Technology Executive Committee

18 March 2020

Twentieth meeting

Virtual meeting, 1–3 April 2020

Draft joint policy brief on technologies on technologies for averting, minimizing and addressing loss and damage in coastal zones

Background note

I. Background

1. As per activity 1 of the thematic area Collaboration and stakeholder engagement of its workplan for 2019–2022, the TEC is to continue the development of a joint policy brief, in collaboration with the Executive Committee of the Warsaw International Mechanism on loss and damage (WIM ExCom) on the topic technologies for averting, minimising and addressing loss and damage in coastal zones.

2. As a background, the TEC and the WIM ExCom held a joint session on 16 March 2018, in conjunction with TEC 16, to discuss specific actions for collaboration between the two bodies and agreed to jointly develop a policy brief as an activity of the long-term collaboration between them. The two committees subsequently established a joint working group comprising members from TEC and the WIM Excom to undertake this work inter-sessionally, including to develop concept note and the outline of the policy brief. At TEC 18 the TEC agreed to the outline of the joint policy brief (see Annex 1).

3. The secretariat, under the guidance of the joint working group, reached out to relevant experts using various channels, including a call for expressions of interests from experts on this topic to participate and engage in this work on a voluntary basis. The contribution from experts includes provision of materials, case studies and relevant data, participation in the expert dialogue, and reviewing the draft of the joint policy brief.

4. The TEC and the WIM Excom also collaborated in convening an expert dialogue on technologies for averting, minimizing and addressing loss and damage in coastal zones, held on 17 June 2029 in conjunction with SB50 in Bonn, Germany.[1] This dialogue was attended by TEC and ExCom members, Parties, observer organisations, and enriched with the contribution from 11 experts and practitioners on the topic. The outcomes of the dialogue provided relevant inputs to the development of the joint policy brief.

5. At TEC 19 the TEC considered the outcomes from the dialogue and, recognizing that longer time was needed to finalize the draft policy brief, requested the joint working group to continue working inter-sessionally. TEC 19 also agreed to finalize the joint policy brief at TEC 20 and to prepare recommendations on this matter for COP26.

6. The joint working group, with the support of the secretariat and further inputs from the experts, finalized the draft joint policy brief. It further developed a summary for policy maker of the brief. In February 2020, the draft was circulated to both WIM ExCom members and members of task force on Collaboration and stakeholders engagement, who under the new rolling workplan provides oversight on this issue. Feedbacks were incorporated into the final draft submitted to the eleventh meeting of the WIM ExCom and twentieth meeting of the TEC.

[1] More information on the event can be accessed here.

7. The joint working group presented the draft joint policy brief to the WIM ExCom during its virtual meeting that took place from 10-12 March 2020. The WIM Excom endorsed the draft, with a few minor adjustments, and provided guidance on dissemination of the final product.

II. Scope of the note

8. Annex 2 of this note contains the draft joint policy brief including a summary for policy makers, that has been endorsed by the WIM ExCom at their eleventh meeting in March 2020.

III. Expected action by the Technology Executive Committee

9. The TEC will be invited to consider the draft and endorse the draft joint policy brief.

Annex I

Outline for the joint policy brief between the Executive Committee and the Technology Executive Committee

Title of the policy brief

Technologies for averting, minimizing and addressing Loss and Damage in Coastal Zones.

Indicative Audience

Policymakers and practitioners at sub-national, national, regional and international scales.

Outline of the policy brief

I. Introduction[1]

Brief overview of types of loss and damage experienced in coastal zones i.e. economic and non-economic;

- Brief overview of approaches and options for recovery and rehabilitation in coastal zones;
- Brief overview of comprehensive risk management. i.e. risk assessment, risk reduction, risk transfer and risk retention;[2]
- Brief overview of categorisation of technology options. i.e. hardware, software, orgware.

II. Technologies for Coastal Zone Risk Assessment

- Overview of types (hardware, software, orgware) of technologies available to observe and assess climate impacts on the coastal sector, including those associated with slow onset events (perhaps pull from CTCN);
- Opportunities and challenges;
- Case studies of use of select technologies.

III. Technologies for Coastal Zone Risk Retention

- Overview of types of available technologies that can be used to both manage and accommodate climate impacts (perhaps pull from CTCN) including hardware, software, orgware;
- Opportunities and challenges;
- Case studies of use of select technologies.

IV. Technologies for Recovery and Rehabilitation in Coastal Zone

- Overview of types of technologies available (perhaps pull from CTCN) including hardware, software, orgware;
- Opportunities and challenges;
- Case studies of use of select technologies.

[1] Technical terms used in this policy brief should be described and accessible to non-technical audiences.

[2] From the scope of the policy brief, as detailed in Paragraph 8 of the concept note for a joint policy brief between the ExCom and the TEC, the brief should focus on technology options to “observe and assess” and to “manage and accommodate”. These two areas follow under risk assessment and risk retention in the comprehensive risk management framework. Thus, the policy brief should focus on technology options for these two areas. This is useful to provide a focus for the brief and to allow for in-depth discussion of these two areas as it relates to technology options.

Annex II

United Nations Framework Convention on Climate Change

Executive Committee of the Warsaw International Mechanism for Loss and Damage

and

Technology Executive Committee

Policy Brief

Technologies for Averting, Minimizing and Addressing Loss and Damage in Coastal Zones

Version 6: 16 March 2020

Contents

Acknowledgements

This joint policy brief was prepared by the Executive Committee of the Warsaw International Mechanism for Loss and Damage (WIM Executive Committee) and the Technology Executive Committee. The work was led by a joint working group comprised of Adelle Thomas (Technology Executive Committee member), Mareer Mohamed Husny (Technology Executive Committee member), Nedal Katbeh-Bader (WIM Executive Committee member) and Yuichi Ono (WIM Executive Committee member).

The following experts provided valuable contributions: Adonis Velegrakis, University of Aegean; Brett Rolf, University of Michigan; Daniel Xie, University of Michigan; Fokko van der Goot, EcoShape; Jacob Rumschlag, University of Michigan; Jeremy Pittman, University of Waterloo; Kanako Iuchi, Tohoku University; Lea Appulo, Wetlands International; Manuel Friedlein, German Agency for International Cooperation; Martin Saraceno, Autonomous City of Buenos Aires - Argentina; Melanie Lück-Vogel, Council for Scientific and Industrial Research; Miguel Esteban, University of Waseda; Regina Asariotis, United Nations Conference on Trade and Development; Solveig Schindler, German Agency for International Cooperation; Susanna Tol, Wetlands International; and Walter Dragani, Servicio de Hidrografía Naval, Ministerio de Defensa.

Summary for policy makers

Management of coastal zones relies on the effective use of diverse data and a wide range of technologies. As climate continues to change, these coastal zones and low-lying areas experience the increased adverse effects of both economic and non-economic loss and damage.

This policy brief provides a synthesis of knowledge on loss and damage experienced in coastal zones and an overview of technologies for averting, minimizing and addressing loss and damage, highlighting tools and methodologies to determine risk, protect coastal zones, build resilience and foster recovery and rehabilitation. The policy brief focuses on technologies needed for risk assessment, risk retention, and recovery and rehabilitation in coastal zones. In addition, the brief explores **how a combination of technologies** can be used to assess, manage and accommodate climate change impacts in a comprehensive manner. These range from hard technologies (e.g. those that monitor and estimate coastal hazards, exposure and vulnerability), to soft technologies (e.g. knowledge and skills training) to organization technologies, known as orgware (e.g. policies, institutional settings, and regulation and governance structures). The brief also illustrates good practices from different regions and possible ways for countries to overcome the challenges to scaling up their use.

