Tenth meeting of the Executive Committee of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts, Bonn, Germany, 23-25 October 2019

Background paper

Item 4 Collaboration and interlinkages with other bodies and work programmes under the UNFCCC: Collaboration with the Technology Executive Committee on the development of a joint policy brief on technologies for averting, minimizing and addressing loss and damage in coastal zones

About this document

This document provides background and previous consideration on the development of the joint policy brief of the Executive Committee of the Warsaw International Mechanism for Loss and Damage and the Technology Executive Committee (section I), information on the intersessional work (section II), next steps (section III), the current draft joint policy brief (annex I) and a list of active contributors (annex II).

I. Background

1. In the context of activity 3(a) of the strategic workstream (c) of the five-year rolling workplan of the Executive Committee of the Warsaw International Mechanism (WIM Excom),[1] the WIM Excom and the Technology Executive Committee (TEC) held a joint session on 16 March 2018 in conjunction with Excom 7 and TEC 16, to discuss specific actions for collaboration between the two bodies.

2. The two committees agreed to jointly develop a policy brief on technologies for coastal zones with the aim of releasing it at or by COP25 (December 2019), and established a joint working group to continue the work intersessionally, including the development of a concept note.

3. Excom 8 (September 2018) endorsed the concept note which includes the scope of the policy brief, modality of work, roles and responsibilities of different actors and indicative milestones, including an organization of an expert dialogue. Excom 8 also requested the secretariat to start engaging relevant organizations for scoping and drafting of the policy brief.

4. Members of the intersessional working group[2] provided progress report to the Excom at its 9th meeting in April 2019.

[1] See: https://unfccc.int/sites/default/files/resource/docs/2017/sb/eng/01a01e.pdf
[2] The joint working group includes two Executive Committee liaison members (Mr. Nedal Katbehbader and Mr. Kimio Takeya who was succeeded by Mr. Yuichi Ono in September 2019) and two representatives of the TEC task force on emerging and cross-cutting issues (Ms. Adelle Thomas and Mr. Mareer Mohamed Husny).

II. Information on the intersessional work

5. In line with the concept note, the intersessional working group, with the assistance of the secretariat, has advanced the technical work, including organizing an expert dialogue in the margins of SB 50 (June 2019), to further facilitate the development of the WIM-TEC joint policy brief.[3]

Engagement of relevant organizations and experts

6. According to the concept note for the joint policy brief, relevant experts in the field of technologies for coastal zone and loss and damage has been engaged, on a voluntary basis, in the work of the joint working group, as appropriate.

7. The secretariat, under the guidance of the joint working group, has conducted outreach to relevant experts, using various channels such as the Nairobi work programme partners network[4] and the consortium partners and network members of the CTCN. A call for expressions of interest was also advertised through the loss and damage related pages of the UNFCCC website to enhance inclusivity, transparency and participatory process of the joint work by the two committees.

8. As at the publication of this note, 17 out of 23 experts who have submitted expressions of interest are actively contributing towards the WIM Excom-TEC joint work (see Annex II).

9. As referred to in paragraph 6 above, the engagement of relevant experts in the WIM-TEC joint work is on a voluntary basis. Due to unforeseen and a varying degree of voluntary contribution by the collaborating experts, the progress in the underlying technical work has been more gradual than anticipated, which has resulted in an adjustment in the timeline to ensure the delivery of high-quality final product.

10. Under the proposed timeline, the release of the final product will be in Spring 2020 to accommodate final review and endorsement by the two committees at their next meetings (TEC 20 in March 2020, Excom 11 dates tbc).

III. Next steps

11. The WIM Excom may wish to take note of the progress made by the joint working group intersessionally and discuss any further guidance in finalizing the WIM Excom-TEC joint policy brief, as necessary.

[3] Unfccc.int/node/195386

[4] See: https://www4.unfccc.int/sites/nwpstaging/Pages/Search.aspx?k=&tags={%22informationtype%22:%22nwppartnerprofile%22}

Annex I: Draft joint policy brief

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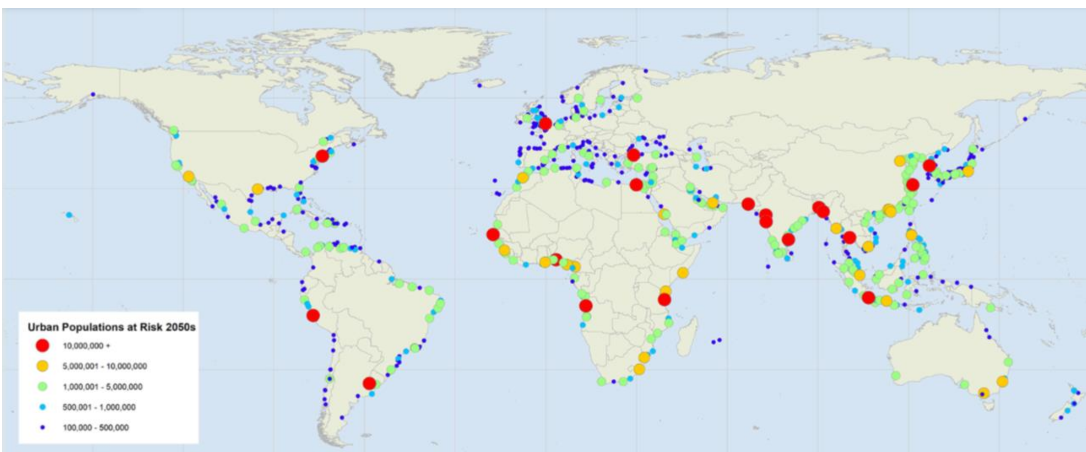
Chapter 1

Introduction

1.1 Background

1. **The importance of the coastal areas**: Throughout human history, the coastal areas attracted human settlements and activities. Richness of coastal services with fish stocks, fertile soil, good bases for ports, made the coasts and low-lying deltas highly desirable places to live and to settle for economic activities. Currently, about 40% of the global population lives within 100 km of the Oceans' coasts (Millennium Ecosystem Assessment, 2005) and approximately 60% of the world's 39 metropolises, with populations exceeding 5 million people, are located within 100 km of the coastline, including 12 of the world's 16 cities with populations greater than 10 million (IPCC 2007; Figure 1). Economic activity in the ocean and coastal areas is expanding rapidly and the projections by the Organisation for Economic Cooperation and Development show that until 2030 on a "business-as-usual" scenario basis, the ocean economy could more than double its contribution to the global economy, reaching over $3 trillion (OECD 2016). Rapid population growth and high economic growth rates are achieved in the coastal areas with economies of some of the coastal countries being dependent on coastal services with Small Island Developing States (SIDS) and states located in low-lying coastal areas (e.g. Bangladesh) in point.

Figure 1 *Urban populations at risk 2050 - Cities at risk from sea level rise, projected to receive at least 0.5 meters of sea level rise by the 2050s under RCP8.5 [source: C40 Cities https://www.c40.org]*



2. **Coastal areas at risk**: By its exposed location to increases of water levels, storm surges, cyclones and tsunamis, the coastal areas are threatened by flooding and land loss. Recent tragic events as Hurricane Katrina (2005), the Asian Tsunami (2004), the tropical cyclone that struck Myanmar (2008), the Sandy (2012), Hurricane Harvey, Irma and Maria (2017) have presented coasts as being hazardous places to live and do business. The increasing extreme events with tropical cycle hazards and severe storm surges threaten countries with substantial populations located on coastal plains and deltas. The World Economic Forum's Global Risk Assessment 2019 highlights that the most frequently cited risk interconnection by the countries is the pairing of "failure of climate-change mitigation and adaptation" and "extreme weather events" (WEF 2019). The coastal countries highly fear the projected climate changes and impacts, which in the coastal zone is exacerbated by additional factors, such as compound floods and subsidence.

3. Lives, assets and socio-economic activities make the coastal areas particularly vulnerable and in an urgent need for proactive action to protect the coasts. As indicated in the IPCC reports (IPCC 2014, 2018, 2019), climate change impacts and derived hazards will continue to play a role with increased storm frequency and severity. Climate impacts along with population increase, will further exacerbate the expected damage to

infrastructure and the vulnerability of coastal population. Global climate change projections emphasize the importance of climate-geared adaptation of the coast (IPCC 2019).

4. **Actions in the global policy context**: As a response to the natural disasters, the international community and national governments have initiated various disaster reduction programmes and policy goals over the past three decades. Legislative measures for coastal flood management are on a crossroad between disaster risk reduction (DRR) instruments and coastal zone planning policies and strategies including Integrated Coastal Zone Management (ICZM). Many governments find themselves in the midst of a paradigm shift from traditional disaster management towards DRR as part of development planning (Lavell et al. 2012). New laws aimed at reducing disaster risks often follow the principles set out by the Sendai Framework for Disaster Risk Reduction (DRR) 2015-2030, adopted by the United Nations Office for Disaster Risk Reduction (UNDRR). A number of the Sendai related targets and indicators are also found in the Agenda 2030 Sustainable Development Goals (SDGs), notably under SDG 13 (Climate Adaptation/DRR plans, Early Warning Systems), SDG 9 (vital infrastructure), SDG 14 (Oceans and coasts), SDG 6 & 15 (ecosystems and wetlands). The UNFCCC recognizes the importance of coastal adaptation and the challenge of needed actions. Since 2018, the work programme of the UNFCCC/Warsaw International Mechanism on loss and damage includes ocean and coastal issues[5]. Under the UNFCCC process, governments agreed to undertake concrete activities addressing oceans, coastal areas and ecosystems to inform adaptation planning and actions at the regional, national and subnational level[6].

5. **This policy brief**: In light of unprecedented climate change impacts on the oceans and coastal areas and with growing need of the countries to prepare to the uncertain future, the Executive Committee of the Warsaw International Mechanism for Loss and Damage (WIM Excom) and the Technology Executive Committee (TEC) commissioned the Policy Brief on Technologies for Averting, Minimizing and Addressing Loss and Damage in Coastal Zones. The objective is to inform the technical committees and Parties on the technologies by providing an overview of comprehensive risk management in coastal zones.

6. The policy brief is meant for two committees of the UNFCCC and policy makers/Parties and henceforth the main part of the report provides balanced information about technologies for coastal risk assessment, risk retention, recovery and rehabilitation. Information is presented in four sections: 1. Types of physical loss and damage in the coastal zone, primarily related to storm and sea level rise related flooding and loss of land (this section); 2. Technologies for coastal zone risk assessment; 3. Technologies for Coastal Risk Retention; 4. Technologies for Recovery and Rehabilitation in Coastal Zones. Additional information, including more scientific background and resources are included in the Appendices.

