefs, created by the dense aggregation of oyster shells, act as natural barriers against wave action. Acting as a physical buffer, the reefs dissipate wave energy, reduce coastal erosion and mitigate the impact of storm surges. They also enhance biodiversity, support marine life, and improve water quality through their filtering capabilities.
- **Sand dunes**, formed by the accumulation of transported sand and stabilized by vegetation like grasses with deep root systems, act as natural barriers against the forces of waves, wind, and storms. Dunes absorb and dissipate wave energy, reduce the impact of storm surges and high waves, and prevent erosion and damage to coastal property. Sand trapping methods, such as installing sand fences and planting dune-stabilizing vegetation, enhance the natural formation and maintenance of dunes.

Case study 2 Coral reefs restoration in Puerto Rico (JM)

Situated in the northeastern Caribbean, Puerto Rico faces significant coastal risks due to its geographic location. The island is vulnerable to sea level rise, coastal erosion, and an increased frequency of hurricanes. These hazards threaten its infrastructure, ecosystems, and communities, particularly along the coastal regions where a large portion of the population resides. Coral reefs, which act as natural barriers to reduce wave energy and protect shorelines, have been degraded by human activities and environmental stressors, weakening their protective function. The United States Geological Survey (USGS) and the University of California, Santa Cruz (UCSC) initiated a project to restore damaged coral reefs. This involved transplanting coral fragments onto degraded reefs and constructing artificial reef structures to facilitate coral growth and habitat restoration, accelerating the recovery of coral ecosystems and enhancing their resilience. Innovative techniques, such as coral nurseries where coral fragments are grown before transplantation, were employed. These nurseries allow for the cultivation of many corals, which can repopulate damaged reefs. Artificial reef structures made from eco-friendly materials were also used to provide a substrate for coral attachment and growth. The restoration efforts have shown promising results, with increased coral cover and biodiversity at restoration sites, improving coastal protection by reducing wave energy and preventing shoreline erosion. The restored reefs have also provided valuable habitats for marine life, contributing to the overall health and productivity of the coastal ecosystem. The project received funding from government agencies, non-profit organizations, and private sector partners, ensuring the availability of necessary resources for successful implementation and monitoring. This collaborative approach underscores the importance of continued financial and technical support to maintain and expand reef restoration initiatives. The reef restoration project in Puerto Rico serves as a valuable example of how targeted restoration efforts can enhance coastal resilience and protect vulnerable communities from climate change impacts.

Source: The United States Geological Survey (USGS) and the University of California, Santa Cruz (UCSC)[63]

Effectiveness. A recent review[64] found that 39% of the reviewed studies compared the cost-effectiveness of NbS with engineering solutions for risk reduction. None found NbS to be less cost-effective. In fact, 65% showed NbS were more effective, and 26% found them sometimes more cost-effective but never less. Over 80% of studies on mangroves and forests, and around 65% of studies on wetlands and other coastal ecosystems, indicated that NbS were more cost-effective. These findings suggest that combining NbS with engineering solutions could be beneficial. [/expand]

Other co-benefits: Compared to engineered, built or fossil-based solutions, NbS approaches may be cost-effective and have many ecologic, social and economic benefits. Co-benefits are additional but complementary to the primary goal of an adaptation solution[65]. If overlooked in performance assessments or neglected during the design and implementation of NbS, the true value of nature restoration can be underestimated, potentially leading to underinvestment. Proper evaluation and consideration of all benefits are crucial to fully realizing the environmental, social, and economic impacts of NbS projects. Incomplete knowledge of these co-benefits is a significant barrier to adopting NbS. Obtaining a thorough understanding of risk-reduction benefits and co-benefits, along with their associated beneficiaries, will help assess their cost-effectiveness and support a better comparison with engineered solutions.

Implementation Challenges: NbS face sizeable challenges and barriers to adoption, which - depending on the contexts - may include poor adaptation to given socio-cultural situations, possible eco-system disservices[66], absence of supportive governance and financial instruments to stimulate implementation, low social acceptance, limited business model innovation, and failure to account for the true social value of the generated benefits[67]. In some cases, NbS can also further amplify, rather than reduce, urban vulnerabilities and inequalities, by contributing to gentrification[68,69]. Gentrification refers to the displacement of vulnerable populations, especially in urban areas where green infrastructure may lead to gentrification and the displacement of low-income residents. Resource allocation for NbS can exacerbate existing inequalities if certain projects are prioritized over others. There is also a risk of greenwashing, where NbS are used as marketing tools without addressing underlying environmental and social issues. Ensuring transparent and accountable implementation with measurable outcomes and benefits for both the environment and local communities is crucial. Active involvement and participation of local communities in planning and implementing NbS projects are essential to protect their rights and interests.