In view of the growing needs among countries, in particular developing countries, to prepare for a challenging future, the Executive Committee of the Warsaw International Mechanism for Loss and Damage (WIM Executive Committee) and the Technology Executive Committee commissioned a joint policy brief on technologies for averting, minimizing and addressing loss and damage in coastal zones that would link to mitigation, adaptation and disaster preparedness activities and be compatible with national climate policy frameworks.

Climate change impacts in coastal zones

The intensity of extreme events and slow onset events, including tropical cyclones, severe storm surges, sea level rise and ocean warming and acidification, has been increasing. These hazards threaten countries with substantial populations located along coastal plains and deltas, and in particular, small island developing States (SIDS) and coastal least developed countries (LDCs). Improved observational networks and early warning systems are invaluable to planning and risk management.

The 2019 Intergovernmental Panel on Climate Change (IPCC) Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)[1] highlighted the escalating impacts and projected risks of climate change on coastal and marine ecosystems, pointing to the importance of protecting coastal and marine zones. The report underscores the conclusion that the impacts of climate change on coastal zones will be increasingly disruptive at all spatial scales and that, in the course of the twenty-first century, the ocean is projected to be subject to unprecedented conditions. Understanding the impacts at different scales and the changing condition of the ocean is necessary to effectively adapt.

Comprehensive climate risk management in coastal zones has the potential to address sudden onset (e.g. tropical cyclones, storm surges) and slow onset (e.g. sea level rise, ocean warming and acidification) hazards, which require different technological considerations. Effective comprehensive risk management of coastal areas requires responsive governance by local institutions which are often constrained by limited technical and financial capacity.

Technologies for coastal risk assessments

The detailed understanding of the topography, hydrology and other characteristics of coastal zones necessary to producing quality risk assessments is dependent on the availability and accessibility of high-quality and timely data, which often come from remote sensing technology. Limited access to existing data, a lack of collection of local data, a lack of knowledge of data as well as limited technical capacity for

[1] See: https://www.ipcc.ch/srocc/

geospatial data processing hinder risk assessment activities and risk management decision-making in coastal zones.

Appropriate methods and tools are required to consider multiple types of hazards (rapid and slow onset events) and governance scales (global, regional and local) and process the complex interactions they involve. Given the limited availability of technology and data, this presents major challenges, especially to determining social and economic impacts.

International partnerships are important for countries' joint efforts and for sharing knowledge and experiences of coastal risk assessment. Such partnerships require a sense of urgency, political willingness and commitments, incentives and budget allocation.

<u>Technologies for coastal zone risk retention</u>

Technologies for directly managing coastal zone risk, referred to as risk retention, can take several forms, including structural/engineered measures, organizational and financial planning, legal and regulatory measures, ecosystem-based approaches, contingency planning and innovation. These approaches provide measures for the protection, retention and sustainable development of coastal zones.

Loss or damage associated with slow onset climatic processes can be partially addressed through resource management, awareness- and capacity-building, land-use planning and management, contingency planning, research, development and innovation. In undertaking these efforts, mainstreaming responses to slow onset climatic processes into sectoral policies and plans and incorporating local and indigenous knowledge is imperative.

Improving technologies for managing coastal zone risk is a continuous process and should be supported by experience-sharing across regions. Sharing knowledge and practices more systematically will help address the challenges of developing climate-resilient technologies.

<u>Technologies for recovery and rehabilitation of coastal zones</u>

Existing international programmes and mechanisms provide some support for recovery and rehabilitation efforts in respect of sudden onset events in developing countries; such efforts rely on data that is acquired and processed rapidly. Recovery and rehabilitation outcomes in certain countries rely on such programmes and mechanisms for human, financial, or other resources, and to facilitate risk-aware, climate-adaptive, and development-focused recovery objectives.

Global agendas enhance the use of policy and regulation tools that are relevant to managing climate risks in coastal zones, and such tools have been increasingly introduced in recent years. In order to facilitate more comprehensive and long-term approaches for rehabilitation and recovery, national adaptation plans and disaster risk reduction strategies should be harmonized, made coherent with and link to global agendas.

New international partnerships are being established with the aim of supporting governments in the process of integrating climate risks into social protection policies. Such partnerships help low-income communities recover more quickly following disasters.

Investing in technologies to reduce disaster risks with a focus on prevention and preparedness, while also ensuring effective emergency response and rehabilitation, is crucial for addressing potential loss and damage associated with climate change impacts in coastal zones. Further investment in social protection programmes and technologies, with a focus on prevention and preparedness and prioritizing the people most vulnerable to climate change, is also crucial for addressing loss and damage.

Involving indigenous peoples and using local knowledge can strengthen recovery and rehabilitation technologies. The use of local and traditional knowledge can be scaled and replicated *vis-a-vis* organizational strengthening.

Chapter 1

Introduction

This policy brief discusses available technologies for comprehensive risk management in coastal zones. Good practices in various regions in the use of the technologies are included to show the existing possibilities and needs, as well as ways to overcome challenges, for example, by building partnerships for exchanging experiences. The policy brief aims to inform policymakers and Parties; the main part of the report therefore provides balanced information about technologies for coastal risk assessment, risk retention, recovery and rehabilitation as well as information, technical guidance and examples for each phase of the comprehensive risk management process. The four chapters cover: (1) types of physical losses and damages in coastal zone; (2) technologies for coastal zone risk assessment; (3) technologies for coastal risk retention; and (4) technologies for recovery and rehabilitation in coastal zones. Each chapter discusses opportunities and challenges indicating the gaps and needs. Additional information, including additional scientific background information and resources, is included in the appendices

1.1. People and the coast

The importance of coastal zones: Today more than 600 million people live in coastal zones that are less than 10 metres above sea level. The ocean economy and related ecosystem services are estimated to be worth USD 3 to 6 trillion annually.[2] Coastal zones, which provide shipping, aquaculture, tourism and other coastal services and industries are a critical commercial component of national economies, especially those of SIDS and low-lying delta countries, where the populations are concentrated in coastal regions. SIDS are home to 65 million people; these human communities are closely connected to their coastal environments. Approximately 60 per cent of the world's 39 metropolises whose populations exceed 5 million people are located within 100 kilometres of a coastline, including 16 of the world's 23 cities with populations greater than 10 million (see figure 1). Given the economic opportunities offered by coastal regions, population growth in such areas exceeds the average population growth rate, and it is expected that coastal megacities in Africa and Asia in particular will see a tremendous population increase during the next decade. Coastal resources are particularly important to the livelihoods of poor and vulnerable coastal communities, LDCs and indigenous communities.

Coastal risk: Coastal areas can experience harmful consequences or losses resulting from a given hazard to a given vulnerable element over a specific time period. Coastal risk is defined by the hazard, the exposure and the vulnerability, which are expressed in terms of potential impacts based on the characteristics of the hazard and the vulnerability of the exposed elements during a particular temporal horizon (Risk = Vulnerability x Hazard). This risk terminology is used in this brief. For more information on the risk terminology used in this brief, see chapter 2 and the appendix.

[2] Innovative Finance for Resilient Coasts and Communities. United Nations Development Programme and The Nature Conservancy. (2018). www.nature.org/content/dam/tnc/nature/en/documents/Innovative_Finance_Resilient_Coasts_and_Communities.pdf.