1.2 Overview of the problem

7. **The nature of coastal areas:** Coastal areas are complex physical environments that are impacted by both marine and terrestrial pressures, including rapid population growth, urbanization and climate change (i.e. sea-level rise, storm surges, increasing flood risks and coastal erosion). These pressures exacerbate the local problems, such as subsidence. As a result, a variety of compound pressures intensify deterioration and land loss. The impact of the pressures along the coast is, however, variable, depending on the exposure of the area, bathymetry and geomorphological conditions, vulnerability, the characteristic of population and community, including demography, livelihoods, planning along with coping capacities, as well as distribution of infrastructure. Although coasts normally show considerable resilience to waves and have capacity to a return to the pre-disaster coastline position, the forces from storm surges and tsunamis can reshape soft coasts, causing coastal erosion. In addition, consistently rising sea levels with subsidence due to geotechnical processes (e.g. compaction), chemical processes (e.g. oxidation of peat soils), and/or anthropogenic sources (e.g. excessive groundwater exploitation), may lead to permanent inundation of the coastal areas, causing enduring impacts of land loss.

[5] FCCC/SB/2017/1/Add.1, FCCC/SB/2018/1
[6] Article 4.1

8. A city's level of climate risk is intensified by socio-economic circumstances and the built environment's shape and form. Although variations in geography leave certain cities acutely exposed to sea level rise and coastal flooding, such as low-lying delta cities in typhoon and hurricane zones, all coastal cities will be impacted to a certain degree, depending on a city's geography, urban development pattern, economic makeup and social structure. Furthermore, current trends show that coastal urban centres are growing faster than any other regions given the economic opportunities they provide, leading to even more pressure on natural coastal spaces and higher exposure to coastal hazards.

9. With this overview in mind and bearing on uncertainty of future conditions, hazards and risks in the coastal zones need to be thoroughly considered by national and sub-national levels, i.e. authorities, coastal managers and urban planners, in order to deliver appropriate adaptive coastal flood management solutions and urban adaptation plans that are tailor-made for the local characteristic. This requires proper understanding of the socio-economic trends, projected climate change and impacts on the coasts as well as risk management technologies in the coastal areas (contained in this policy brief).

10. **Global Climate Change imposing a threat to the coastal areas:** Projected impacts of climate change indicate with high confidence the effects of various climate scenarios on coastal areas (IPCC AR5, 2014, 2019), which induces precipitation change, sea level rise and extreme weather events including storms and sea surge. Slow onset events (including sea level rise, increasing temperature, ocean acidification, glacial retreat) with related impacts, and rapid onset events are and will be a source of hazards for the coastal areas and ecosystems. The IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019) alerts that over the 21st century the ocean is projected to transition to unprecedented conditions with increased temperatures, greater upper ocean stratification and further acidification. The report identifies that Global mean sea level (GMSL) is rising with acceleration in recent decades. Extreme sea level events are projected to occur frequently at many locations, and they will be exacerbated by increases in tropical cyclone intensity and precipitation. Increases in tropical cyclone winds and rainfall, and increases in extreme waves, combined with relative sea level rise, are projected to exacerbate extreme sea level events and coastal hazards. The most immediate and significant of these coastal hazards are coastal flooding and erosion, drought, saltwater intrusion and ecosystem change, which have further implications on health and socio-economics.

11. **Loss and damage in coastal zones:** *PHYSICAL IMPACTS:* Under the uncertainty of future climate change, increasing risks of weather and climate extremes occur, with implications for the frequency of coastal flooding and land loss. The sea-level rise as a slow, continuous and relatively predictable process, could inundate low-lying areas, submerge coastal wetlands and marshes, erode beaches, exacerbate flooding and increase the salinity of bays, deltas, estuaries and rivers. Rising sea level and subsidence will lead to permanent flooding in the long term that causes major threats on densely populated low-lying coastal areas and island states, because their low topography does not allow for retreat to higher areas.

12. Coastal flood hazards, on the other hand, are highly unpredictable and can be diverse, including storm surges, tsunamis, tropical storms, seiches etc. Although the coasts also experience other types of flooding, for example from rivers and local rainfall, the hazards from the sea are unpreventable, are often difficult to predict, and are amongst the most forceful of floods (GWP, WMO 2013). However, it is the combination of extreme events (e.g. high tides, surge and sea storms) in conjunction with the ongoing sea level rise that will result in a major increase in the intensity and occurrence of potential impacts associated with hazardous events (Nel *et al*., 2014). Likewise, storm surges (and sea-level rise in the long term) have the potential to affect coastal environments through wind and wave impacts on the sandy coasts' sediment dynamics, leading to coastal erosion and damage even in areas which are not directly affected by storm-surge flooding. A profound understanding of these hazards, their mechanisms and potential impacts is crucial to derive an appropriate coastal risk management response.

13. *SOCIO-ECONOMIC IMPACTS*: With the fast urban development in the coastal areas, the economic damage through storm surges has increased dramatically over the last two decades. Examples are the damages by Hurricane Katrina in 2005 (ca. 1,836 fatalities, total damage is estimated at $125 billion[7]), Hurricane Sandy in 2012 (with close to 90,000 of flooded buildings, total damage is estimated at $19 billion), and more

[7] https://en.wikipedia.org/wiki/Hurricane_Katrina

recently Hurricane Harvey with the direct economic losses $95 billion. Also a threat is attributed to the potential damage to harbours and ports due to sea-level rise, which could lead to overall economic losses of $111 billion by 2050 and $367 billion by the end of this century (Noone, Sumalia and Diaz, 2012).

14. The increasing trend in damages in the coastal areas is highly related to societal factors, such as an increase in coastal populations and associated higher economic investments (Pielke Jr., et al., 2008, Raghavan & Rajesh 2003). Estimates suggest that the global economic costs to cities, from rising seas and inland flooding, could amount to $1 trillion by mid-century. Cities as Miami, Guangzhou, and New York are the top three cities in terms of the value of assets exposed to coastal flooding between 2010 and 2070, in a range of $2 to 3.5 trillion. In terms of exposed communities, it is Kolkata, Mumbai and Dhaka that have the highest number of people at risk from coastal inundation: $11-14 million.

15. However, even storms hitting less industrialized coasts are causing tremendous damage and loss to the usually highly vulnerable rural population, as recently shown by two cyclones that hit the southwestern African coast in March 2019 ("Idai", the deadliest tropical cyclone with >1,297 fatalities, costliest tropical cyclone in the South-West Indian Ocean with >US $2billion damage[8]) and in April 2019 ("Kenneth", 52 fatalities, >US$ 100 million damage[9]). While the economic damage of storm impacts in rural areas might not be comparable to storm impact on a developed coast, usually the resilience of the rural communities is much lower.

16. **Comprehensive risk management in coastal areas**: Due to past natural disasters and as a response to the projected climate change impacts, many governments have been embarking on disaster management measures, such as flood control, early warning systems and evacuation planning. Capacities in the integration of coastal hazards preparedness and climate change adaptation are being developed. As proactive actions, coastal management and adaptation measures are being implemented worldwide, which aim at safeguarding/enhancing resilience of coasts while integrating socioeconomic activities on the coasts and the natural dynamics of the coastal areas. The coastal/adaptation measures encompass traditional engineering options, such as strong embankments and dikes, as well as nature-based solutions and various other measures as early warning, spatial planning.

17. Traditionally, people tried to control floods for coastal risk retention through structural measures. However, in order to reduce the consequences in case protection fails, non-structural measures are nowadays applied. Beach nourishment may for instance be applied to compensate for coastal erosion. The combination of these measures aims at reducing vulnerability and protecting against hazards. A number of nature-based solutions serve for recovery and rehabilitation in coastal zones with coastal vegetation playing a significant role in mitigating coastal erosion and promoting sediment deposition. As such, mangroves and saltmarshes are especially capable to grow with rising sea levels. Managed realignment is an alternative measure that usually entails moving the coastal embankment landward in order to reduce the maintenance cost of a coastal defence. It is observed globally that while wealthier countries and coastal metropolitan areas can respond by commissioning coastal risk assessments and investing in heavily engineered coastal protection structures, such as breakwaters and sea walls, less developed countries and/or smaller municipalities usually lack the capital and capacity for these interventions and thus are much more vulnerable to coastal hazards. For these regions, coastal risk assessments and interventions have to take place at a higher governance level.

18. In the context of climate change impacts and projected increased risks in the coastal zones, which will have much broader geographical extension, it will no longer be feasible to defend only single sections of coastlines due to widespread threats and financial feasibility. For this reason, comprehensive coastal risk management approaches, such as Integrated Coastal Zone Management (ICZM) and Integrated Flood Management (IFM), are applied to minimize the negative consequences that physical impacts might cause on people, economy and ecosystems. These approaches provide a risk-informed decision-making on flood hazards based on estimates of flood risk, as well as costs and benefits of flood mitigation and management. Depending on needs, they can also be embedded in legal/institutional and participatory frameworks for integrated decision-making and adaptive planning to allow government-driven management of the coastal areas.

[8] https://en.wikipedia.org/wiki/Cyclone_Idai

[9] https://en.wikipedia.org/wiki/Cyclone_Kenneth

19. Recent assessments have shown that the impacts of climate change on coastal areas will be increasingly disruptive at all spatial scales (IPCC 2019). This Policy Brief informs about the available technologies for comprehensive risk management in coastal areas, including *hardware* (i.e. the technology itself), *software* (i.e. skills, knowledge and capacity that accompany the transfer of technology) and *orgware* (i.e. the capacity building of the different institutional actors involved in the adaptation process of a new technology). The technologies are illustrated by good practices from various regions in order to show existing possibilities and needs, as well as ways to overcome the challenges, e.g. by building partnerships for exchange of experiences.

Chapter 2

Technologies for Coastal Zone Risk Assessment

2.1 Setting the scene: key perspectives on coastal risk assessment

20. **Status**: Technology, technical and knowledge-based approaches are constantly developed and improved, and they are commonly applied in the coastal zone risk assessments around the world, as shown in hundreds of good practices in both developed and developing countries (e.g. databases of best practices by Ourcoast 2011, 2012; Misdorp 2011). Identifying trends and projecting future coastal risks is today challenging, related to variable and changing climate and evolving socio-economic circumstances. However, the coastal risk assessments are integral components in sustainable development plans. There are now technologies available, which make monitoring and modelling coastal hazards, exposure, and vulnerability to climate change manageable and affordable. There are also developed policies, regulation and governance structures at different levels, which, together with an increased awareness, promote the planning and implementation of coastal risk assessments and adaptation responses.