Financing. Various insurance & investment solutions have been proposed and elaborated conceptually, and some of them made operational. InsuResilience recently conducted a survey of how insurers employ NbS. The survey's initial results show that there is awareness across the industry of examples in which risk transfer builds upon NbS in some way, including through risk pricing. Some 70% of insurance solutions referred to in the survey focused on marine and costal ecosystems (e.g., mangroves). However, the survey also indicates a lack of agreed assessment tools for the NbS benefits, with most insurers relying on pilot studies rather than widely accepted methodologies. There is a growing number of initiatives which cooperate with insurance to protect biodiversity, enhance climate resilience, and improve the sustainable management of ecosystems and the economies and communities that depend on them whilst increasing financial resilience. Providers of reinsurance, insurance and other insurance-based forms of risk transfer showed increasing interest in designing and financing NbS.

Willis Towers Watson launched the **Mesoamerican Reef Insurance Programme** - the first multinational reef insurance collaboration that will design and implement parametric insurance covering hurricane risk to the Mesoamerican Reef (MAR) and the communities that depend on it for protection, food security, and livelihoods. This scheme builds upon the insurance solution protecting Mexico's Quintana Roo coral reef, developed by Swiss Re in collaboration with The Nature Conservancy. Swiss Re also supported the reconstruction and enhancement of the natural habitat of Prince Hendrik Sand Dyke on the island of Texel in the Netherlands. The outcome protects the island against rising sea levels and has made it larger, with additional natural habitat and enhanced biodiversity. Emerging tools combine *nature-based insurance and investment solutions* with innovative financing strategies. Created by the Global Innovation Lab for Climate Finance, RISCO is a social enterprise that invests in mangrove conservation and restoration, securing revenue from insurance companies who pay to lessen their risk exposure, and from the sale of blue carbon credits. In the Philippines, Conservation International is currently implementing the RISCO pilot phase to capture the risk reduction and carbon sequestration value of mangrove forests. Future projects will target Indonesia, Mexico, Brazil, and Malaysia. The implementation of innovative and efficient nature-based risk-transfer strategies often requires new reliable data and new metrics and indicators. Swiss Re has created the *Biodiversity and Ecosystem Services (BES) Index* assessing and scoring the state of ten ecosystem services at 1 sq.km resolution (i.e., habitat intactness, pollination, air quality, climate regulation, water quantity, water quality, soil fertility, erosion control, coastal protection, food provision, and timber production). The data provides a current view that can facilitate risk, underwriting, and environmental policy recommendation. NBIS complement other economic and financial instruments such as payment for ecosystem services, environmental taxes, tradable rights, and sustainable business (model) innovation.

Insurance can play an important role in protecting nature and ecosystems by incentivizing sustainable practices, supporting conservation and restoration efforts, and providing financial protection against environmental risks. Insurance companies can offer policies that incentivize environmentally friendly behaviour by providing discounts or lower premiums for businesses and individuals that take steps to reduce their impact on the environment. Insurance can provide financial support for conservation and restoration efforts. Insurance-linked investments can help fund nature-based solutions such as reforestation, wetland restoration, and other projects that can provide multiple benefits, including reducing carbon emissions and protecting ecosystems. There are several ethical aspects related to how nature-based insurance and investment solutions are implemented and these need to be carefully considered and addressed. Firstly, the practice of risk selection means that insurance companies may only provide coverage to certain valuable or profitable ecosystems, leaving others unprotected and exacerbating existing inequalities. Secondly, insurance coverage may create a moral hazard, leading individuals and organizations to feel less responsible for protecting the environment. Additionally, a lack of transparency around insurance policies can cause confusion and misunderstanding about what is covered. The use of insurance to incentivize nature-based solutions may also have unintended consequences on local communities and ecosystems. Finally, holding insurance companies accountable for their role in biodiversity and nature protection may be challenging, especially if their policies contribute to negative environmental impacts. These drawbacks highlight the importance of carefully considering the role of insurance companies in promoting biodiversity and nature protection.

4.3.2 Social protection (MA, AS)

Social protection can support multiple sustainable development outcomes including efforts to reduce poverty while facilitating climate change mitigation and adaptation and promoting environmental stewardship. Formal social protection consists of policies and mechanisms aimed at overcoming poverty and inequality through state support to vulnerable groups to anticipate and respond to various risks. Main instruments include non-contributory social transfers (e.g. cash transfers), housing support, social services, public employment programmes, contributory social insurance, and skills development. Some of these could be instrumental for **marine and coastal protection and restoration** in the context of accommodating loss and damage (see Table X). First, social protection mechanisms can help buffer impacts resulting from environmental degradation and respective environmental protection policies and measures (such as restricting the use of natural resources), e.g., loss of income generating opportunities and food insecurity. Second, social protection can support effective response to loss and damage associated with SLR by delivering dual social and environmental objectives. For example, well-designed public work programmes for mangrove restoration or conditional cash transfers for fish stock conservation can help mitigate income-related risks and incentivise behavioural change.