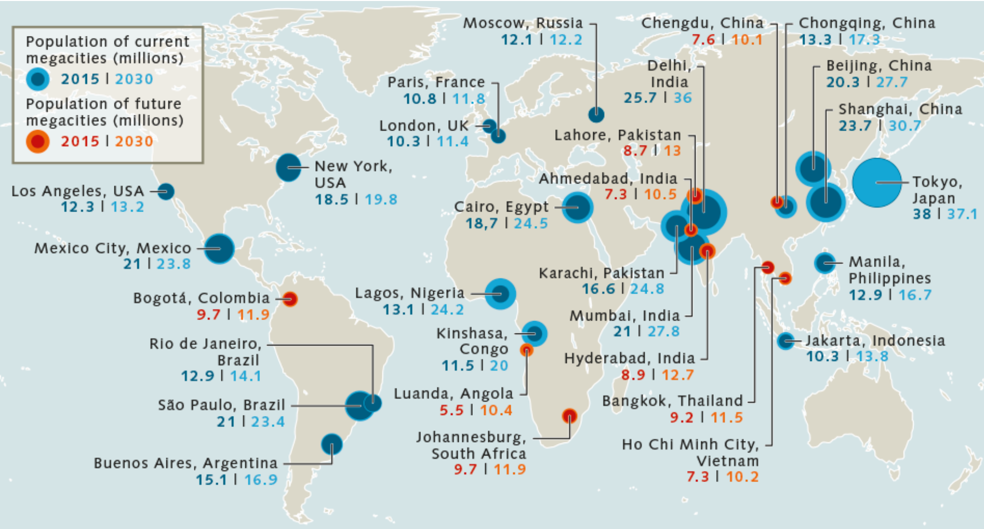

Figure 1: Current and future population of global megacities.[3]

Climate change, coastal hazards and aggravating factors: Projections of the impacts of climate change indicate with high confidence the effects of various climate scenarios on coastal zones (IPCC AR5, 2014, 2019).[4] These effects include slow onset events (including sea level rise, increasing temperature, ocean acidification, glacial retreat) and their related impacts, and sudden onset events, such as storm surges. SROCC warns that over the course of the twenty-first century the ocean is projected to shift to unprecedented conditions, including increased temperatures, greater upper ocean stratification and further acidification. The report notes that the global mean sea level has been rising at an accelerated rate in recent decades. Extreme sea level events are projected to occur more frequently in 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 storm surges and waves associated with extreme winds, combined with relative sea level rise, are projected to exacerbate coastal hazards. Climate-related saline ocean water intrusion, ocean acidification and deoxygenation, harmful algal blooms, redistribution of marine biodiversity and responses to multiple development-related drivers, are further threats originating from the sea-side that will have devastating impacts on coastal socio-ecological systems.[5]

There are also climate change threats originating from the land-side that will put coastal zones at risk. Heavy inland precipitation leading to high water levels in rivers will result in more intense riverine floods and compound flood[6] effects in coastal zones. A common inland action to prevent inland floods and respond to climate-related inland drought and water scarcity is the construction of dams and reservoirs. Dams and reservoirs are, however, the most important factor influencing land–sea sediment flows, trapping around 30 per cent of global sediment flows.[7] This contributes to the erosion of riverbeds and coasts as well as the sediment starvation of deltas, which also leads to coastal sediment starvation and erosion, as river outlets act as important suppliers of sediment to the coast. Further risks are related to the disruption of the

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3 See: https://worldoceanreview.com/en/files/2017/12/wor5_k2b_abb_2-28_en.png.

4 IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland; IPCC, 2019: Technical Summary [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, E. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

5 Fuller overview in the UNFCCC-NWP Scoping Paper on the Ocean, Coastal Areas and Ecosystems.

6 Bevacqua et l. 2019 Higher probability of compound flooding from precipitation and storm surge in Europe under anthropogenic climate change: https://advances.sciencemag.org/content/5/9/eaaw5531; Paprotny et al. 2018 Compound flood potential in Europe: https://www.researchgate.net/publication/324607083_Compound_flood_potential_in_Europe.

7 Charles J. Vörösmarty, Dork Sahagian, Anthropogenic Disturbance of the Terrestrial Water Cycle, BioScience, Volume 50, Issue 9, September.

pathways of fish that serve as an important source of protein and income for many vulnerable communities downstream in deltas and coastal zones.

The combined effects of climate change from the sea- and land-sides could be further exacerbated by local factors, including coastal land subsidence and tsunamis (also: meteorological tsunamis). Human-induced subsidence can heavily contribute to the effects of local sea level rise, as is the case in Jakarta, Indonesia. Combined extreme sea level rise and tsunami inundation can lead to tremendous devastation. Climate change impacts, augmented by local conditions and circumstances, act as threat multipliers by combining with anthropogenic impacts, such as unsustainable coastal development, historic and ongoing over-exploitation and degradation of coastal resources, and changes in land use, which contribute to decreased fresh water availability and polluted freshwater. Hazards and risks in coastal zones relating to safety, food security, livelihoods and the development of communities are thus intensified.

1.2 Loss and damage in coastal areas

Coastal zones, communities and infrastructure at risk: Owing to their exposure to increases in water level, storm surges, cyclones and tsunamis, coastal zones are threatened by flooding and land loss. The recent tragic cyclones that hit the southwestern African coast are evidence of this vulnerability: in March 2019, Idai, the deadliest and costliest tropical cyclone in the South-West Indian Ocean region caused more than 1,000 fatalities and more than USD 2 billion in damage;[8] it was followed by tropical cyclone Kenneth in April 2019, which caused a further 52 fatalities and more than USD 100 million in damage.[9] The increasing intensity of extreme events, including tropical cyclones and severe storm surges, threatens countries with substantial populations located on coastal plains and deltas. Coastal countries face high risks from the impacts of projected climate change; in coastal zones such risks are exacerbated by additional factors, such as compound floods and coastal land subsidence. The concentration of people, assets and socioeconomic activities in coastal zones make them particularly vulnerable and in urgent need of proactive protective action. Climate impacts along with population increases will further exacerbate the expected damage to infrastructure and the vulnerability of coastal populations. SROCC emphasizes the importance of climate-geared adaptation of coastal zones and that adaptation measures generate many co-benefits at different scales.

Types of economic and non-economic loss and damage faced by coastal zones

Projections of future climate change indicate increasing risk of impacts from weather and climate extremes, with serious implications for loss and damage in coastal zones. The slow and continuous process of sea level rise could inundate low-lying areas, submerge coastal zones and wetlands, erode beaches, exacerbate flooding, increase the salinity of bays, deltas, estuaries and rivers, and further increase groundwater and soil salinization which already impacts agriculture. Rising sea levels and increased subsidence will lead to continuous flooding in the long term, constituting a major threat to densely populated low-lying coastal zones and island States. Flood hazards can also be highly unpredictable and take diverse forms, including storm surges, tsunamis, tropical storms and seiches. However, it is the combination of extreme events and 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).

Storm surges have the potential to affect coastal environments, leading to coastal erosion and devastation of coastal wetlands, such as mangroves and salt marshes. Under normal circumstances, intact coastal ecosystems reduce the energy of storm surges, provide coastline stabilization, and have great potential to counteract the effects of sea level rise. Their degradation, such as that of coral reefs produced by ocean acidification and the depletion of mangroves by over-exploitation, therefore leads to further loss and damage.

[8] Available: http://thoughtleadership.aonbenfield.com//Documents/20190723-analytics-if-1h-global-report.pdf.

[9] Available: http://thoughtleadership.aonbenfield.com//Documents/20190723-analytics-if-1h-global-report.pdf.