21. **Frameworks**: The international disaster risk management organizations (UNDRR) and community emphasize the need for preventing hazards and for applying technologies in order to increase disaster preparedness and response of all regions to climate change impacts. Coastal risk assessments form a starting point towards raising awareness of the potentially devastating impacts and encourage commitment to more comprehensive studies in order to identify needs as well as build sectoral and integrated strategies for coastal adaptation and disaster risk mitigation. International policy enhances the use of policy and regulation tools relevant to the coastal risk under climate change and such tools have been increasingly introduced in recent years. Of particular significance are the UNFCCC 2010 Cancun Adaptation Framework, and the 2015 Sendai Framework for Disaster Risk Reduction. At a basin scale, the 2008 Protocol to the Barcelona Convention for the Integrated Coastal Zone Management-ICZM of the Mediterranean focuses on the impacts of the increasing flooding and coastal erosion. There are complementing EU instruments (e.g. the Water Framework Directive[10], the Flood Risk Directive), and the amended Environmental Impact Assessment Directive[11] that prescribe coastal risk assessments.

22. **Demand**: Any step towards preparedness requires data and information that is collected, generated and visualised by various tools, methods and solutions. The use of these technologies is broad from fundamental and applied science communities, hydrological services to operational agencies of the governments. In Europe, the national agencies together with hydraulic services of all EU Member States were mobilized to make the national assessment and management of flood through the EU Flood Directive[12]. Examples of such regional mobilization for flood risk assessments are unique, because it is usually at the national and sub-national levels that the needs for flood information are addressed.

2.2 Overview of types of technologies

23. Technologies for coastal risk assessment include a rich variety of methods and tools, including hardware, software and orgware, that can be applied independently, or in combination for obtaining better results. These technologies are mostly highly dependent on data with good spatial and historical coverage. The technologies presented in this policy brief to show the wealth of possibilities for assessing hazards and risks in the coastal zones, include Ocean/Coastal Observation, Geospatial Technology, GIS-based tools, simulation models, interactive decision support tools. These technologies can be built in the integrated frameworks, as flood risk

[10] 2000/60/EC

[11] 2015/52/EU

[12] 2007/60/EC

management and Integrated Coastal Zone Management systems, as the input component for formulating integrated plans.

Coastal Risk Assessment – examples of technologies	
Ocean/Coastal Observation	International ocean and coastal observation networks and systems, projects and programmes that are organised around data collection and data management. Data serves for enhanced modelling and forecasting, risk assessments, improved early warning, understanding climate-ocean interactions and ocean's role in the global system.
Geospatial	Geospatial technology (e.g. high-resolution satellite imagery, Digital Elevation Models-DEMs) provide time series of historical coastal geo-spatial records that serve for assessing trends: coastal changes to provide estimates of the coastal erosion rates and development.
Numerical model simulations	Numerical models are used to predict weather and ocean conditions, flood and coastal erosion, but also to build historical records anywhere in the world to look at trends and define design conditions used to dimensions civil structures or identify risks for human populations/activities.
Interactive decision support tools	Tools that provide for the decision-makers essential information of the scientific research in indicating areas at risk, suggest adaptation options, and focus on the geo-spatial indication of risk areas (several flood scenario viewers), etc.

2.2.1 Ocean/Coastal Observation and Geospatial Technology

24. **Ocean/Coastal Observation Technology**: Ocean observation data is critical for enhanced modelling for forecasting and risk assessments, improved early warning, as well as understanding climate-ocean interactions and ocean's role in the global system. International ocean and coastal observation networks and systems, projects and programmes are organised around data collection and data management. There are many well-founded and structured ocean and coastal data infrastructures in many regions, including the USA (National Centres for Environmental Information, National Oceanographic Data Centre - NOAA), Australia (Integrated Marine Observing System, Australian Ocean Data Network) and the European Union (e.g. Copernicus Marine Environment Monitoring Service – CMEMS, Jerico). The Global Ocean Observing System (GOOS) is a sustained collaborative system of ocean observations, encompassing in situ networks, satellite systems, governments, UN agencies and individual scientists. International organisations such as IOC-UNESCO and its International Oceanographic Data and Information Exchange programme (IODE) actively promote and support the development of such data infrastructures. These data infrastructures are building blocks for wider global services, such as the IODE Ocean Data Portal (ODP), and the GEOSS portal that provide wider availability and access of data on a global scale. The International Council for Science World Data System (ICSU WDS) will provide access to a wide range of data, including environmental data, data from the social and health sciences.

25. **Geospatial Technology**: High resolution satellite imagery and Digital Elevation Models-DEMs of improved resolution and elevation accuracy are currently available, together with efficient software platforms for analysis, to provide time series of historical coastal geo-spatial records that serve for assessing trends. Observations of coastal change can provide estimates of the coastal erosion rates and development, whereas high resolution DEMs are necessary for the estimation of the flood hazard. In smaller scale studies (e.g. regional and/or local) other effective/efficient technologies can be used to identify coastal change trends, such as repeated airborne LiDAR and/or UAV optical photogrammetric surveys. At local scale, where assessments are carried out to support local decision making for adaptation responses, accurate information on trends (and projections) is required. In such assessments can also be used coastal morphodynamic trends based on the acquisition/combination of highly accurate ground topographic data from surveys (e.g. Real Time Kinetic- Differential and Terrestrial Laser Scanners), as well as high frequency optical data from ground video monitoring stations.

26. Geographic Information Systems (GIS) store, analyse and display both spatial and temporal information. GIS facilitate the analysis of rapidly changing and complex developments. To deal with huge databases and models, Geographic Information Infrastructure is in use enabling sharing data among the users. Exposure of coastal assets and activities can be extracted from the refined *CORINE* Land Cover - CLC dataset. Geo-spatial information on the global road and railway infrastructure has lately become available from OpenStreetMap[13]. Based on this information, a recent global-scale study has projected that in several countries (including some *SIDS*), expected annual damages-*EADs* to their road/railway assets can reach up to 0.3-1% of *GDP* annually. For regional and local assessments, improved accuracy/resolution of the geo-spatial information is required, particularly when assessing the exposure of important and expensive infrastructure/assets (e.g. seaports and airports).

2.2.2 Numerical simulation models

27. Numerical models are used to predict weather and ocean conditions, flood and coastal erosion, but also to build historical records anywhere in the world to look at trends and define design conditions used to dimensions civil structures or identify risks for human populations and human activities. Generally, due to limitations in monitored data (spatial and temporal limitations), numerical and physical models are set up in order to make projections and generate (numerical) information of the conditions encountered at specific locations. The past decades show an increase in numerical models being developed and considerably improved to reliably predict a possible flood event and its possible damage. Many tools have been developed that can simulate the extent of inundations given particular hydrodynamic boundary conditions as well as their impacts mostly in terms of casualties, direct damages to people, infrastructure and other assets.

28. Coastal erosion and flooding under climate change is forced by the global/regional drivers and is estimated with models of different spatio-temporal resolution. Many numerical models exist that can capture different processes: atmospheric, ocean circulation, wave and current action, tides and storm surges, sand transport, morphological changes, damage to vegetation. Although the computational power is increasing every day, models able to capture all relevant processes are usually very expensive in the computational sense. As a consequence, academics and engineers rely on models where assumptions have been made to be able to represent a few phenomena correctly. These models can then be coupled together to combine processes occurring on different scales, such as: cyclone atmospheric processes and storm surges, storm surge and local wave action, ocean currents and sediment transport in the coastal zone. These models also have different spatial coverage because different processes dominate on different scale (e.g. global atmospheric models cannot capture the effect of hills or buildings on the wind conditions in a port city), and downscaling is often used by nesting[14] one model into another of a finer scale. The behaviour of these numerical models is verified against in-situ measurements (obtained from monitoring/ocean observation) when they are available, or when looking at very specific physical processes, against physical model results.

29. In addition to numerical models, also physical models exist. These are scaled down physical reconstruction of relatively small areas and are usually used in academic research or at the final stage of an engineering design, to investigate specific physical phenomena that might not be accurately represented in numerical models (e.g. coastal defence stability, harbour penetration and ship response).

30. There are varying approaches for risk assessments of flooding and coastal erosion, which are determined by the spatial (global, regional, local) and temporal (short- and/or long-term) scales of the study, and the available information. The data generated by the bigger-scale models is used for boundary conditions of the lower-scale models what serves for the risk assessments in the coastal zones. The models are constantly being upgraded and new technologies emerge with the ability to model reality better and faster, in order to provide more reliable trend analyses and projections. New models enable scientists to cover larger areas and broader

[13] *OSM*, https://www.openstreetmap.org/#map=0/0/110)

[14] "Nesting" is the process of inserting a smaller model into a larger model and have the models exchange information

combinations of processes like extreme winds, storm surges, waves and currents and their action on the coastline or on civil structures.

Numerical models	Purpose	Needs / limitations e.g.:
Global model suites	Primary: forecast at global scale Secondary: generating data for boundary conditions for finer regional models, and generating long term data sets	Measurement Data for verification or data assimilation, limitations: coarse resolutions
Regional models	- forecast - generating data for boundary conditions for the local models	
Local (coastal) models	- coastal flooding - coastal erosion	

I. Global models

31. Global and/or continental-scale assessments are of particular importance as they can inform discussions for global and/or multi-national Climate Variability and Change adaptation policies. Mean sea level rise coupled with potential changes in the magnitude and recurrence frequency of storm events will aggravate coastal hazards, with severe impacts on the natural and human coastal systems, which will require efficient adaptation responses. These models can capture global processes like El Nino, La Nina, the migration of the ITCZ, wave growth in the roaring 40s, changes in ocean circulation or in water exchanges between the different oceans/basins, and are used for short and long term prediction and historical reconstructions. The global models then provide reasonably accurate boundary conditions for regional models. Global models are usually a suite of different models coupled with each other (atmospheric, ocean, land, sea-ice, example: GFS and IFS) and are run in large computational facilities by National Institutes (like NOAA or ECMWF). Some other global models just focus on some specific features like ocean circulation (HYCOM, NEMO). The global models require accurate data to be built (topography, land-use, bathymetry), initial conditions and boundary conditions variation over time (solar radiations, etc..) and usually assimilate measurement data to adjust their behaviour because of their coarse resolutions (wind speeds, ocean temperature, water levels, etc). Recently, global short-term forecasting frameworks have become available, like the Global Storm Surge Forecasting and Information System- GLOSSIS, which can provide global 10-day forecasts on total water levels and storm surges.