Furthermore, traditionally, social protection plays an important role in **responding to disasters through preparedness, relief and recovery**. Conditional and unconditional cash transfers can buffer the impacts of intensifying coastal hazards on food and income security and broader social spheres such as access to health support and education (see Text box 2). **Anticipatory approaches** to social protection allow for delivering support before forecasted shock by linking existing social protection mechanisms to national or local early warning systems. This enables target groups to plan and prepare for anticipated shocks and avoid negative coping strategies. For example, cash transfers can help households to improve flood defences, stocking food, or relocate from risk zones. Social protection measures are also critical to **long-term recovery and rehabilitation** efforts following an extreme event. Examples include psychosocial support, cash transfers for women to recover their small businesses, or public works for the rehabilitation of disaster-affected coastal ecosystems.

Table 2 Overview of social protection measures (selected examples)

Element	Social protection measures to accommodate loss and damage associated with SLR (selected examples)
Enabling conditions for strengthening social protection systems	▪ Linking climate services and EWS with social protection systems; ▪ Improved institutional and policy environment through integration of social protection into national climate change strategies and plans (and vice versus), as well as into responses in relevant sectors such as disaster risk reduction; health; fisheries and food security; housing sector; coastal urban and rural development plans; ▪ Enhanced institutional capacities for integrated responses such as trainings and development of long-term finance strategies to sustain social protection systems; ▪ Strengthened coherence across social protection sectors (policy and legal frameworks) and across levels of governance (vertical coherence).
Instruments relevant to accommodate loss and damage from SLR and related hazards	▪ Conditional and unconditional cash transfers to limit the impact of coastal hazards on income and access to health services and education; ▪ Social transfers for people affected by environmental policies in the fisheries sector; ▪ Public work programmes integrated with ecosystem-based adaptation programmes, such as mangrove forest restoration; ▪ Subsidised microinsurance schemes for extending the risk coverage and reaching informal workers in the fisheries sector; ▪ Livelihood promotion and diversification through integrated social protection programmes: extension services for fish farmers and fishers, such as trainings for sustainable fishing, and in-kind transfers (e.g. fishing nets); support establishing/ strengthening capacities of fisheries-based organisations; ▪ Social transfers, housing support and social services for climate migrants and planned relocation. ▪ Social health protection programmes for risks emerging from SLR (e.g., psychosocial support; public awareness on health risks related to SLR and coastal hazards)

Text box 2 The role of conditional cash transfers [AS]

In the aftermath of the super Typhoon, Typhoon Haiyan, which hit the Philippines in 2013, UNICEF provided unconditional cash transfers to thousands of affected households for six months. An evaluation of the programme showed gains even for the short-term. The cash transfer provided cash for food, purchases of medicines, housing repair, conducting income-generating activities, and spending for education. Since a significant part of the cash received was spent on food, it helped reduce children's malnutrition. Because of the money provided by the programme, most of the beneficiaries recovered, partially or fully, from the onslaught of the typhoon after the six-month programme[70].

Conditional cash transfer programmes are social protection schemes aimed at reducing poverty and inequality while transforming people's behaviour[71]. For instance, CCT have been used to encourage health preventive behaviour, to reduce inequalities in terms of access to health care and educations, as well as to incentivise environmental stewardship. Some CCT schemes are designed to reduce child poverty and improve child health by providing predictable and regular cash payments to low-income families that agree to carry out certain 'conditions' on health behaviour, typically related to the health and education of their children. These conditions include sending their children for regular health check-ups, ensuring regular school attendance, and improving children's nutrition[72]. These programs were first introduced in Mexico with the PROGRESA (later Oportunidades) programme and in Brazil with Bolsa Família. Today, they are implemented in many countries, including the Philippines, Indonesia, Jamaica, India, Costa Rica, and Sub-Saharan Africa.

The Pantawid Pamilyang Pilipino Program is one such programme aimed at reducing extreme poverty by investing in child health and education. The programme has been used for disaster response. Despite several challenges and the need for further improvement, notable outcomes of the programme include impacts on children's education, health improvements for children and pregnant women, increased household welfare, expanded community participation, enabling awareness of basic means to mitigate vulnerabilities, and building children's grit or determination[73]. Some of the improvements needed in the programme include ensuring transparency and communication of the program's eligibility requirements, making monitoring beneficiary compliance less rigid, and addressing delays in receiving cash transfers[74].