The trend of increasing damages to coastal zones is closely related to societal factors, including an increase in coastal populations and the associated higher economic investments in those zones (Pielke Jr., et al., 2008). Estimates suggest that the global economic cost of rising sea levels and inland flooding to cities could amount to USD 1 trillion by mid-century. Miami, Guangzhou and New York are the three cities with the highest value in assets, ranging from USD 2 to 3.5 trillion, exposed to coastal flooding between 2010 and 2070. In terms of communities, it is Kolkata, Mumbai and Dhaka, cities with populations that range from 11 to 14 million, that have the highest number of people at risk from coastal inundation.[10] Rapid urban development has resulted in a dramatic increase in the economic damage caused by storm surges in coastal zones over the last two decades. In the United States of America alone, Hurricane Katrina in 2005 caused around 2,000 fatalities and an estimated total damage of USD 125 billion;[11] Hurricane Sandy in 2012, caused the flooding of nearly 90,000 buildings, with the total damage estimated at USD 19 billion; and more recently, Hurricane Harvey resulted in direct economic losses of USD 95 billion. Another threat attributed to sea level rise and extreme events is the potential damage to harbours and ports, which could lead to overall economic losses of USD 111 billion by 2050 and USD 367 billion by the end of this century (Noone, Sumalia and Diaz, 2012).

However, even storms hitting less industrialized coasts are causing tremendous damage and loss to historically highly vulnerable rural populations. While the economic damages of a storm in a rural area might not be comparable to the impact on a developed coast, the resilience of rural communities is usually much lower. Impacts due to extreme events are particularly challenging for SIDS given their high exposure and vulnerability to tropical cyclones, as revealed during Hurricane Dorian in 2019 and Hurricanes Maria and Irma in 2017. Devastating hurricanes in the Caribbean in 2017 revealed the non-economic loss and damage associated with prolonged climate-induced displacement of entire populations of islands due to the complete destruction of their communities.[12] The direct implications of such non-economic loss and damage include threats to human health and well-being and a loss of culture and agency.

Other important socioeconomic impacts include the salinization of coastal zones owing to saline ocean water intrusion (as a result of sea level rise) which has implications for coastal agriculture practices and can significantly affect coastal communities. Moreover, bio-ecological impacts, such as ocean acidification, ocean deoxygenation, unprecedented influxes of sargassum, harmful algal blooms and the redistribution of marine biodiversity have devastating impacts on coastal socio-ecological systems, with serious implications for food supply and security, livelihoods and the development of communities, in particular those in SIDS and LDCs. The damage to and loss of critical infrastructures to climate change impacts is one of the most demanding challenges. The serious malfunctioning of and disruption to such infrastructures could involve severe consequences for the economy, society and the environment. A profound understanding of all climate-related risks to coastal areas, their mechanisms and potential impacts is crucial to derive an appropriate coastal risk management response.

Comprehensive risk management of coastal zones

Comprehensive risk management is a multifaceted approach to dealing with risk. It includes multiple components, which progressively build on one another to foster a holistic approach to risk management. The components include risk assessment, reduction, transfer and sharing, retention, and transformational approaches (United Nations International Strategy for Disaster Reduction (UNISDR), 2009; UNFCCC WIM, 2019).

In response to the projected climate change impacts, the international community and national governments have initiated various coastal adaptation and disaster reduction programmes and set policy goals that aim to support national risk management efforts in coastal zones. These follow the principles set out by the Paris Agreement under the UNFCCC, the Sendai Framework for Disaster Risk Reduction 2015–2030 of the United Nations Office for Disaster Risk Reduction (UNDRR) and the Sustainable Development

10 https://www.c40.org/tags/resilience.

11 https://www.aoml.noaa.gov/general/lib/lib1/nhclib/mwreviews/2005.pdf; https://www.nhc.noaa.gov/news/UpdatedCostliest.pdf.

12 Thomas and Benjamin 2019 "Non-economic loss and damage: lessons from displacement in the Caribbean" Climate Policy: https://www.tandfonline.com/doi/full/10.1080/14693062.2019.1640105.

Goals (SDGs) under the 2030 Agenda for Sustainable Development, which call for strengthening adaptation and resilience through the prevention and retention of new risks and the reduction of existing disaster risks.

Comprehensive risk management in coastal zones concerns two types of onset climatic processes: sudden (e.g. hurricanes, storm surges) and slow (e.g. ice melting, sea level rise, salinization) onset events, which require different technological considerations. Overlaps between national adaptation plans, disaster risk reduction instruments and coastal zone planning policies and strategies challenge the development of coherent legislative measures. In the light of the unforeseeable impacts of climate change in the future, Governments find themselves in the midst of a paradigm shift from traditional disaster management and risk reduction towards risk retention and resilience-building when planning the development of coastal zones.

In the context of the projected increased risks in coastal zones resulting from climate change and the associated widespread threats, there will be a need to protect coastlines on a much broader geographical scale than has been seen until now. Thus, capacities for the integration of coastal hazard preparedness and climate change adaptation are being strengthened through proactive coastal adaptation measures that aim to safeguard and enhance the resilience of coasts, taking into account socioeconomic activities and the natural dynamics of coastal zones.

Adaptive planning and management offer a way to address the combined effects of climate change and anthropogenic impacts via short-term decision-making with a long-term perspective. This approach explicitly considers the fact that the longer-term outlook is unknown and includes ways to deal with uncertainties. For example, adaptive planning and management uses the adaptive capacity of economic sectors to implement adaptive developments or systems through policy measures. Comprehensive risk management approaches, such as integrated coastal zone management (ICZM) and integrated flood management, provide for adaptive planning and risk-informed decision-making concerning coastal hazards based on estimates of risk and of the costs and benefits of mitigation and management. Depending on a country's needs, these approaches can be embedded in legal/institutional and participatory frameworks for integrated decision-making to allow government-driven management of coastal zones.

The above-mentioned instruments constitute aspects of comprehensive risk management technology and are examples of coastal zone risk retention technologies (Chapter 3) that use findings from coastal zone risk assessments (Chapter 2) and provide a basis for recovery and rehabilitation in coastal zones (Chapter 4).

Technologies for comprehensive risk management are comprised of three components: hardware (physical equipment and capital goods), software (the processes, knowledge and skills required to use the technology) and orgware (ownership and institutional arrangements pertaining to a technology). The three components should be a whole constituting the technology; that is, the term "technology" implicates not only a physical entity but also how it works to serve a given purpose, how it is actively used and how an organization supports and benefits from the technology. Hence, the various reasons why a given technology is not performing could relate to any of these components.

Complementarity between hardware, software and orgware

Hard technologies, or hardware, refer to physical tools; soft technologies, or software, refer to the processes, knowledge and skills required in using the technology; and organizational technologies, or orgware, refer to the ownership and institutional arrangements pertaining to a technology (Christiansen et al., 2011, UNFCCC, 2014b). In the coastal sector, hard technologies refer to, among others, ocean/coastal observation data collection and management systems and infrastructures, geospatial tools and numerical simulation model suits for coastal risk assessment, structural/engineered measures for coastal protection (e.g. seawalls, tetrapods, dykes, sand nourishment, living shorelines, 'Building with Nature'), NbS and early warning systems (EWS), whereas soft technologies are those applied to improve coastal risk and adaptive management efficiency through, for example, (innovative) financing instruments and knowledge and skills capacity-building for technologies. Institutional arrangements and mechanisms, such as legal and regulatory policies for the coastal zones, coordinated cross-sectoral and regional planning approaches (e.g. ICZM, marine spatial planning (MSP)), source-to-sea (S2S) management and community-based approaches, are examples of orgware.

Though all types of technology are necessary, there is a concern that hard technologies are often applied in isolation, as their perceived impact is prioritized over software and orgware (Christiansen et al, 2011; UNFCCC, 2014b). Countries require encouragement and assistance in implementing all three technology types in a mutually supportive manner in order to ensure sustainable and effective application of technologies for adaptation under comprehensive coastal risk management. A key challenge to ensuring complementarity is that while wealthier countries can respond to climate change impacts by commissioning coastal risk assessments and investing in developing technologies and 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.