II. Regional models

32. Assessments at the regional (10s to few 100s of km of coastline) scales, can inform the planning of national/regional integrated adaptation policies and improve the efficiency of human and economic resource allocation. These are forecast and hindcast models that serve for generating atmospheric and hydrodynamic boundary conditions for the coastal models. Forecasts are generated in “ensembles” (range of possible future states of the atmosphere) in a very short time span using large amounts of computational power for analysis and identification of most reliable trends, while hindcasts are generated by comparing model output to historical measurements and are carefully tuned over long periods of time in an iterative manner. These models are used to predict hazards such as cyclonic and winter storm winds, surges and waves, tsunamis, ice coverage and movements, e.g. ADCIRC, WRF, MOST https://nctr.pmel.noaa.gov/model.html.

III. Local (Coastal) models

33. Local scale assessments (< 10 km coastline) support on-the-ground decision-making and the design of the technical adaptation measures. Coastal risk assessments consist of constituent assessments: hazard, exposure and vulnerability assessments. Concerning coastal erosion, there is a choice of approaches and morphodynamic models depending on the scale/resolution of the application, the type of coast (‘sandy’ or ‘cliffed’ coasts), the availability of topographic and hydrodynamic information, as well as the type of hazard. In large scale applications, simpler approaches and/or models are used due to prohibitive computational costs. At smaller spatial scales, various ‘validated’ numerical coastal morphodynamic models can be used (e.g. CMS, GENESIS, SBEACH, Delft3D, Mike21, XBeach and custom-made models) to obtain projections of erosion at ‘sandy’ coasts under extreme events, whereas slow-onset erosion (due to sea level rise) is mostly

projected using analytical morphodynamic models. At present, models can simulate processes occurring at one main spatio-temporal scale.

34. The available coastal inundation/flooding models range from simplified to elaborate and computationally intensive: (i) static models that assume that coastal areas hydraulically connected with the sea having elevations below mean sea levels will be inundated; (ii) semi-dynamic approaches, where water volume discharges are computed on the basis of time series of modelled water levels; (iii) flood intensity approaches that simulate flooding using approximations of the shallow flow equations, considering the local topography, terrain roughness and information on the flood scenario; and (iv) dynamic inundation modelling using 2-D hydraulic models of varying complexity. These can include various developed models: waves (e.g. SWAN, SWASH), flow (e.g. DELFT suite, TUFLOW, MIKE 21 suite, TELEMAC suite) and sediment models, dune models, shoreline evolution modelling, etc.)

2.2.3 Interactive decision support tools

35. Given that geo-spatial datasets and software technologies or datasets might not be easily accessible to policy-makers and other decision-makers (and the general public) and that the information required by decision makers can be at a different level than the scientific/engineering information, the development of interactive decision support tools is increasingly gaining importance. Such tools provide essential information of the scientific research in indicating areas at risk, suggest adaptation options, and can focus on the geo-spatial indication of risk areas (several flood scenario viewers), or providing statistical information on the municipal level. Such efforts should be collated, validated and uploaded to easily accessible and operated platforms, within the framework of the new generation geo-portals. Also relevant are methodologies, tools and guidance for risk assessment, including as developed by UNCTAD, with respect to operational disruptions to coastal transport infrastructure and flood modelling.

36. In order to describe future global socio-economic conditions, scenarios have been developed (Shared Socio-economic Pathways-*SSPs*), which outline plausible alternative states of human (and natural) systems at a macro-scale, and include qualitative and quantitative descriptions of demographic, political, social, cultural and institutional development, economic and technological variables and trends, and the human impacts on ecosystem services. Although the S*SPs* have been designed for global use, they can be applied at smaller spatial scales.

2.3 Opportunities and Challenges

37. The current technologies for coastal risk assessment offer enormous diversity of infrastructures, models, tools, methods and solutions, which due to the urgency are continuously being developed and improved. High dependence of the technologies (like numerical modelling) on reliable data can, however, make them unusable in some parts of the world. Meteorological and oceanographic *in-situ* measurements are by definition limited in time and in space. Satellite missions, although they now span decades, have limitation in space coverage and accuracy. Scientists and engineers therefore use numerical models to have a full spatial coverage and expand the duration of data sets to the maximum possible.

38. In view of projected extreme weather and climate events, with already now experienced high occurrence frequency of the destructive natural disasters, there is a bigger need than ever to make use of data for improving the understanding of the dynamics of severe events and delivering an improved risk assessment. Linking different kinds of models to make the accountable assessments is equally important. As such, pure flood models generally do not map tropical cyclones, which means that one component of the risk is missing. Another aspect for consideration is that as much as the forecasts nowadays are of high quality, they only simulate losses from wind and storm surge but not flooding losses due to torrential rain.

Considering coastal erosion and flooding, there is a need for data harmonization concerning the drivers (e.g. the *sea level rise* and *extreme sea levels and waves*) of the coastal erosion/flooding hazards. The use of different databases and tools restricts inter-comparisons of results and may lead to over-interpretations.

39. **The need for international collaboration and partnerships is emphasized in order to provide the critical ocean information to mitigate and adapt to climate change.** As such, the recently launched Global Ocean Observing System 2030 Strategy (2019) envisages one fully-integrated global ocean that by 2030 will be fully operational with greatly expanded coverage, delivering a wider variety of essential information to a broader range of end users across operational services, climate and ocean health (GOOS Strategy 2030). Currently, on a basin scale, an All-Atlantic AtlantOS Programme (developed as AtlantOS project) aims at supporting harmonization and collaboration between existing ocean observation activities, their data collection methods, data management and applicability of the data in Atlantic waters (AtlantOS 2019). **Such partnerships are important for joint efforts of the nations and regions, and for sharing knowledge and experiences, but they require the international and national sense of urgency, political willingness and commitments, incentives and allocated budgets.** The upcoming UN Decade of Ocean Science for Sustainable Development (2021-2030) strives to bring together a diversity of players including governments, knowledge research institutes and enterprises in order to collectively contribute to achieving the ocean-related SDGs. The Executive Planning Group of the UN Decade emphasizes in Decade Paper No.1 (2019) the need to growing the capacity of all nations to collect, manage, analyse, and use ocean data and information.

40. Efforts are made for the transfer of knowledge and technologies to the developing countries with the financial support of the international donors, regional partnerships and/or multilateral governmental cooperation. Although in many cases data can be freely available, the capacity to analyse the data and make assessments is required and that can be a limitation for many regions. Therefore, **in poor developing countries, there are significant challenges in terms of human and economic resources and organizational structures that can constrain the acquisition and use of the technologies mentioned**. For instance, LiDAR data, which are freely available on the web for some (European) coastal states, are seldom available for the coasts of many African States and *SIDS*. Usually there is a reciprocal relation between the resolution of geo-spatial information and affordability. High-resolution data, which are particularly important to assess risks in the complex coastal areas, might be not accessible in economically developing regions. It appears that the areas and regions, which would benefit most from this information usually do not have the capacities to acquire and/or use them. Resource limitation, capacity limitation and data limitation can preclude consideration of climate risks in coastal areas, especially in the generally data-poor Developing Countries.

2.4 Case Study

41. In recent years there have been increasing efforts to use the emerging technologies to assess coastal risks at different spatio-temporal scales. Some representative case studies are presented in Appendix.

42. A major opportunity relates to e.g. remotely-sensed Earth Observations, which are increasingly available from various openly accessible repositories. These data, which are highly valuable because of their consistent information, could (together with scientific expertise and appropriate tools) support economic development, decision-making, and policy implementation for all (coastal) States. There is also emerging information on coastal hazard trends and projections at different spatio-temporal scales. However, the full potential of such datasets has not yet been realized. Coastal risk data can be now considered as ‘big data’, i.e. data that are too large, fast-lived, heterogeneous and complex to be exploited to their full potential. To address these challenges, traditional local processing and data distribution methods might not be effective or efficient. Instead a paradigm shift, such as that represented by EO Data Cubes, is needed to store, organize, manage, and analyse coastal risk data.

Chapter 3

Technologies for Coastal Risk Retention

3.1 Setting the scene: key perspectives on coastal risk retention

43. **Status**: Coastal floods, especially tsunamis, often occur with a short warning time and can cause large number of fatalities characterized by severe flood effects. That leaves little or no time for preventive evacuation of vulnerable communities. With projected rising sea levels and increased frequency and intensity of storms, coastal retention technologies will be in a bigger need than today. These technologies aim at protecting against floods, but also reducing of flood hazard, adapting of the coastal areas, raising of awareness and preparedness. The Sendai Framework for Disaster Risk Reduction articulates strengthening resilience through prevention of new, and reduction of existing disaster risk.

44. **Framework**: Flood management includes prevention/mitigation (to reduce the probability and/or impact of disasters), preparedness (to reach readiness to any emergency situation), response (to provide assistance to maintain life) and recovery (to restore livelihood and to reduce future vulnerability by enhancing prevention and increasing preparedness). In this context, to increase the effectiveness of flood protection and build adaptive capacity in the coastal areas, the integrated approaches are often implemented in the frameworks of Integrated Flood Management (IFM) and Integrated Coastal Zone Management (ICZM). They provide the integrated vision for protection and sustainable development, producing strategic frameworks of coherent strategies with the application of a well-balanced mix of technologies, promoting local linkages to various policy domains such as urban development, and enhancing stakeholder engagement. These approaches consider uncertainties related to climate change, coastal development and socio-economic growth by providing a flexible approach to increase resilience to climate change and increased climate variability. IFM and ICZM also provide a linkage to the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals.

45. **Demand**: In a view of projected climate change impacts, implementing adaptive management is increasingly needed by the governments, and they are (or can be) included in the integrated approaches. Strengthening flood resilience relates to (i) maintaining, protecting and restoring the natural capacities to reduce the levels and duration of flooding; (ii) the ability to recover; (iii) the ability to adapt to changing conditions. Adaptive management encourages an integrated and flexible approach to increase resilience, reduce vulnerability, and monitor the measures in order to apply adjustments. These approaches enable linking short-term decisions with long-term challenges concerning coastal risks and in the last decade various communities of scientists and practitioners have been exploring them worldwide. They commonly involve a mix of technologies seeking a balance between prevention and mitigation on the one hand, and response and recovery on the other hand (IFM, WMO 2017).

3.2 Overview of types of technologies

46. Technologies for coastal risk retention vary from the solutions that protect and reduce the exposure to coastal floods, such as traditional structural solutions (hard and soft measures) to technologies that reduce the vulnerability of people with their goods. Different typologies may be considered for coastal retention. In short, the technologies include the traditional engineered solutions, nature-based solutions, hybrid technologies, and non-structural solutions that aim at building resilience of the natural system and coastal communities. In view of climate change projected impacts and deep uncertainties, the joint use of these technologies is currently practiced in order to both protect and build resilience.