As one of the most affected countries by flooding and other SLR-related risks, the Philippines has implemented a CCT programme known as the Pantawid Pamilyang Pilipino Program (4Ps). Despite several challenges and the need for further improvement, notable outcomes of the programme include impacts on children's education, health improvements for children and pregnant women, increased household welfare, expanded community participation, enabling awareness of basic means to mitigate vulnerabilities, and building children's grit or determination. Some of the improvements needed in the programme include ensuring transparency and communication of the program's eligibility requirements, making monitoring beneficiary compliance less rigid, and addressing delays in receiving cash transfers.

Effectiveness and sustainability. Integrating environmental objectives into social protection programmes could overburden state social protection systems in countries with limited institutional and financial capacities. In addition, some social assistance programmes have been linked to negative environmental outcomes such as increased natural resource extraction and vegetation loss. Furthermore, evidence shows that social protection instruments like cash transfers alone have been more effective in terms of buffering income shocks than in terms of reducing inequality and bringing transformation. To that end, careful programme and policy design, and sustained financial flows are essential[7]. At a policy level, horizontal and vertical integration of social protection into sectoral responses to climate change like in the fisheries, water, disaster risk reduction, and forestry sectors, could help define the role of social protection within broader climate risk management strategies across levels of governance. At a programme level, social protection interventions can be more effective when combined with livelihood protection and development approaches such as income diversification, improved access to financing, index-based insurance, and fisheries extension services. Private sector actors can complement state support through the provision of climate services, financial products for the poor, jobs and skills development.

Financing: Domestic sources of finance for social protection include tax revenues, social security contributions, re-allocating public expenditures, and debt restructuring, among other. International public finance sources encompass bilateral and multilateral flows for social protection, disaster risk reduction and climate change adaptation. In addition, climate funds established under the UNFCCC (GCF, GEF, LDCF, SCCF, AF - see section 4) can support social protection interventions aimed at: (1) integrating climate change considerations into national social protection systems through climate services provision; improved institutional, policy and regulatory environment; and enhanced knowledge and capacities; and (2) transforming existing or developing innovative social protection mechanisms[75].

Case study 3 Social protection interventions supported by the Green Climate Fund (MA)

The Green Climate Fund (GCF) is a core operating entity of the Financial Mechanism of the UNFCCC. The GCF can be accessed by accredited entities (public or private international, regional, and national organizations). The GCF supports climate change mitigation, adaptation and cross-cutting projects in eight results areas: (1) health, food and water security, (2) livelihoods of people and communities, (3) infrastructure and built environment, (4) ecosystems and ecosystem services, (5) energy generation and access, (6) transport, (7) buildings, cities, industries and appliances, (8) forests and land use. In addition, the GCF has been noted as a provider of finance for loss and damage "to the extent consistent with the existing investment, results framework and funding windows and structures". Projects activities funded by the GCF relevant to accommodate loss and damage include e.g., development of climate services and early warning systems, community-based disaster risk reduction, building climate-resilient infrastructure, and promotion of NbS.

To date, the GCF has supported several projects aimed at strengthening social protection systems. Some of these address SLR and coastal hazards. For instance, the adaptation project FP184 "Vanuatu community-based climate resilience project (VCCRP)" seeks to support community-based adaptation through, among other activities, the development of locally defined shock-responsive social protection mechanism. The multi-country project FP215 "Community Resilience Partnership Program (CRPP)" foresees to strengthen resilience of communities in target countries (Cambodia, Indonesia, Lao PDR, Pakistan, Papua New Guinea, Timor-Leste, Vanuatu) through the provision of finance for climate risk-informed social protection. Planned activities include capacity building (e.g. developing adaptive and shock-responsive social protection systems; provision of technical equipment; and training), and exploration of options to design innovative social protection schemes or to expand existing programmes in the future.

Other projects, though not targeting SLR, could further exemplify the potential of the GCF to support social protection interventions in coastal areas. The project SAP042 "Building climate resilience by linking climate adaptation with social protection through decentralised planning in Mozambique" aims at mainstreaming climate risk into the national Productive Social Action Programme among other activities. Few GCF-funded projects also invest in developing social protection instruments linked to environmental initiatives that could be replicated to coastal protection and restoration. The project FP062 "Poverty, Reforestation, Energy and Climate Change" in Paraguay pilots an additional conditional transfer scheme under existing national social protection programme (Tekoporã) to incentivise ecosystem stewardship through reforestation and forest conservation in degraded lands. Similarly, the project FP158 "Ecosystem-Based Adaptation and Mitigation in Botswana's Communal Rangelands" seeks to transform an existing public works programme (Botswana Ipelegeng Programme) to support rangelands restoration and promote ecosystem-based adaptation including through adjustment of policies and regulations, a new job creation programme (public works) and skills development. Through the transformed job creation programme, the project helps to tackle unemployment and to reduce costs of reactive drought relief.