1.3 Response to hazards and risks to prevent losses and damages by the UNFCCC process

In light of unprecedented climate change impacts on the ocean and coastal zones, and in view of countries' growing need to prepare for an uncertain future, the Executive Committee of the Warsaw International Mechanism for Loss and Damage (WIM Executive Committee) and the Technology Executive Committee commissioned this joint policy brief on technologies for averting, minimizing and addressing loss and damage in coastal zones, which is closely linked to activities in mitigation, adaptation and disaster preparedness and is compatible with national climate policy frameworks. This topic reflects the common areas of work of the two committees, in particular their work to ensure the coherence of efforts on averting, minimizing and addressing loss and damage through a comprehensive risk management approach and to respond to priority technology needs as identified by Governments.

Chapter 2

Technologies for Coastal Zone Risk Assessment

2.1 Setting the scene: key perspectives on coastal risk assessment

Risk assessment is a set of methods that help characterize risks to inform risk management decisions and actions. It helps establish the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which societies depend (UNFCCC WIM, 2019).[13]

Coastal risk assessments offer a starting point towards raising awareness of the potentially devastating impacts of climate change and encouraging 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. Assessments concerning floods and coastal erosion specifically include features such as: the technical characteristics of hazards (i.e. their location, severity, frequency and likelihood of occurrence); the level of exposure of people and structures or other assets to those hazards; the susceptibility of people and assets to harm from a hazard (vulnerability); and an evaluation of the effectiveness of prevailing and alternative coping capacities with respect to likely risk scenarios.[14]

Observed and projected impacts of climate change indicate adverse effects under different climate scenarios for oceans and resources, with high confidence (IPCC: AR5, 2014; 2019), and SROCC highlights that the impacts of climate change on coastal zones will be increasingly disruptive at all spatial scales. Understanding how the earth system dynamics function and will evolve in the next decades and what the impact will be on coastal zones is a prerequisite for coastal risk assessments. Understanding the present state of the ocean, particularly its role in earth system dynamics, as well as the global drivers of climate (including thermal expansion and mass redistribution) is important to initializing and producing accurate medium- and long-term weather and climate forecasts and projections and climate scenarios, which have implications for long-term change and adaptation for countries. In order to raise awareness of the potentially devastating impacts on coastal zones and build strategies for adaptation and disaster risk mitigation, coastal risk assessments require accurate data and information.

The unforeseen evolution of the earth system and climate change impacts combined with local factors (such as coastal land subsidence) and anthropogenic drivers (such as the devastation of mangrove forests), present a complex set of issues that need to be addressed in risk assessments and comprehensive risk management. These include, but are not limited to, forecasting of weather and climate extremes (mid- and long-term projections) and the resulting predictions of hydrological risks, tropical storms and storm surges, coastal erosion and flooding, sea level rise, seawater intrusion and soil salinization, droughts, terrestrial impacts, bio-ecological conditions, as well as impacts on infrastructure, cities and communities.

2.2 Overview of types of technologies

Technologies for coastal risk assessment include a variety of methods and tools, such as hardware (e.g. to monitor and estimate coastal hazards, exposure, and vulnerability), software (e.g. knowledge and skills trainings for technologies) and orgware (e.g. policies, institutional settings, regulation and governance structures) at different levels, which, together with an increased awareness, enable coastal risk assessments and promote the planning and implementation of risk management responses.

2.2.1 Hard technologies

[13] The UNFCCC *WIM Compendium 2019*.

[14] UNISDR, 2009.

Hard technologies facilitate the data, information, methods, services and products that enable the provision of information at the global, regional and local scale that is vital for carrying out coastal risk assessments and addressing local needs (e.g. information on tropical storm forecasts, flooding and coastal erosion, groundwater salinization, impacts on infrastructure and water quality and biological assessments). Hard technologies provide ocean/coastal observations, geospatial data, numerical modelling information and flood mapping. Depending on the local availability of data, resources and capacity, different approaches can be taken. For example, some countries might opt for risk assessments based only on geospatial information, or all technologies could be used in tandem (see the example on coastal erosion and flooding in the box below).

Ocean/coastal observation technology is critical for understanding climate–ocean interactions and the role of the ocean in both the global system and ecosystem functioning (sea–land). Ocean observations enable our understanding of the impact of global phenomena and global drivers, including thermal expansion, mass redistribution and sea level rise. This understanding is a prerequisite for generating projections and climate scenarios as well as for forecasting hydro-meteorological conditions, which facilitate accurate coastal risk assessments. Existing ocean/coastal observation technologies are organized into two main categories of networks and systems: ocean observation networks, which are platforms that provide specific measurements (e.g. Global Sea Level Observing System (GLOSS)); and ocean observation systems, which measure many different variables (e.g. the United States Integrated Ocean Observing System, Prediction and Research Moored Array in the Tropical Atlantic (PIRATA), South African Environmental Observation Network). In recent years, significant progress has been made in developing and establishing well-founded and structured ocean data infrastructures in many regions, including the United States (National Centres for Environmental Information, National Oceanic and Atmospheric Administration (NOAA)), Australia (Integrated Marine Observing System, Australian Ocean Data Network) and Europe (Copernicus Marine Environmental Monitoring Service of the European Union). The Global Ocean Observing System (GOOS) is a sustained collaborative system of ocean observation systems encompassing in situ networks, satellite systems, Governments, United Nations agencies and individual scientists. The global ocean observation systems receive contributions from national entities, such as SONEL,[15] an integrated sea level monitoring system. SONEL handles data from different observation networks and serves as the global navigation satellite System (GNSS) data assembly centre for GLOSS. Established in France, the system works closely with the Permanent Service for Mean Sea Level[16] and the University of Hawaii Sea Level Center[17] by developing an integrated global observing system.

Geospatial technology: High-resolution satellite imagery and digital elevation models (DEMs) of improved resolution and elevation accuracy are available, together with efficient software platforms for analysis, to provide a time series of historical coastal geospatial records that serve to assess regional and local trends. In small-scale studies, other technologies, such as repeated airborne light detection and ranging technology (LiDAR) and/or unmanned aerial vehicle (UAV) optical photogrammetric surveys, can be used to identify coastal change trends. At the local scale, where assessments are carried out to support local decision-making for adaptation responses, accurate information on trends and projections is required. Coastal morphodynamic trends based on the acquisition/combination of highly accurate ground topographic data from surveys (e.g. real-time kinematic differential and terrestrial laser scanners) and high-frequency optical data from ground video monitoring stations can be used when conducting such local assessments. Geographic information systems (GIS) that store, analyse and display both spatial and temporal information facilitate the analysis of rapidly changing and complex developments. Esri ArcMap is a common tool for digitizing cartographic representation and performing modelling work and carrying out coastal hazard mapping (see Chapter 3). Geospatial technologies, such as satellite imagery, on their own can serve to

[15] Système d'Observation du Niveau des Eaux Littorales (SONEL): https://www.sonel.org.

[16] The global data bank for long-term sea level change information from tide gauges and bottom pressure recorders: https://www.psmsl.org.

[17] https://uhslc.soest.hawaii.edu/datainfo/.

analyse coastal erosion. For example, a global shoreline monitor enables efficient and automatic shoreline detection and analysis of the global changes over the last decades based on satellite imagery.[18]

Numerical simulation models are used to predict weather and ocean conditions and flood and coastal erosion and can also serve to build historical records anywhere in the world to observe trends and define design conditions for civil structures or identify risks to human populations and human activities. The behaviour of these numerical models is verified against in situ measurements when they are available, or when looking at very specific physical processes, against physical model results. Over the past decades there has been an increase in the number of numerical models being developed and improved to reliably predict a possible hazard event and its possible damage. Today's numerical models can capture different processes: atmospheric change, ocean circulation, wave and current action, tides and storm surges, sand transport, morphological changes and damage to vegetation (e.g. to mangrove forests and wetlands). Although the computational power is increasing, models that are able to capture all relevant processes are usually very expensive in the computational sense. As a consequence, different models are coupled together to combine processes occurring at different scales, such as cyclone atmospheric processes and storm surges, storm surges and local wave action, and ocean currents and sediment transport in coastal zones. The models are constantly being upgraded and new technologies are emerging with the ability to model changing processes and conditions better and faster and thus provide more reliable trend analyses and projections. New models enable scientists and engineers to study large areas and broad combinations of processes like extreme winds, storm surges, waves and currents and their action on the coastline or on civil structures.