Coastal Risk Retention – examples of technologies	
Structural / engineered	Hard measures: sea-walls, storm surge barriers and closure dams, revetments, groins, detached breakwaters, dykes, artificial reefs, tetra pods, riprap, land reclamation, multifunctional use of infrastructure (e.g. in the urban areas)
	Soft measures: sand nourishment, rock revetment, beach fills, sand engine, dune restoration
Nature-based	Wave energy dissipation and coastline stabilization: mangroves, salt-marshes, coral reefs, reef building oyster beds, wetland restoration, revegetation of shorelines,
Hybrid	Living shorelines (e.g. inclusion of natural plants into a revetment) /Building with Nature, climate smart agriculture
Non-structural	Coastal zone planning and management, land use, flood-proofing, flood mapping, early warning, evacuation procedures, protection of critical infrastructure, coping and insurance of (residual) risk, community preparedness, raising awareness, education, legal and regulatory

3.2.1 Traditional structural/engineered technologies

47. Generally, engineered technologies serve for protection of coasts and risk reduction. Hard measures are built to reduce wave impact on the coast. There are a variety of types of hard technical technologies and their application mostly depends on costs of construction and maintenance, and often needed effort in engineering design. In this sense, riprap is the common armouring on many coastlines, like in California, and its popularity stems from the fact that riprap requires less engineering expertise to design and construct than seawalls or revetments (Stanford Centre for Ocean Solutions 2018).

Engineered technologies: examples of hard measures
Seawalls can protect against the effects of high waves. There are a variety of types of coastal structures, which can be constructed using a range of materials. Some of them are vertical, and may feature a promenade on top of them. Others are inclined, sometimes made of interlocking blocks or large boulders. In cases where the wave conditions may be severe throughout the year, return walls can be placed at their top. It is common that the entire wall is not always exposed to water. Common types can be found of reinforced concrete, boulders, steel or gabions.
Storm Surge Barriers and Closure Dams are typically large and complex protection projects, which require the usage of a movable barrier that can close the mouth of a tidal inlet or estuary. Closure dams are much simpler, in that they are non-movable barriers that can be constructed using much simpler construction techniques. Such structures will prevent extreme surge levels to propagate land inward. These structures often involve large investments and are designed for a lifetime of 100-200 years. Therefore, this design should consider future climate change conditions like sea level rise.
Dykes are often built in low-lying areas, to prevent the water from intruding during high tides or storm surges. In some areas such as the Netherlands, Tokyo or Jakarta, which are below water level at all times, they are essential for the normal functioning of the areas that they serve, which would otherwise be flooded at all times. Typically, the seaface of the dyke is covered in a strong material such as concrete or rock, in order to protect against the effect of waves. However, following the large failures that took place during the 2011 Tohoku Earthquake Tsunami, Japanese engineers currently also recommend covering the landward side to avoid brittle failures during overtopping.
TetraPods allow water to flow around the structure to dissipate the force along coastal areas. These waves dissipating blocks can take different shapes and material, but typically formed out of concrete. They are used primarily to enforce coastal structures such as seawalls and breakwaters.
Geotextiles/Geosynthetic materials: Geotextile fabrics are a key innovation to provide a structural support to maintain sediment deposition and support shoreline construction works, such as dune construction. Applications exist for filter fabric at the base of construction, similar to that of gabion used in seawalls. Regardless of tensile strength and durability, these must be appropriately sealed and secured to ensure the longevity of the rehabilitated mass over time. These benefit from being shipped empty and filled on site, allotting for finer granular materials and flexibility in placement. Additionally, high density polyethylene structures already exist for laying road surfaces that can be simpler than laying a bitumen layer and used in the conversion of dirt roads.
Riprap is a type of shoreline armouring structure that consists of stacks of large boulders and smaller rock fill, designed to mitigate wave impact and prevent erosion. These structures are often placed parallel to the shoreline in front of a

cliff or along a beach to prevent further erosive events and wave overtopping during large storms. Because of its design, riprap requires the most space of all the armouring strategies and, therefore, leads to the largest placement loss.

Land reclamation can be used to increase the elevation of coastal zones by creating a barrier for the areas behind them. This can be seen, for example, throughout Tokyo Bay, where the original land is at a lower level than newer reclaimed land (for instance Odaiba island, Rinkai park or MinatoMirai). Economies of scale have provided recent impetus for large-scale reclamation. This can be seen in places such as Australia and the Middle East. This relies in large on the deep suction dredging pumps, using centrifugal devices, barges, and vertical drainage techniques for settling have provided recent advancements. When viewed as a system, these also consider the platform vessels used, in addition to gantries and suction piping for the proper transportation of the machinery and material.

48. The hard structures are of a highly protective nature and they are commonly applied, however, they are no remedy for sediment deficiencies due to sea level rise, nor for dune erosion during conditions with high surge levels. In addition, high costs of implementation of these technologies (e.g. storm surge barriers and automated dam closures), exacerbated by the maintenance, can make them inaccessible to many countries. Another challenge is the perceived aesthetic impact, namely, obstruction of views, which can be encountered in coastal communities. Popular are therefore soft measures that are engineered methods making use of the natural resources, such as sand and dunes. In applying beach and foreshore sand nourishments, modern modelling and surveying techniques are used to optimize this solution and make best use of the prevailing local physical conditions. In recent years there has been some experimentation with extreme types of beach nourishment, culminating with the concept of the "Sand Engine" in the Netherlands.

Engineered technologies: examples of soft measures

Beach and foreshore sand nourishments are mainly used to protect against shoreline erosion. Essentially, it involves the artificial addition of sediment to a beach area, which can be obtained from nearby quarries or dredging of the sea bottom, amongst other sources. The types of beaches that are most commonly nourished are the sandy type. These kinds of measures need to be repeated every few years, due to wave and current forces. Such artificial nourishments will be gradually spread to the onshore and offshore directions.

Sand engine: The Netherlands constructed 'The Sand Engine' ('super-nourishment') in front of the Dutch coast. An extra amount of sand was dredged offshore and applied on the shoreface with the idea behind that the sand would be redistributed by nature itself, thus stimulating natural dynamics of the coast, increasing a buffer zone for future sea level rise and enlarging the coastal intertidal zone which is beneficial for natural and recreational values alike.

Artificial sand dunes and dune restoration: It is possible to use a variety of techniques to create artificial sand dunes or rehabilitate degraded ones. Potential methods to do so include the building of fences on the seaward side of the dune, with the intention to trap sand, or the planting of vegetation. Nourishment can be done with gravel material (such as 15 mm in diameter), and can take the shape of pyramids to stabilize the structural foundation. In terms of erosion resistance, an important factor is having new and old gravel sizes match.

49. The engineered technologies, in particular hard protection, are mostly applied along open stretches of coast, in the harbours and ports, to protect industrial activities as well as the recreational value of the shoreline. The coastal cities, as an essential livelihood asset and highly exposed to the natural risks, equally require risk retention technologies. However, increasing pressure on space in urban areas (inhabited or used for economic activities) as well as aesthetic aspect, make the use of engineered technologies in the cities a compromise. Linking flood protection to urban development through multifunctional use of infrastructure is therefore a promising solution. It also combines more immediate benefits of e.g. urban development with the long-term benefits of flood protection and it may contribute to secure the necessary funds for improvement or maintenance of flood protection works.

50. Traditional engineered protection technologies are a crucial element in coastal risk retention. However, there is an increasing attention towards using a broader range of measures, especially the ecosystem-based services and non-structural measures.

3.2.2 Nature-based solutions

51. Nature-based solutions (ecosystem-based services) refer to the use of coastal ecosystems for prevention and mitigation as well as adaptation and response/recovery. They offer cost-effective solutions for adaptation that build resilience to a range of climate change impacts and provide significant co-benefits for people and biodiversity, and are increasingly prominent across international frameworks to address societal challenges particularly in developing nations (IUCN).

52. Coastal ecosystems such as mangroves, coral reefs, seagrass beds and saltmarshes can reduce the energy of the waves. In particular mangroves are able to significantly reduce the energy of storm surges that accompany cyclonic depressions. Coastal vegetation also plays a significant role in mitigating coastal erosion and promoting sediment deposition with mangroves and saltmarshes especially capable to grow with rising sea. Ecosystem engineers may also be present in the higher zones, e.g. the salt marsh. The nature-based solutions consider the conservation, sustainable management and restoration of natural ecosystems, e.g. restoring and conserving mangroves and coastal wetlands that are referred to as a "green" engineering solution (more on this in Chapter 4).

Nature-based solutions
Dissipation of wave energy: Coastal ecosystems such as mangroves, coral reefs, seagrass beds and saltmarshes can physically exert an effect on waves. They cause a hydraulic resistance that can break the waves and reduce their velocity, thereby reducing the energy of the waves. Mangroves are especially able to significantly reduce the energy of huge waves such as storm surges that accompany cyclonic depressions. The coral reefs constrain ocean swells, thereby transforming wave characteristics and attenuating wave energy. In temperate areas, services similar to coral reefs are provided by reef building shellfish species, such as mussels or oysters. (IFM-WMO 2013)
Coastline stabilisation: Coastal vegetation plays a significant role in mitigating coastal erosion and promoting sediment deposition. Mangroves and saltmarshes are especially capable to grow with rising sea levels provided the tidal movement is not restricted by human interference. Beach nourishment may be applied to compensate for coastal erosion. Managed realignment is an alternative measure that usually entails moving the coastal embankment landward in order to reduce the maintenance cost of a coastal defence. It creates a new shallow foreshore which can effectively reduce the wave energy. The measure can only be implemented if at the landward side sufficient space can be made available at acceptable economic and social cost. (IFM-WMO 2013)
Wetland restoration is intended to re-establish or rehabilitate an impaired wetland. Once restored, operative wetlands provide a range of ecosystem services. These services include increasing floodwater storage capacity, buffering storm surge, limiting saltwater intrusion into freshwater aquifers, and reducing coastal erosion, as well as increasing habitat in the region. Wetland restoration can be pursued in areas where wetlands persist or previously existed. Specifically, restoration can allow tidal wetlands to proliferate in areas that have been diked or otherwise altered from their original condition.

3.2.3 Hybrid technologies

53. Hybrid technologies are landscape adaptation approaches that combine engineered approaches with nature-based solutions and/or indirect actions. The emphasis of this technologies is on sustainable development in densely populated coastal areas. It encourages stronger integration by bringing together multi-sectoral actors in biodiversity, engineering, landscape planning, communities and governmental agencies. Key examples that combine engineered and nature-based actions include climate smart agriculture (e.g. local irrigation schemes), engineered (living shorelines and Building with Nature) and indirect measures (e.g. dams, irrigation schemes, upgraded embankments, etc.) for resilient water infrastructure. As such, dikes that are bordered by salt marshes require less height and enforcement; therefore salt-marsh restoration is now combined with dike design in order to provide solutions that offer nature value, sustainable safety and a flexible basis for future dike adaptations, with sufficient space for additional uses such as recreation.