It is important to note that, to date, the GCF has provided finance for strengthening social protection systems, but not for financing national social protection budgets. Therefore, GCF funding could be used to enable effective delivery of loss and damage finance in the future. ***Source***: Aleksandrova et al.[75]

4.4 Retreat (EC)

Retreat involves relocating people, infrastructure, and activities to another location to reduce exposure to climate and environmental hazards. It both refers to spontaneous relocations and coordinated movements facilitated by governments and organizations at various levels. The concept of "managed retreat" started to gain prominence during the 1980s and 1990s in the context of coastal management and in response to a growing recognition of the limitations of hard engineering solutions to address the increasing risks posed by sea level rise, coastal erosion, and extreme weather events. Within current scholarly debates, the terms planned relocation, resettlement and managed realignment are also used to refer to similar conceptualizations of movement. The latest IPCC Assessment Report (AR6) employs the term planned relocation to refer to managed retreat and resettlement[76], and defines it as "a form of human mobility response in the face of sea level rise and related impacts" which "*is typically initiated, supervised and implemented from national to local level and involves small communities and individual assets but may also involve large populations*"[77].

Legal and policy tools for managed retreat. Managed retreat can take multiple governance forms[78] and can be voluntary or mandatory for the people involved. It can be implemented at different scales, from households, to communities, to villages and cities. It can rely on a range of tools, from property acquisitions (e.g., buyouts) to land use planning and zoning regulations (e.g., rezoning residential land and abandonment), or a combination of them. Table 3 provides and overview of different legal and policy tools as outlined and discussed in the Georgetown Climate Center's new

Managed Retreat Toolkit (/REF) developed to support decision-making around managed retreat and adaptation. Managed retreat may be used as a preventive measure or in response to climate and environmental hazards such as coastal erosion and sea level rise.

Table 3 Overview of policy tools

Planning tools	To be completed, but for example: • Hazard Mitigation Plans • Coastal Management Plans • Local Comprehensive Plans • Climate Adaptation Plans • Long-Term or Visioning Plans • Post-Disaster Recovery and Redevelopment Plans • Managed Retreat or Relocation-Specific Plans • Wetlands Migration or Ecosystem-Specific Plans • Long-Range Transportation Plans
Infrastructure	• Design Modifications and Asset Protection • Asset Relocation and Realignment • Infrastructure Disinvestment
Acquisition tools	• Voluntary Buyouts • Open Space Acquisitions • Conservation Land Trusts • Land Swaps • Leasebacks • Life Estates and Future Interests
Regulatory tools	• Living Shorelines • Setbacks and Buffers • Development Permit Conditions • Zoning and Overlay Zones
Market-based tools	• Transfer of Development Rights

Limitations. Managed retreat is often considered a measure of last resort when the protection of socio-ecological systems is no longer viable from technical, social, or economic standpoints[79]. It is also recognized as a sensitive intervention due to the significant social costs it can entail[80]. Research on development-forced displacement and resettlement (DFDR) has extensively documented the impoverishment risks faced by relocated communities, including homelessness, joblessness, and social disintegration[81]. Similarly, when implemented in response to climate change impacts, managed retreat can lead to negative outcomes for affected households and communities[82,83]. There is increasing evidence of adverse psychosocial consequences among resettled communities, including impacts on anxiety, well-being, and perceived safety[84]. This has prompted adaptation research to explore how relocation planning decisions influence livelihood outcomes as a way to prevent maladaptation[85] and to interrogate what constitutes 'success' in the context of relocation programs[86]. From a financial perspective, relocation be very expensive (Ferris & Bower, 2023). Recent examples show how it can range from 10.000 USD per person in the case of Fiji to 100.000 USD per person in the United States[87].

Case study 4 Planned relocation in Fiji (JM)

Fiji's Planned Relocation Program[88] is an initiative designed to address the escalating impacts of climate change, particularly sea level rise, on vulnerable coastal and rural communities. The program was necessitated by the insidious effects of incremental sea level rise and shifting climate patterns, which have increasingly tested the resilience of these communities. Recognizing the need for proactive measures, the Fiji Government established a comprehensive policy and legal framework in 2018 to guide national responses to planned relocation. This framework includes the Climate Relocation of Communities Trust Fund, the world's first national trust fund dedicated to community-driven planned relocation, established through national legislation in 2019.