The focus of numerical models typically varies depending on the scale; they can be used to study large-scale weather and ocean phenomena, or they can be used to downscale large-scale phenomena to the regional and local scale. Based on the downscaled data dedicated models can be used to simulate the actual impact (or exposure) at the local scale, for example, in terms of flooding, erosion and associated damages. The impact models can include many effects and take into account coastal erosion and breaching of sea defences, flash flows from rivers and rain bursts, and the impact of these phenomena on specific rural and urban topographic settings, including impacts on drainage systems. This makes the models a strong tool to study 'what if' scenarios and to simulate the effect of different mitigation measures.

In addition to numerical models, there are also physical models. These are scaled-down physical reconstructions 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, such as coastal defence stability and harbour penetration, that might not be accurately represented by numerical models. Physical models at reduced scale are costly to implement because great effort is required to reproduce the full-scale phenomena within the constrained space and using the mechanical forcing available in laboratories. Numerical models cost less to implement but their underlying equations usually rely on targeted approximations to represent a specific phenomenon. Their computational cost is usually proportional to the complexity of the phenomena they are trying to capture. The implementation of both type of models requires boundary conditions, which are usually obtained from the analysis of long-term measurement stations or global numerical models.

Technologies for generating socioeconomic information: Socioeconomic information is crucial to determining exposure and vulnerability and conducting risk assessments. Establishing trends and providing projections of the exposure of the human coastal environment depends on the availability of historical information and future projections of a large variety of socioeconomic data (e.g. population, assets, infrastructure and economic activity). Exposure of coastal assets and activities can be extracted, for example, from the refined Coordination of Information on the Environment (CORINE) land cover data set [36], while geospatial information relating to the global road and railway infrastructure has recently become available from OpenStreetMap (OSM).[19] Based on this information, a global-scale study has projected that in several countries (including SIDS), expected annual damages to road/railway assets could be as high as

[18] https://www.nature.com/articles/s41598-018-24630-6.

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

0.3 to 1 per cent of gross domestic product annually. In order to describe future global socioeconomic conditions, scenarios have been developed (shared socioeconomic pathways) that set out 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.[20]

Coastal erosion and flooding: example of methodology and applied technologies

Coastal erosion and flooding are estimated using models with different spatio-temporal resolution. Coastal risk assessments of coastal erosion and flooding consist of constituent assessments: (i) hazard assessments of the trends and projections of coastal erosion/flooding due to mean sea level rise, extreme sea levels and waves, and extreme river and pluvial flows; (ii) exposure assessments of the natural and human coastal environments (ecosystems, people, infrastructure, property and activities) present in hazard zones and thereby subject to potential damages/losses; and (iii) vulnerability assessments of the characteristics and circumstances of coastal ecosystems, communities, assets and activities that make them susceptible to damages/losses from coastal hazards.

Hazard assessment

In order to obtain accurate information on trends and projections, various effective/efficient technologies are used to estimate coastal morphodynamic change trends, including: comparisons of time series of historical coastal geospatial records; high-resolution satellite imagery (WorldView2 – 4, GeoEye, Pleiades) to estimate coastal erosion rates and development; DEMs for the estimation of the flood hazard; repeated airborne LiDAR and/or UAV optical photogrammetric surveys; acquisition/combination of highly accurate ground topographic data from surveys using real-time kinetic differential GPS, terrestrial laser scanners; and continuous, high-frequency optical data from ground video monitoring stations[18].

Available data from ensembles of general circulation models and/or regional climate models provide estimates of the climatic factors forcing the drivers at different spatio-temporal resolution [20]. In order to estimate the drivers, more efficient models and approaches, some of them open access, have been developed and tested, and an increasing number of resulting data sets have become available for different spatio-temporal scales and emission scenarios [20]. Concerning coastal erosion, there is a choice of approaches and morphodynamic models depending on the scale/resolution of the application, the type of coast, the availability of topographic and hydrodynamic information, as well as the type of hazard (i.e. slow onset erosion and drowning due to sea level rise or rapid episodic erosion due to extreme events). Various 'validated' numerical coastal morphodynamic models can be used to obtain projections of erosion at coasts under extreme events, whereas slow onset erosion is mostly projected using analytical morphodynamic models [6]. However, projections involving different spatio-temporal scales may have interdependencies that constrain their accuracy; for instance, the response of a coast to extreme events will likely be different in 2050 when the coastal topography will have adjusted in line with the 2050 mean sea level. At present, models can simulate processes occurring at one main spatio-temporal scale. The available coastal inundation/flooding models range from simplified to elaborate and computationally intensive [29],[30]. With regard to riverine and pluvial flooding caused by extreme rainfall, global-scale geospatial data can be found in the Fathom Global Flood Hazard dataset. Global river flooding in a warmer climate has also been recently projected [33]. Hazards associated with flooding can impact coastal zones independently, or in combination, particularly under extreme events associated with high winds and precipitation; the joint occurrence of and interaction between storm surges, waves and inland runoff can result in extreme compound floods. Such compound events can be extremely hazardous for islands in the tropical cyclone belt, including many SIDS [3].

[20] Murakami, Yamagata (2019) Estimation of Gridded Population and GDP Scenarios with Spatially Explicit Statistical Downscaling.

Exposure assessment

Exposure of coastal zones in the current and projected hazard zones concerns natural and human environments. In order to establish exposure trends and projections of the exposure of the natural coastal environment, accurate geospatial data are used (e.g. DEMs, LiDAR information, high-quality land cover data). However, more accurate ecosystem mapping is required to assess exposure to coastal erosion and flooding. Technologies for generating socioeconomic data and scenarios are used for assessing socioeconomic trends. This information is important for making assessments of the exposure and vulnerability to coastal hazards over time [37] to elaborate coastal risk.

Vulnerability assessment

Crucial components of the coastal vulnerability assessment are the estimation of (a) the erosion of coastlines, which can damage backshore assets[6] and decimate 'sun-sea-sand' (3S) tourism activities[44]; and (b) the vulnerability of coastal infrastructure, societies and ecosystems to flooding, which can be expressed through depth–damage functions (which can define the relationship between flood inundation depth and direct damage for each land use) [36]. Areas that are (or will be) located below the total water level are considered to be fully damaged. For areas that have been eroded/inundated during extreme events, damages are estimated by applying the depth–damage functions in combination with the simulated erosion/inundation depth. Other factors affecting coastal vulnerability include (a) the diminishing riverine sediment supply due to river management schemes that can starve the downstream beaches; (b) the occurrence of natural and/or artificial coastal erosion and flood protection structures already in place; (c) the availability/cost of materials to use in future technical adaptation measures (e.g. beach replenishment, breakwaters, river defences); (d) the human and economic resources available to plan, design, finance and implement the required adaptation measures; and (e) governance and regulation, which control the current and future decision-making regarding the development of the coastal zone. Information on the aforementioned factors is not always available and/or easily accessible, particularly for larger-scale applications. For example, there is a dearth of information on coastal erosion and flood protection schemes with sufficient spatial resolution for use in larger-scale vulnerability assessments [36]. Information on the availability of human and economic resources is also scarce and/or difficult to access, whereas the management/regulation that can control future coastal development is diverse among coastal countries and also difficult to access.