54. Recently, a Building with Nature solution is encouraged. It is an engineering approach that applies traditional engineering measures alongside ecosystem restoration and conservation measures in support of sustainable and climate-resilient coastal development. The emphasis is on flexible soft structures in harmony with the sea, such as dunes and beaches, while solid sea-wall elements, such as dams and dikes, are kept to a minimum. Building with Nature solutions work with and along the dynamics of nature. For example, allowing sea currents to reinforce the coast-line with sediment restores ecosystems so that they provide protection against extreme events and offer valuable 'natural capital' in the form of shell-fish, timber and recreational opportunities. Building with Nature solutions are adaptive, and typically cheaper to construct and maintain, compared to static infrastructure solutions (Rijkswaterstaat 2014). The environmental co-benefits enable more productive and multi-functional land-use.

Hybrid: examples of hybrid solutions
Living shorelines use plants or other natural elements, sometimes in combination with harder shoreline structures, to stabilize estuarine coasts, bays, and tributaries. Living shoreline projects utilize the physical characteristics of biological structures, such as oyster reefs and marshes, to achieve both ecological and protective benefits for an area. Living shorelines can range from major wetland restoration projects to smaller-scale inclusion of natural plants into a revetment. Living shorelines include oyster and eelgrass restoration projects intended to mimic the protective benefits of a breakwater.
Building with Nature solutions, also referred to as 'Engineering with Nature' or 'Green Infrastructure' come in many different shapes and forms. Coastal solutions may consist of levees, lined with wetland foreshores and oyster reefs further down the coast. Delta solutions may involve restored floodplains that capture flood waters alongside embanked urban centres. Various groups have been demonstrating these approaches including Rijkswaterstaat (NL), the Ecoshape consortium, PIANC and the US Army Corps of Engineers.
Floating Agricultural Systems: Certain areas provide the opportunity to utilize floating substrate beds in flooded and flood-prone areas. These can aid in local employment, along with utilizing free and abundant resources. Common structures of this type have used existing, abundant invasive species as substrate.

3.2.4 Non-structural technologies

55. The 'non-structural' measures aim at reducing the vulnerability and susceptibility of people and their goods living in the coastal zone. They include solutions for protection against floods, mitigation as well as raising of awareness and preparedness. These can be various approaches including coastal planning and land use management, early warning and evacuation procedures, protection of critical infrastructure, elevation of structures, coping and insurance of (residual) risk, community preparedness, poverty reduction and self help.

Non-structural technologies: examples of non-structural solutions
Coastal planning and management is used to address various economic activities that occur in the coastal areas, as well as policy and management interventions, and integrate the use of coastal waters into land-use planning. The overall objective to protect the coastal areas and to achieve sustainability.
Land use is utilized to reduce the impact of flooding. It includes measures and coping mechanisms by which people have adapted their way of living and their livelihood to regular or incidental flooding, such as houses on raised land (mounds) or on poles, growing flood resistant crops, diversifying livelihood, etc.
Flood proofing of the buildings include elevation of structures (raising a building or the ground level), dry flood-proofing (ensuring that water does not enter a building by making the walls, doors, windows and other openings of the building watertight); and wet flood-proofing (a design that allows floodwaters to freely enter the house, but minimises impact by reducing structural damage due to the force of the water).
Flood mapping: Coastal flood hazard maps provide a key input for vulnerability assessments by showing different scenarios (low, medium, high) and impact across a variety of possible events of flooding in numerous areas. ESRI ArcMap is a common tool for digitizing cartographic representation and performing modelling work. It also provides web servicing and the ability to share information about flooding events. These can be broken up

into those that assess hazard from sea to land, when the risk originating from the sea entering the riparian system or from the land to the sea when rivers or canals are flooded.
lood warning: Early Warning Systems can aid in both preparation and response to flooding events. Current solutions depend on mobile services technologies. Furthermore, these consist of those that voice message broadcast (VMB), or short messaging systems (SMS). The audience and scope of the service can vary depending on the response and personnel.
ommunity preparedness: is important to allow people to respond to the forecasted flood risk, flood warning and minimise adverse consequences of the flood. Besides an effective flood warning system, community preparedness includes community disaster management programmes to increase their resilience.
vacuation procedures: Evacuation requires sufficient time and adequate organization. Evacuation plans and should exist and be known to the population at risk prior to the event as part of preparedness measures.

56. For protection against floods, adaptation of land use and flood-proofing are being applied. Maintaining or increasing resilience of built environments, and even adapting the function of edifices fall into flood proofing. Techniques can involve efforts to: 1) elevate 2) wet flood-proof 3) dry flood-proof 4) provide barrier systems, and 5) backup measures. As seen in the United States, the city of Boston is targeting strategies for raising buildings to meet one-foot sea rise and all five techniques are considered in city operations. These vary based on building design, building systems and landscapes, but span fortification to moving critical systems, and floor space to rooftop levels, raising the lower levels.

57. Raising awareness/preparedness considers early warning systems, flood mapping, and community preparedness. Emergency measures require timely information on when and where the flood will come, how extensive the flood will be, how long it will last, etc. For this purpose, Flood Early Warning Systems are being used on an increasing scale globally. These systems are an essential technology to identify when a flood hazard is imminent, and they can also be part of a multi-hazard early warning system (WMO 2013, 2017). Flood hazards maps, on the other hand, provide information and raise awareness where the flood will take place, and they comprise important input for emergency management. Flood hazard mapping may also play a role in local capacity-building.

58. By providing meaningful warnings of flooding ('when and where'), mitigating actions, such as moving assets to higher ground, laying sandbags, and preparing for evacuation, take place. In this view, improved community preparedness is important to allow people to respond to the forecasted flood risk and minimise adverse consequences of the flood.

3.3 Opportunities and Challenges

59. Utilizing technologies for retention of risk to coastal zones are urgent for the communities. They provide numerous economic and social benefits by protecting infrastructure and communities from damage. Implementation of these technologies can also benefit ecological systems by building with nature. The benefits can be maximized when these technologies are implemented proactively, and an opportunity exists to shift away from the current strategy of retroactive implementation to more proactive management. Increasing the success of any one particular technology relies on its implementation within the broader integrated approach, such as integrated coastal zone management context, and highlighted through the participatory planning process. This increases the likelihood of a given project to perform to the proper level of risk reduction in the face of a multitude of environmental factors. Recent consideration of coastal adaptation with bigger focus on preparing for, prevention and managing impacts of climate change and safeguarding resilience of coast, requires involvement of more governmental agencies in the process and better coordination into other topics, policies and sectors.

60. Effective measures for reducing flood risk are location-specific. With a risk present at the local scale, the appropriate application of technology to address a risk can vary depending on a number of factors, including knowledge and expertise, regulatory environment, and the technology choice sets and size thereof from which to choose measures from. Furthermore, multiple factors affect the unit costs of implementation and marginal

improvements within local economies. For each technology, these trade-offs should be considered and evaluated against one another, through a participatory planning process to improve successful outcomes. **The Nature-Based Solutions are cost effective alternatives and complementary to grey infrastructure, and therefore should be more encouraged for prevention**.

61. A big variety of technologies for coastal risk retention provide overwhelming number of options for mitigating coastal erosion and/or reducing flooding risk. This leads to a challenging task of selecting the technologies by the governments, authorities and other decision makers. Modern ICZM plans, which address climate adaptation and resilience building, encompass a variety of adaptation measures considering both short-term and long-term perspectives. These catalogues of measures include various options for coastal erosion and/or coastal flooding, that come together with their effectiveness, cost, and potential impact on biodiversity, among other topics. In addition, multicriteria analyses can be provided that help to evaluate the measures, including non-engineering such as nature-based solutions.

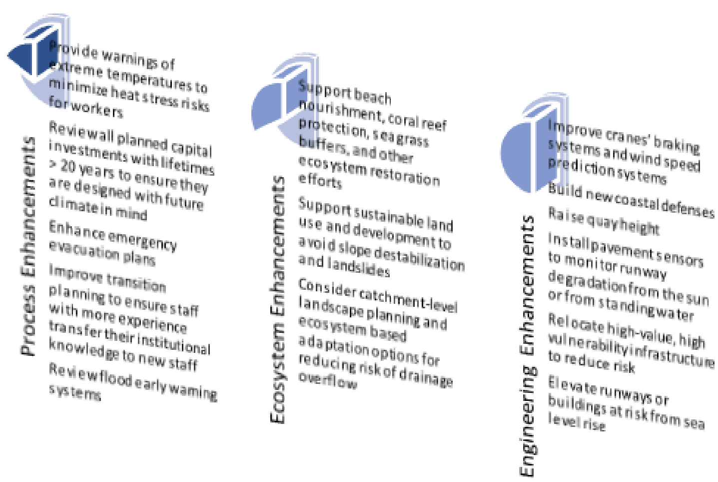
62. With modern technologies for hazards and risk assessment like modelling tools and availability of data and information generated by ocean/coastal observation (Chapter 2), the operational systems can be set up as the backbone of the coastal monitoring and information systems. These primary decision-support tools providing early warning system, however, depend strongly on quality and availability of data in order to guide, support, and monitor on different time-scales. Also, although the ability to predict floods has improved through a combination of real time data collection and model application, false alarms may still be given and some events missed as early warning cannot be fully accurate.

63. Many societies are showing a growing aversion to risk and are adopting strategies, which aim to further reduce the probability of failure so as to avoid the impacts of failure. This trend of risk aversion, together with the expected impacts of climate change, has triggered the development of more robust flood protection works to help protect society by virtually preventing flood losses. **The improvement of technologies for retention of risk is therefore a continuous process and experience-sharing across regions. Sharing knowledge and practices more systematically will help address challenges of a climate-resilient technologies.**

3.4 Case study

Frameworks & Methodologies

64. As part of a technical assistance project[15], the United Nations Conference on Trade and Development (UNCTAD) has developed a methodology to assist transport infrastructure managers and other relevant entities in Small Island Developing States (SIDS) in identifying priorities for adaptation and in developing effective adaptation response measures for critical coastal transport infrastructure, notably seaports and coastal airports. The methodology provides a structured framework for adaptation planning and takes a practical approach that uses available data to inform decision-making at a facility, local, and national level. The methodology is transferable, subject to location specific modification, for use in other SIDS within the Caribbean and beyond. The framework includes four major stages: Set Context and Scope, Assess Criticality, Assess Vulnerability, Develop Adaptation Strategies and Mainstream in Existing Processes. Stage 4 aimed to identify



[15] SIDSport-ClimateAdapt.unctad.org

where further analysis is needed, and where action can be taken without further analysis. For each stage in the methodology, the framework provides guidance and examples for how to conduct the assessment. The framework allows for flexibility based on the available data, stakeholder engagement, and other relevant factors[16]. Some of the major lessons learnt fall into the categories:

65. *Data availability*: data collection efforts take time; many SIDS lack baseline data; site visits to facilities and interviews with local stakeholders are essentia*l ('the map is not the terrain')*; steps to validate stakeholder input from facility managers can ensure high-quality inputs; identifying facility specific sensitivity thresholds can help streamline and improve the vulnerability assessment process; further research, including detailed technical studies, as well as collaborative concerted action at all levels is urgently required.