The program aims to manage loss and damage by relocating communities when in-situ adaptation efforts are no longer viable. It is anchored in Fiji's Climate Change Act of 2021, which provides a robust legal foundation for the organized, governance-driven relocation process. The Act mandates the involvement of multiple government ministries and the creation of Standard Operating Procedures (SOPs) to ensure a consultative, evidence-based approach.

Financing for the program is multifaceted, leveraging domestic funding mechanisms like the Environment and Climate Adaptation Levy (ECAL) and international contributions. The ECAL, a policy-based taxation system, contributes 3% of its revenue to the trust fund, which is supplemented by bilateral and multilateral funding sources. This innovative financing structure ensures that resources are available to support the comprehensive relocation needs, from technical assessments to the construction of new infrastructure, thereby safeguarding the long-term resilience and sustainability of the relocated communities.

5 Resources available for supporting approaches

Adaptation finance refers to funding aimed at helping countries, especially developing ones, manage the impacts of climate change. This includes investments in infrastructure, technology, and practices to enhance resilience and reduce vulnerability to climate-related hazards like floods, droughts, and sea-level rise. Under Paris Agreement, developed countries committed to mobilize USD 100 billion per year by 2020 to support climate action in developing countries, striking a balance between mitigation and adaptation finance. This commitment extends to 2025, with a plan to set a new, higher goal before then.

There is a significant gap between available adaptation finance and actual needs, estimated to be 10–18 times the available public funding. Bridging this gap requires enhanced international cooperation, increased public and private sector investments, and innovative financing mechanisms. The most recent Adaptation Gap Report[89] estimates adaptation costs for developing countries at USD 215–387 billion per year this decade, which is a significant increase from previous editions and a level expected to be reached only by 2030. Modelling suggests costs could be USD 215 billion annually, rising towards 2050, while analysis of national plans estimates USD 387 billion needed annually for 2021-2030. In 2021, international public adaptation finance to developing countries was USD 21 billion, a 15% decrease from 2020. Only 66% of bilateral finance commitments were disbursed compared to 98% for all development finance, highlighting barriers to adaptation[89].

Climate Policy Initiative (CPI) annually publishes an overview of public and private climate finance flows for both mitigation and adaptation[90]. It analyses the status, trends, and future needs. In 2021/2022, adaptation finance reached an all-time high of USD 63 billion, a 29% increase from 2019/2020. Despite this growth, the funding still falls significantly short of the estimated USD 212 billion needed annually by 2030 for developing countries alone. Most of the adaptation finance is provided by public actors, with development finance institutions (DFIs) contributing 86% of the total. National DFIs were the largest source, followed by multilateral DFIs. Adaptation funding primarily targets sectors like water and wastewater, which received almost half of the tracked finance. This focus highlights the importance of infrastructure to build resilience against climate-related risks such as floods and droughts. However, other critical sectors, such as agriculture, forestry, and land use (AFOLU), received much less funding, underscoring the need for a more balanced allocation of resources[90].

Climate finance for adaptation to climate change involves various funding sources and instruments aimed at enhancing resilience and reducing vulnerabilities. Key funding instruments include grants, concessional loans, and bonds, such as green bonds and resilience bonds, which provide capital for climate-resilient infrastructure and projects. Additionally, public-private partnerships and insurance mechanisms, like catastrophe bonds, offer financial protection against climate-related losses. Major sources include international funds such as the Green Climate Fund (GCF), the Adaptation Fund, and the Global Environment Facility (GEF) (Text box 3). Bilateral and multilateral development banks, including the World Bank and regional banks like the Asian Development Bank, also play significant roles.

Text box 3 Financial solutions available under the UNFCCC

Various financing sources, some of which established under UNFCCC, aim to support developing countries in their climate change mitigation and adaptation efforts.