Numerical models are also useful for other applications to coastal zones, such as measuring pollution and soil salinization, which are aggravated by a rising water table, and increased seawater intrusion into the groundwater. The future increase of salt loads will cause salinization of surface waters and shallow groundwater and place pressure on the total volumes of fresh groundwater available for drinking water, agricultural purposes, industry, ecosystems and the livelihood of coastal communities as a whole. Today's technologies assess future soil salinization and estimate the consequences of further soil salinization and how it can be dealt with and prevented.[21]

Examples of other hard technologies: There are various technologies available to carry out flood mapping and assessments of impacts on infrastructure, as well as tools to provide decision makers with essential information derived from scientific research that indicates areas at risk, suggests adaptation options, focuses on the geospatial indication of risk areas (several flood scenario viewers), etc. Coastal flood hazard maps provide a key input for vulnerability assessments by showing different scenarios and impacts across a variety of possible flooding events in many areas. Ecosystem risk assessments are being used at the local, regional and global levels to understand the level of risk of collapse that coastal ecosystems face, and identify which ecosystems are a priority for conservation actions. For example, the International Union for Conservation of Nature Red List of Ecosystems[22] seeks to assess the global risk of collapse for mangrove forests and coral reefs, and regional assessments of coastal ecosystems are underway. Such assessments

[21] Vermeulen et al, 2017 https://publicwiki.deltares.nl/display/ZOETZOUT/FRESHEM; https://oss.deltares.nl/web/imod.

[22] https://www.iucn.org/theme/ecosystem-management/our-work/red-list-ecosystems.

are used to check for gaps in protection and inform ecosystem-based actions, such as NbS. There are also validated satellite-based technologies for monitoring and assessment of chlorophyll (e.g. the Joint Monitoring Programme of the Eutrophication of the North Sea with Satellite data (JMP-EUNOSAT)).[23] In terms of developing and maintaining technical critical infrastructure that has a very long lifetime (50+ years) and hence requires major capital investments, the risk assessments consider long-term horizons and methods that are developed for critical infrastructure in a changing climate, including adaptation pathways.

2.2.2 Soft technologies

Stakeholder engagement process: In addition to interactive decision-support tools (section 2.2.1), workshops are another effective method to foster stakeholder engagement. For example, workshops can be held to determine the consequences of hazards and risks (e.g. workshops on understanding the consequences of undesired events on communities, cities and infrastructure); to determine the probabilities, top risks and locations (knowledge of risks and threats); and to determine action plans for adaptation (e.g. workshops to estimate risks related to climate change on critical infrastructure).

Various **means of funding** support the development of technologies to carry out coastal risk assessments, which require the knowledge and experience of research centres, academia, engineers and private parties (e.g. for infrastructure). Funding/co-funding sources include regional funding mechanisms for research and innovation, such as Horizon 2020, the European Union (EU) Research and Innovation programme. In addition, national funding mechanisms managed by national public and research institutions, such as the United States Corps of Engineers, significantly support the development of technologies for coastal risk assessments. Through these various funding means, technologies have been developed and are being tested for coastal risk assessments. Given that these technologies have been developed largely by countries that have the means and resources to do so (e.g. to collect and generate the data), international donors (e.g. the World Bank), programmes (e.g. United Nations Development Programme), adaptation funds (e.g. GEF), multilateral cooperation agreements (e.g. between Germany and Caribbean countries) and others finance projects and knowledge/technology transfer initiatives to share such technologies with poorer countries and those with urgent needs, in particular LCDs and SIDS, around the world.

Knowledge of technologies for coastal risk assessment is shared and made available by educational facilities. The research centres and private companies that develop or professionally apply the technologies provide international trainings, courses, master classes and webinars on the use of technologies, designed to address particular needs and challenges. These entities include DHI Academy (Denmark), Deltares Academy (the Netherlands and United States), Digital Coast NOAA (United States), IHCantabria (Spain) and the Griffith Centre for Coastal Management (Australia). There are often continuing education courses for practitioners, taught by practitioners, provided as standard and/or tailor-made trainings and high-intensity and/or on-the-job interval programmes, offered face-to-face and online. There are also online knowledge platforms on assessing vulnerabilities and risks that provide a good example of knowledge-sharing. For example, the Caribbean Community Climate Change Centre Regional Clearinghouse Database[24] houses tools, reports and case studies. The knowledge available grows through research and consultancy projects, and through use of an open-source policy (e.g. numerical models), technologies are freely available to all communities to both test and use the technologies, and to contribute to their development. This encourages the process of capacity-building and community learning in respect of risk management. This process supports a community-based approach in the development of technologies for risk assessments in coastal zones.

2.2.3 Organizational technologies

Policies exist at the national and regional levels to enhance risk assessments of coastal zones. In Europe, there are complementary EU instruments, such as the Marine Strategy Framework Directive,[25] the Water

23 https://www.ospar.org/news/jmp-eunosat.

24 https://www.caribbeanclimate.bz/caribbean-climate-chage-tools/clearinghouse-search-tool/.

25 2008/56/EC.

Framework Directive,[26] the Flood Risk Directive,[27] and the amended Environmental Impact Assessment Directive,[28] that prescribe coastal risk assessments. These policies enhance the use and development of technologies. The Flood Risk Directive, for example, has promoted capacity-building in the use of GIS and numerical simulation technologies for flood risk assessments (coastal and inland) throughout Europe. However, such examples of regional mobilization for flood risk assessments are rare, since the need for flood information is normally addressed at the national and subnational levels. At the regional sea-basin level, the Regional Sea Conventions stimulate the development of technologies and innovations in environmental assessments. For example, in order to enable States parties to the Convention for the Protection of the Marine Environment of the North-East Atlantic to monitor the region coherently, a validated satellite-based chlorophyll technology was developed for a joint monitoring programme (JMP-EUNOSAT, see section 2.2.1).

Institutional arrangements and governance: Technologies for coastal risk assessment are developed by scientific communities, Governments, public authorities and private companies. Each of these entities has a different governance model, which affects the development of technologies. Some countries take the lead in developing specific technologies, which is largely a product of the national interests and the governmental support provided to local research centres/knowledge institutes to develop them. International knowledge exchange networks and platforms, such as Joint Programming Initiatives (JPIs) on Water, Oceans and Antimicrobial Resistance, Joint Technical Commission for Oceanography and Marine Meteorology (under the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC–UNESCO)) and the European Marine Board, stimulate joint programming and harmonization of marine and coastal research programmes for science and technology among countries. Governance of specific technologies could comprise of international ocean and coastal observation networks and systems (e.g. EuroGOOS), projects and programmes (e.g. All-Atlantic AtlantOS Programme, new EuroSea project) that are organized around data collection and data management. The OceanObs conferences organize and continuously improve the governance of a global ocean observation system network, including issues like advocacy, funding and alignment with best practices, and designate responsibility for product definition, including production and timely delivery at the appropriate scales (global, basin, regional and national) to serve user needs. This governance has had tangible achievements. For example, the OceanObs'09 Conference built a common vision for the provision of routine and sustained global information on the marine environment to describe, understand and forecast variability, weather, seasonal to decadal climate variability, climate change and sustainable management, and to assess longer-term trends. As a result, the Essential Ocean Variables were established, which today provide a common terminology and governance framework on ocean observation technologies.