***Awareness and Coordination*: communication and collaboration among public and private sector stakeholders is key; ports/airports are already taking action to increase their resilience should share their success stories; there is a need for regional cooperation, and to build a knowledge base and community of practice around vulnerabilities.**

66. *Implementation*: Organizational "best practices" can increase resilience, and vice-versa; "Mainstream" adaptation activities into existing planning and decision-making processes; climate adaptation often comes down to a policy decision related to risk tolerance; financing for capital projects remains a major hurdle; Ecosystem enhancements can play a significant role in reducing natural hazard risks, including coastal hazards and inland flooding.

[16] For full details, see UNCTAD (2017) Climate Risk and Vulnerability Assessment Framework for Caribbean Coastal Transport Infrastructure (pp. 59-73)[16]; additional training and guidance material is available at SIDSport-ClimateAdapt.unctad.org.

Chapter 4

Technologies for Recovery and Rehabilitation in Coastal Zones

4.1 Setting the scene: key perspectives on recovery and rehabilitation in coastal zones

67. Status: Economic losses from natural disasters totalled $92 billion in 2015 (Hallegate 2017). Munich Re (2018) communicated that in terms of original values, the 2017 hurricane losses (from major hurricanes Harvey, Irma, and Maria of 2017) were higher than in the previous record year of 2005 that included hurricanes Katrina, Rita and Wilma (overall losses US$ 163bn, insured losses US$ 83bn). The aftermaths of natural disasters are fatalities, huge economic losses and devastating damage in the coastal areas. Coastal resources such as mangroves, wetlands, coral reefs suffer extensive damage. Severed communities and associated trauma are among many other social issues that are inflicted on people. The damage to the environment hampers the coastal populations in rebuilding their livelihoods. The United Nations has been calling for the recognition of the importance of local coping capacities to the disasters since (at least) the early 2000s (e.g. United Nations 2005). Lessons-learned from the disasters show now that impacted countries and communities are oftentimes much better equipped to use methods on recovery and rehabilitation and reconstruction when they have taken actions to strengthen recovery capacity and decision-making effectiveness prior to the onset of disaster (UNISDR BBB 2017).

68. Framework: Sendai Framework for Disaster Risk Reduction addresses recovery and rehabilitation in coastal zones under Priority 4 as “Build Back Better” in recovery, rehabilitation and reconstruction (UNISDR Sendai 2015). It articulates the need to integrate disaster risk reduction in response preparedness and ensure that capacities are in place for effective response and recovery at all levels due to the growth of disaster risks. “Build Back Better” emphasizes that the recovery, rehabilitation and reconstruction phase, which needs to be prepared ahead of a disaster, should integrate disaster risk reduction into development measures, making nations and communities resilient to disasters. Disaster Risk Management, with the message ‘Preventing hazards from becoming disasters’, is currently one of the Action Tracks of the Global Centre on Adaptation. The actionable targets, which will be announced in the Autumn 2019, will address blockages in complex adaptation challenges and enable accelerated learning to take place across similar programmes in different jurisdictions.

69. Demand: Local coping capacities are urgent for recovery of the coastal communities and the coastal areas. The physical rehabilitation process of the coastal ecosystems requires long years, however, social systems are longer to establish. The need to build long-term resilience against disasters among the resident communities is identified as the key issue for the recovery process. UNISDR (2009, 2015) emphasizes building resilience in order to make a system (e.g. physical), community or society to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. National-level disaster recovery frameworks provide the structure and context required by stakeholders active in recovery planning and operations. Recovery outcomes depend heavily on the existence of programs and mechanisms that support recovery, whether through the provision of human, financial, or other resources, or by promoting, informing, and as necessary, mandating risk-aware, climate-adaptive, and development- focused recovery goals (UNISDR BBB 2017).

4.2 Overview of types of technologies

70. Recovery and rehabilitation in the coastal zone involve a number of potential technologies, which assist in restoring coastal communities, infrastructure, ecosystems, and livelihoods following a disaster. Recovery and rehabilitation happen over multiple time scales, and priorities may shift as a situation progresses. The technologies, presented in this policy brief, address solutions for the physical systems recovery process and for the socio-economic recovery process.

Recovery and Rehabilitation in Coastal Zones – examples of technologies	
Physical recovery	Mangrove planting, coral reef gardening, wetland restoration
Socio-economic recovery	Building resilience, mainstreaming of disaster management into sustainable coastal planning, development of emergency measures, framework to assess adaptation and building resilience efforts, models to assess the socioeconomic resilience to natural disasters of an economy, frameworks to integrate social vulnerability into traditional cost-benefit analyses

4.2.1 Technologies for physical recovery and rehabilitation

71. From the physical point of view, long-term recovery in the coastal zone is increasingly seen as related to the protection and rehabilitation of coastal ecosystems (Spalding et al., 2014). Mangroves and coral reefs can act to hold coastal sediment in place and prevent erosion along the shoreline. Mangroves in addition can help to reduce high-energy wind and wave action on the coasts. Estuaries and wetlands play a critical role in modulating energy flow across coasts.

72. These coastal ecosystems can suffer extensive damage following the disaster and can be affected severely for years to come. Due to human induced degradation (i.e. conversion to aquaculture and agriculture, coastal development and infrastructure), they are weakened and scarce. Poverty and inequity issues within the communities that depend on the mangroves often result in overexploitation of the shrinking resources (Global Mangrove Alliance). Sea level rise and ocean carbon uptake with resulting acidification highly impact survival of coral reefs. Threats are further exacerbated by weak institutional arrangements, policies and management systems. Given their ability to protect the coasts, the current effort is focused on recovery and rehabilitation of the coastal ecosystems.

73. Restoration of mangroves has great potential to counteract the effects of sea level rise, as these types of trees can trap sediments and keep up with rising water levels. Planting mangroves, however, can be difficult once they have been removed, and often requires placing revetments or the use of bamboo breakwaters (Rasmeemasmuang and Sasaki, 2015), to ensure that the young trees can survive long enough. Managing the survival of coral reefs requires watershed and catchment level evaluation, monitoring and operational parameters. Different approaches are currently explored to encourage the uptake and survival of coral species through artificial reefs. Typically, these projects include a mix of techniques aimed at restoring distinctive coastal and marine habitats and each seek a distinct set of ecological objectives. For example, electro-mineral accretion, powered by solar panels that float atop the water's surface. The likelihood and magnitude of losses from coastal hazards may be reduced by intact reefs and coastal vegetation, especially when these habitats fringe vulnerable communities and infrastructure.

74. Restoration can play a role in reclaiming wetland to provide a mediating function through an ability to absorb water and buffer against changing conditions. Particular species of seagrass, native, restored naturally or by insemination, can dampen the effects of strong currents and prevent the scouring of bottom areas. Techniques may include land purchases, and breaching and excavating levees for tidal marsh restoration. Additionally, restoring tidal marshes may include fortifying new levees fronted by restored tidal marshes to reduce wave heights, including levees that are lower and more aesthetically benign. Restoration may include but is not limited to hard substrates, eelgrass seed planting, and the addition of spawning stocks.

Physical Recovery and Rehabilitation in Coastal Zones
Mangrove Planting: Mangrove forests are home to plants that grow in intertidal coastal regions, and which have special characteristics that allow them to live in both salt and brackish water. Due to the complex nature of their trunks and root systems, they can help to reduce high-energy wind and wave action, thereby holding coastal sediment in place and preventing erosion along the shoreline.
Coral Reef Gardening: In nearshore zones, coral reefs provide many ecosystem services. These can act to hold coastal sediment in place and prevent erosion along the shoreline. Various entities are exploring different approaches to encourage the uptake and survival of coral species through artificial reefs.
Wetland Restoration: Estuaries and wetlands play a critical role in modulating energy flow across coasts. Particular species of seagrass, native, restored naturally or by insemination, can dampen the effects of strong currents and prevent the scouring of bottom areas.

4.2.2 Technologies for socio-governance recovery and rehabilitation

75. Recovery and rehabilitation aim to restore public services and to create conditions for socio-economic activities. Short-term recovery often involves responding and recovering from a suite of immediate threats and concerns in the coastal zone. These threats and concerns range from ensuring people are safe to restoring critical functions of communities and municipalities. Technology can play an important role in collecting data to provide intel regarding on-the-ground conditions during recovery and rehabilitation. A major innovation is the use of smart-phones and other technology to provide responders and organizations with the knowledge they need to effectively respond and recover to disasters and emergencies. KoBoToolbox (Pham and Vinck, 2019) is an example of a platform that can assist in data collection during recovery from events. It allows for rapid collection

and analysis of various types of data to inform recovery efforts and allows for both online and offline collection, which can be extremely beneficial when communications are affected by the disaster.

76. The process of recovery and rehabilitation aims at building long-term resilience against disasters among the resident community. This process provides an opportunity for building back better in order to reduce future impact of disasters and pledge the community is better prepared. This requires efforts at policy and other levels. Recovery provides opportunities to integrate risk reduction and preparedness measures into development planning. Such measures will help to reduce the impacts of future flood events and disasters. Recovery also provides opportunities for institutional strengthening of disaster risk management activities.

77. To assess adaptation and building resilience efforts as well as to grasp diversity, uncertainty and long-term horizons, frameworks are being developed and applied in the affected regions. As such, for 'Rebuild by Design' initiative (of the President's Hurricane Sandy Rebuilding Task Force and the U.S. Department of Housing and Urban Development) in Sandy-affected region at the Atlantic coast, an assessment framework was developed for designing plans for more resilient and adaptive development with a long-term vision how to adapt to future in terms of climate change and socio-economic development (Kind et al. 2014). The framework considers an economic, social and environmental long-term (climate scenarios) perspective, financial feasibility of the solutions, and funding and financing solutions enhancing financial feasibility. Such frameworks can be equally applied to the coastal hurricane-affected regions as well as in the low-lying deltas (Dutch Delta Program, 2012).