- **Green Climate Fund** (GCF) (https://www.greenclimate.fund) is a financial mechanism established to support developing countries in their efforts to mitigate and adapt to climate change. It provides funding for projects and programs that aim to reduce greenhouse gas emissions and enhance climate resilience.
- **Global Environment Facility** (GEF) (https://www.thegef.org) is a multilateral environmental fund that provides grants and blended finance for projects related to, among others, to transition to low-emission and climate-resilient development pathways. It was established in October 1991 and serves as a financial mechanism for other UN Conventions, in addition to UNFCCC, such as the Convention on Biological Diversity (CBD) and United Nations Convention to Combat Desertification (UNCCD).
- **Special Climate Change Fund** (SCCF) (https://unfccc.int/topics/climate-finance/resources/reports-of-the-special-climate-change-fund) was established under the UNFCCC in 2001 to finance projects related to climate change adaptation and mitigation, technology transfer, and capacity building in developing countries. It is managed by GEF and addresses specific needs not covered by the GEF.
- **Least Developed Countries Fund** (LDCF) (https://www.thegef.org/what-we-do/topics/least-developed-countries-fund-ldcf) is dedicated to addressing the special needs of the Least Developed Countries (LDCs) under the UNFCCC. It supports the preparation and implementation of National Adaptation Programs of Action (NAPAs) to help LDCs adapt to climate change impacts. Together with SCCF, it is managed by GEF.
- **Adaptation Fund** (AF) (https://www.adaptation-fund.org/), established in 2001, finances concrete adaptation projects and programs in developing countries vulnerable to climate change. Initially funded by a 2% share of certified emission reductions (CERs) from the Clean Development Mechanism (CDM) of the Kyoto Protocol, and other sources, the Fund now serves the Paris Agreement as of January 1, 2019..
- **Loss and Damage Fund** (https://unfccc.int/loss-and-damage-fund-joint-interim-secretariat) is a new mechanism under the UNFCCC aimed at addressing loss and damage associated with the impacts of climate change, particularly in vulnerable developing countries. It is intended to provide financial support to help developing countries that are particularly vulnerable to the adverse effects of climate change in responding to economic and non-economic loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events.
- [/add details on the way to access this resource and how to use it for the implementation of approaches. Add case studies of projects having been supported will illustrate the use of this resource]

Case study 5 Climate Bridge Fund in Bangladesh (JM)

Bangladesh, situated in the delta of the Ganges, Brahmaputra, and Meghna rivers, faces severe coastal risks due to its low-lying geography and extensive coastline along the Bay of Bengal. The country is highly susceptible to sea level rise, which exacerbates coastal erosion, salinity intrusion, and increases the frequency and intensity of cyclones and storm surges. These hazards threaten critical infrastructure, agricultural land, and freshwater resources, putting millions of people at risk. The densely populated coastal regions, such as the Sundarbans, a UNESCO World Heritage site, are particularly vulnerable. Adaptation measures, including the construction of cyclone shelters, embankments, and improved early warning systems, are crucial for mitigating these risks and enhancing the resilience of coastal communities in Bangladesh. Additionally, sustainable land use planning and the restoration of mangroves play a vital role in protecting the coastline and reducing the impacts of climate change.

The Climate Bridge Fund (CBF) is a funding mechanism enabling locally led action on loss and damage for climate-vulnerable communities. Established by BRAC – a developed specialised NGO – with funding from the German government, the Fund supports adaptation activities for communities displaced or at risk of displacement due to climate-induced impacts. It operates under the regulation of the Government of Bangladesh, with BRAC managing the Secretariat and disbursing funds to local civil society organizations in alignment with the principles of locally led adaptation. The Fund comprises two lines of funding: Climate Change and Emergency Response. Under the Climate Change line, EUR 10 million were invested in government treasury bonds to ensure financial sustainability, with the investment income supporting projects annually. The Emergency Response line received an additional EUR 10 million to implement projects in districts most affected by climate shocks and COVID-19. Despite challenges, the Fund has supported nearly 150,000 people through initiatives like climate-sensitive disease awareness, climate-resilient water, sanitation, and hygiene (WASH) services, and infrastructure support. The CBF ensures efficient spending with 60-70% of operational costs at the local level, enabling scalability and relevance to global climate financing for loss and damage. The CBF adheres to eight principles of locally led adaptation: devolving decision-making to local levels, addressing structural inequalities, providing predictable funding, investing in local capabilities, understanding climate risk, flexible programming, ensuring transparency and accountability, and promoting collaborative action and investment. This model illustrates how international climate finance can effectively support communities most affected by the climate crisis.

Source: Climate Bridge Fund

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6 Monitoring systems for assessing the effectiveness of the approaches

Monitoring, evaluation, and learning (MEL) are vital part of the UNFCCC processes, designed to for tracking progress, assessing effectiveness, facilitating learning, adjusting strategies towards climate goals, and communicating the outcomes.

The Paris Agreement, adopted in 2015, emphasizes transparency, accountability, and continuous improvement through MEL mechanisms. Article 7 of the Paris Agreement established the **Global Goal on Adaptation** (GGA[7]) to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change. The GGA aims to accelerate collective adaptation actions that are aligned with the Agreement's temperature targets. The **Glasgow-Sharm el-Sheikh** (GlaSS) work programme, adopted in 2021, outlined the steps for specifying the GGA. The UAE **Framework for Global Climate Resilience**, adopted in 2023[91], resulted from this process and set seven key thematic targets: (i) reducing climate-induced water scarcity and ensuring climate-resilient water and sanitation; (ii) achieving climate-resilient food and agriculture and equitable food access; (iii) enhancing resilience against climate-related health impacts and promoting resilient health services; (iv) protecting ecosystems and biodiversity through nature-based solutions; (v) increasing the resilience of infrastructure and human settlements; (vi) reducing the adverse effects of climate change on poverty and livelihoods with adaptive social protection measures; and (vii) safeguarding cultural heritage with adaptive strategies and climate-resilient infrastructure informed by traditional and Indigenous knowledge. **All these thematic areas are important for tracking the progress made in adapting to sea-level rise (SLR) and associated risks**.

Moreover, the UAE Framework for Global Climate Resilience includes four process targets that are essential for effective adaptation, building upon the National Adaptation Plan (NAP) process. By 2030, all Parties should conduct up-to-date climate hazard assessments, establish multi-hazard early warning systems, and create gender-responsive, participatory, and transparent national adaptation plans. These plans should address ecosystems, sectors, people and vulnerable communities, mainstreaming adaptation into all development strategies and plans. Significant progress in implementing these plans by 2030 should reduce climate hazard's social and economic impacts. Moreover, all countries should establish and operationalise a MEL system, building the necessary institutional capacity to implement the system. To define the indicators for measuring progress towards these targets, a two-year UAE – Belém work programme was established.

The global stocktake of progress, outlined in the Paris Agreement, will be guided by the UAE Framework, likely starting in 2026. This gives countries three years or less to implement and provide essential evidence on adaptation for the upcoming comprehensive assessment of the Paris Agreement[92]. Since 2015, 52 developing countries, including 23 least developed countries, have submitted their NAP documents by January 2024[93]. Over half of these NAPs include a MEL framework and indicators, and three-quarters commit to reporting progress. However,

[7] https://unfccc.int/topics/adaptation-and-resilience/workstreams/gga

implementing MEL systems faces several challenges and less than 40% of countries with a National Adaptation Plan (NAP) monitor or evaluate its implementation[94]. Even with approved MEL designs, most lack systematic mechanisms to track progress, and the presence of a NAP can misleadingly suggest that adaptation efforts are adequately managed and monitored. Europe has the most advanced MEL system, and all EU Member States have developed national adaptation policies. Adaptation is integrated into sectoral policies, with monitoring and reporting mechanisms in place to evaluate effectiveness comprehensively[95]. As a contribution to the UAE – Belém work programme, EU has compiled a list of over 300 indicators and methodologies to assess them.

The National Adaptation Plan (NAP) Global Network developed guidance documents on monitoring, evaluation, and learning (MEL). The "Toolkit"[93] provides practical advice for integrating MEL into adaptation planning, detailing methodologies for assessing climate risks, implementing adaptive measures, and evaluating their effectiveness, with case studies illustrating best practices. "Reporting on Progress in NAP Processes"[96] addresses challenges in tracking progress and offers recommendations for improving reporting mechanisms. "Integrating Learning into the NAP Process"[97] emphasizes the role of deliberate learning, defining it as a collective process enhancing knowledge and behaviors related to climate adaptation, and outlines strategies for embedding learning throughout the NAP process, highlighting key enablers like institutional arrangements, leadership, and stakeholder engagement.

Effective coastal adaptation MEL frameworks are crucial for assessing sea-level rise (SLR) risks and the associated economic, environmental, and social damages and costs. Monitoring systems should manage long-term coastal adaptation and identify tipping points where approaches become ineffective. They should define financial, biophysical, and technical limits using tools like cost-benefit analysis[98]. However, only a small fraction of the largest coastal cities have developed comprehensive adaptation plans with defined indicators and metrics. Most of these existing indicators measure the outputs of adaptation processes rather than their impacts, which are necessary to assess effectiveness. Many indicators lack detailed information, clear targets, and defined monitoring timeframes, leading to challenges in accurately measuring progress[99]. Various examples of monitoring systems assess the effectiveness of interventions in terms of social acceptability, socio-economic development, sustainability, and considering cultural, ethical, economic, and political concerns[6,7,100].

An important aspect of any MEL process is its ability to be iterative and enable learning among project implementors. This is particularly crucial in situations where risks cascade through the systems so that impacts on one will not lead to impacts on another system or that the interaction of changes in different systems will not cause negative impacts on another. An appropriate MEL framework that is actively implemented will help prevent maladaptation due to various SLR interventions.

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