78. Development of emergency measures to help mitigate the impacts of disaster and/or flood event, is an important task during the recovery and rehabilitation process. Effective and efficient emergency response is based on adequate flood preparedness. Such activities include planning for various emergency flood scenarios, simulation exercises, demonstrations and drills as well as training and education in specific skills (e.g., sandbagging). Good coordination and management of organizations and activities are essential for containing the flood disaster and minimizing loss of life and injury during and after the event. Specific activities can also be planned to quick start economic recovery through assistance and stimulus measures for businesses.

79. The financial burden of flood impacts may be relieved somewhat by relief funds and flood insurances. Many countries have some form of flood insurance coverage. These insurance systems differ widely between countries in their treatment of risks. Insurance against floods are mainly limited to urban properties, although crop insurances do exist (e.g. in India). Parvin and Shaw (2013) demonstrate how microfinance – or access to small loans, insurance ,etc. – can help with the recovery process in an example from Bangladesh. They note how longer-term engagement with microfinance programs are likely necessary to realize the benefits to recovery; however, they note how this longer-term engagement helps with short-term recovery actions. The mechanisms that link engagement with microfinance to improved recovery appear to be through improved awareness and access to knowledge.

80. Models exist to assess the socioeconomic resilience to natural disasters of an economy. For instance, Hallegatte et al. (2016) presented such model together with a tool to help decision makers identify the most promising policy options to reduce welfare losses due to floods. Social vulnerability in cost-benefit analysis for flood risk management is also recently addressed. Kind et al. (2019) developed a framework to integrate social vulnerability into traditional cost-benefit analyses, and showed how financial protection reduces social flood vulnerability and provides welfare benefits, in addition to offering physical flood protection.

4.3 Opportunities and Challenges

81. The impact of disasters on people's lives and livelihoods in vulnerable areas and poorer developing countries is generally much more dramatic. When in 2017 the floods with torrential rainfall devastated Houston and a powerful monsoon in South Asia caused severe damage to the region, life in Houston went back to normal just a few days after the disaster. Devastation in Asia was felt months after the incident. **A sense of urgency to prevent and reduce the vulnerability is big. Prevention saves money and alleviates suffering and distress. However, all technologies for risk prevention require mechanisms and incentives for implementation, where governance, institutional settings, system approach and financing are important driving forces.**

82. The UNDRR communicates that the countries most affected by disasters are usually the ones least capable of dealing with them, therefore **prevention and resilience efforts are crucial and they pay off, even in**

developing countries. The recovery and rehabilitation technologies aim at prevention by building resilience of the physical and socio-economical systems. Investment in water-related disaster risk reduction with a focus on prevention and preparedness, while also ensuring effective emergency response and reconstruction and rehabilitation, is crucial for achieving sustainable development. To prevent recurrence of tragedies and ensure progress towards the achievement of sustainable development, the countries are strongly encouraged to implement the ambitious goals and targets as agreed in the Sendai Framework, the Paris Agreement and the Sustainable Development Goals. **This requires, however, coherence of multiple global agendas and their link to the national DRR plans**.

83. The international mechanisms exist to support the developing countries in prevention and recovery, such as Climate Risk and Early Warning Systems (CREWS[17]) hosted by the World Meteorological Organisation Secretariat, which is a mechanism that funds Least Developed Countries and Small Island Developing States for risk informed early warning services based on clear operational procedures. Such mechanisms **leverage, accelerate and upscale the needed intervention** and CREWS seeks synergies. **They also encourage partnerships for synergies**, e.g. a new partnership on Risk-informed Early Action, was launched in 2019 at the UN Climate Action Summit, where the CREWS initiative is identified as a key financial mechanism to scale-up support to least developed countries and small island developing states.

84. A common opportunity associated with recovery and rehabilitation is the notion to 'Build Back Better', which usually implies some form of improvement in social-ecological systems during recovery and rehabilitation (Kennedy et al., 2008). Building back better represents an important policy narrative and vision for enhancing resilience in coastal zones, which in some cases can translate into on-the-ground improvements in livelihoods, communities, and other elements of social-ecological systems (Kennedy et al., 2008; Mannakkara and Wilkinson, 2013). However, building back better can be a challenge to implement. Khasalamwa (2009), in a case from Sri Lanka, demonstrates how efforts to build back better did not result in changes to the underlying structural vulnerabilities creating hazards, despite the policy narrative and support for the concept.

85. Local or regional disaster management committees are essential to assist communities to prepare themselves before, during and after flood events, since the organization of (inter)national response usually takes time. The resilience of households and communities can be further enhanced by improving their economic status. This allows them to recuperate more quickly following the flood. Improving the economic well-being may also lead to better houses and reduced hazard exposure that when combined make them more resistant to floods. Flood Early Warning Systems are essential for prevention and they are encouraged, and as such the countries develop them. It is, however, **important that projects as early warning systems or other interventions, should be backed up with identified need in the countries' national adaptation plan, or NDC, or national DRR plan**. This might still be largely lacking.

86. It is emphasized that investing in prevention needs to be a part of a long-term strategy with continued political support in order to be effective. A lack of available options is often the reason that few preventive measures are taken (Munich Re 2018). People do not have enough financial resources, and there is insufficient help from government agencies to identify and implement appropriate solutions. Often the insurance cover against natural hazards cushion the negative consequences. **Urgency is to act, share knowledge and experience, leverage, as well as accelerate and upscale the needed interventions**. As such, **governments and institutional setting have the primary responsibility for creating the right prevention and recovery strategy by establishing regulatory and incentive-based mechanisms to ensure resource allocation.** It is often enough communicated that there is insufficient help from government agencies to identify and implement appropriate solutions. Governance remains a challenge.

4.4 Case study

Achieving coastal resilience after catastrophes: Trends in the early 21st century and future considerations

87. In the 21st century, ideas began to emerge about rebuilding the coast in a more resilient fashion. Smart rebuilding offers an opportunity to mitigate future coastal hazards especially in the face of rising sea levels induced by climate change. However, empirically we observe that rebuilding plans and programs often result in outcomes not envisioned or that these plans are inadequate to the needs of the coastal residents.

[17] https://www.crews-initiative.org/en

88. When a tsunami hit Aceh region of Indonesia in December 2004, the Indonesian government planned to rebuild cities and villages 2 km from the coastal line so that the setback would act as a buffer. At the same time, different actors, including international agencies, NGOs and private firms, provided financial support and material assistance to rebuild on-site, conflicting with the national planning policies. Facing these pressures, the Indonesian government then had to adjust the overall rebuilding trajectory and shift their rebuilding strategy from prohibiting to allowing the use of coastal areas (Pardede & Munandar, 2016). Instead of dictating the rebuilding policy in a top-down fashion, the Badan Rehabilitasi dan Rekonstruksi (BRR), the agency in charge of rehabilitation and reconstruction, required field actors (INGOs and philanthropic organizations) to develop community plans for approval. In this process, community needs are discussed and included in the rebuilding plans that considered social and economic aspects. This decentralization of decision-making was possible due to concomitant institutional changes in the governance of the country from strong central to more decentralized structure at that time. The devastated coastal zone in the Aceh region was transformed to a vibrant area; a mix of old residents and large numbers of newcomers (re)made their home here. Communities that are relocated to areas far from redeveloped coastal downtowns show signs of distress including high vacancy and turnover rates. Coastal disaster risk of Aceh region continues to be high, but communities and businesses in coastal downtown are functioning and operating well.

89. Tohoku region of Japan was devastated by the tsunami caused by the 2011 Great East Japan Earthquake (GEJE) in March. Immediately after the event, the national government took on planning the rebuilding of the affected coastal areas. Having a principal goal of protecting communities from future tsunamis, the rebuilding strategy called for regulation of coastal inhabitation through community relocation or elevation of coastal lands that are at risk from a tsunami that is likely to occur once in a thousand years. Regional and local governments followed the decisions and advice of the national government to implement recovery projects. While local governments had some flexibility to adjust and iterate initial land use plans and programs, no significant changes were evident across the affected areas throughout the rebuilding process (Iuchi & Olshansky, 2018). Furthermore, key rebuilding actors – national, regional and local governments as well as contractors to governments – continued to make key decisions without adapting and modifying much of the original plans. Eight years after the event, almost no residences are found in areas identified high tsunami risk, an outcome that is different from other international coastal regions that experienced large-scale disasters. Communities targeted for relocation are living in the new sites, most of which are located on hill-sides, inland and solely residential. Relocated communities are predominantly older, exacerbating the aging issue that existed before the disaster. Land use of the coastal areas is far from mixed, distancing businesses, urban services, and residence. Tsunami risk has reduced with community relocation and the coastal levees reconstructed.

90. After Typhoon Yolanda (AKA Haiyan) struck Leyte region in the Philippines in November 2013, coastal communities saw buildings decimated. Storm surge exceeding 5-meters swept away almost all structures, including evacuation centers and schools. The national and local governments ultimately supported the adoption of a 40-meter no-dwelling zone when rebuilding to avoid future damage and loss, with speculation of exacerbated impacts with the sea level rise. While the national government initially took a lead to develop resilient rebuilding policies, the local governments gradually became the central actors responsible for planning and deciding local rebuilding processes. This transformation naturally occurred as the Philippines' governance has long been decentralized. Local governments then had to decide whether or not to adopt the no-dwelling zone policy initially proposed by the national government. If decided, localities would aim to keep coastal zones uninhabited as the initial land use plan specified. To do so, the local governments continue to work with the private sector organizations, including NGOs and religious groups, to relocate communities away from coastal hazards (Iuchi & Maly, 2017). Four years after the typhoon, the national government suddenly took over the local governments' task of providing and coordinating community relocation to expedite the rebuilding process. However, this disruption increased the time needed for housing construction, site development, and community relocation, which pushed back the momentum to achieve the rebuilding goal – to relocate coastal residents inland. Currently, community relocation projects are on-going, but many affected residents are re-establishing life both in the coastal and relocated areas. Community members continue to be willing to relocate, even agreeing to abandon coastal buildings, as long as the new sites are physically and financially ready for living in. Gradually, various life activities are fulfilling the relocation sites, but many still prefer to be active in the coastal areas. Members of relocated communities still rely heavily on coastal economic activities that have reemerged after Typhoon Haiyan, even though storm surge risk continues to be high.

91. These cases suggest different governance and rebuilding strategies create varied outcomes even if they all are aiming for resilient rebuilding via community relocation. While there is no single correct solution to governance and policy questions, considering local needs upon rebuilding, especially ways to foster livelihoods, is essential when choosing engineering-based hazard mitigation solutions. Furthermore, having local key decision makers

in the driving seat, e.g. local governments, is crucial. Local actors are better placed to create locally contingent definitions of resilience and incorporate local needs.

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