Partnerships: The need to dramatically scale up the collection and sharing of ocean/coastal data, expand global coverage of platforms and observation systems, and grow the capacity of all nations to collect, manage, analyse and use ocean data and information, is currently emphasized in global policy and decisions, such as the United Nations Decade of Ocean Science for Sustainable Development (2021-2030). The GOOS 2030 Strategy, launched in 2019, envisages one fully integrated global ocean observing system with greatly expanded coverage that will be fully operational by 2030 and deliver a wider variety of essential information to a broader range of end users across three key application areas: operational services, climate and ocean health. New partnerships are envisaged under the GOOS 2030 Strategy to provide one integrated system that can deliver data and information that support climate change adaptation and resilience-building. While ocean/coastal observations are well organized though supporting infrastructure and international partnerships, technologies used for coastal risk assessments are not systematically governed. Instead, they develop independently, steered by local national needs, business opportunities, and (sometimes) international considerations and ambitions, rather than by infrastructure/institutional arrangements. This is the case for a broad range numerical simulation models, some of which serve the

[26] 2000/60/EC.

[27] https://ec.europa.eu/environment/water/flood_risk/.

[28] 2015/52/EU.

exact same purposes (i.e. they model the same phenomena) and have been developed by different knowledge institutes or private companies.

2.3 Opportunities and challenges

Technological opportunities today

Opportunities to raise awareness of climate risks and technologies for risk assessment are increasing around the world, including in small coastal communities in SIDS and LDCs. A big variety of technologies for coastal risk assessment is in place and accessible worldwide, often free of charge. In addition, capacity-building trainings are offered by many international organizations, and the funding mechanisms of international organizations and multilateral collaborations have helped to disseminate technologies and the most updated information of knowledge institutes and specialized consulting firms in the countries that need them. Furthermore, the scientific dialogue in peer-reviewed papers has helped improve all sorts of technologies for coastal risk assessments, including technical/engineering and financial considerations, as well as economic and social aspects.

Technological challenges today: limited availability of technologies for combined effects and/or climate change slow-onset events

In order to obtain accurate assessments of the complex risks to coastal zones, broad consideration must be given to the combined effects of climate change (atmospheric, sea, land) and their various scales (global, regional, local). In that regard, different kinds of technologies must be linked to ensure accountable comprehensive coastal risk management. This presents major challenges, in particular for hard technologies. Some of these challenges are listed below:

- Pure flood models generally do not map tropical cyclones (i.e. one component of the risk is missing);
- As much as current forecasts are of high quality, they only simulate losses from wind and storm surge and not flooding losses due to torrential rain;
- Assessments of the combined risks from the sea- and land-sides remain a challenge. For example, compound floods (i.e. combined sea- and river-floods) are mainly estimated based on data from different modelling or monitoring technologies and the assessments are done by considering correlations between the results obtained by these technologies (e.g. river and coastal numerical models);
- The combined effect of sea level rise and large tsunami inundation events are challenging to assess;
- The general difficulty in understanding and analysing the probability of very extreme events – that is, events occurring very seldom (on a historical scale) but that have devasting effects – that should be addressed not only at the global scale, but also at the regional and local scales;
- A unified zero-point datum that allows bathymetry and topography to be aligned is missing in large parts of the world. In many places, bathymetry and topography are also low resolution, while precise and accurate three-dimensional models of the coastline are needed in order to prepare accurate adaptation plans;
- The technical and management capacities to understand hazards and risks associated with a diverse range of climate change impacts, such as ocean acidification, sea level rise, bio-ecological and other combined effects, are very limited;
- Understanding the long-term impacts on livelihood, food security, businesses and well-being, and carrying out risk assessment of communities, remains difficult, in particular attributing and differentiating loss and damage from slow onset events.

These many challenges demonstrate that in order to assess the vulnerability of coastal zones to climate change impacts, current technologies for risk assessments need to be improved so that they can illuminate complex phenomena and combined risks, as well as the impacts of slow onset events and other variables. There are ongoing research projects to develop innovative technologies to measure climate change vulnerability and adaptation in a holistic manner, but there is still work to be done to make them coherent.

The increasing cost of developing technologies that address combined effects is another major consideration.

Technological challenges today: restricted availability of technologies globally

Data on many ocean variables is missing, particularly data with the granularity needed to make predictive models work well for many regions of the world. In addition, the current technologies have a relatively poor scope and geographical coverage and few or limited time series for many variables, which has an impact on the preparation of adaptation plans for coastal zones. Some of the specific challenges include:

- The data gaps concerning the deep ocean are vast; this lack of basic knowledge has implications for climate change research and for managing coastal zones in many parts of the world (e.g. recurring problems of sargassum and the associated economic implications of loss and damage);
- There is a need for data harmonization concerning climate drivers in order to carry out assessments of coastal erosion and flooding hazards and risks (e.g. sea level rise and extreme sea levels and waves);
- The use of different databases and tools restricts comparisons of results and may lead to over-interpretations;
- There is limited availability of technologies to collect socioeconomic data to complement, bio-physical data for adaptation plans.

Another major problem regarding the availability of technologies is the strong dissymmetry between the relatively limited number of stakeholders that have the means and resources to collect and manage data, including large countries and industries, and the rest of the international community. To overcome this challenge, the recently launched GOOS 2030 Strategy envisages one fully integrated global system that by 2030 will deliver a wider variety of essential information to a broader range of end users across operational services. Such international partnerships are important for the joint efforts of nations and regions, and for sharing knowledge and experiences for coastal risk assessment, but they require a sense of urgency, political willingness and commitments, as well as incentives and allocated budgets at the international and national level.

Technological challenges: lack of knowledge of existing technologies

The lack of knowledge of existing technologies concerns three issues globally: (i) policy makers are often not aware of existing technologies and/or how data and information from these technologies could support risk-informed decision-making in coastal zones; (ii) while local communities often recognize the problems in coastal zones, there is a lack of knowledge of what technologies could be used for quantified risk assessment and/or to design adaptation measures in coastal zones; (iii) private enterprises develop specific knowledge and technologies to maintain their competitiveness and the research community therefore might not have access to the full know-how available or might lag behind a few years.

There is a lack of understanding of science and technology, including the need to support efforts in these areas, at the local level. This challenge calls for capacity-building and strengthening the feedback loop and flow of information between research communities working on technologies, policymakers and communities that could make use of such technologies. For example, strengthening the link between technology, climate information and policy planning and assessments. There is also a lack of technologies that can assess coastal vulnerability and be applied to policy effectiveness and the efficiency of climate change actions.

International donors, regional partnerships and multilateral governmental cooperation provide financial support for efforts to transfer knowledge and technologies to developing countries. Although in many cases data may be freely available, many regions are limited by a lack of capacity to decide which technology is needed to make risk assessments and a lack of capacity to analyse data and make assessments. In poor developing countries, there are significant challenges in terms of human and economic resources and organizational structures, which can constrain the acquisition and use of the technologies mentioned. For instance, LiDAR data, which are freely accessible on the web, are available for some, mostly European coastal States, but are seldom available for many African coastal States and SIDS. High-resolution data, which are particularly important to assess risks in complex coastal zones, might not be accessible in economically developing regions – the areas and regions that would benefit most from such data usually do not have the capacity to acquire and/or use them.

Lack of knowledge of the technologies, resource limitations, capacity limitations and data limitations can preclude consideration of climate risks in coastal zones, especially in the generally data-poor LDCs.

Furthermore, it is important to note that while the public research community is the main source of knowledge related to climate change impacts and extreme events, some private companies develop specific knowledge and tools, usually narrowing important knowledge gaps for some very specific industries. These products are used to deliver advice or products to public or private clients. The knowledge obtained by these companies could be used for the benefit of larger communities, but it is usually proprietary and not accessible without paying a fee or royalties. The associated published research also usually lags behind a few years to allow these companies to keep a competitive edge, meaning that the research community does not have access to the full know-how.

Technologies used to conduct coastal risk assessment serve to identify and categorize coastal risks in tandem with advances in science and technology that are useful to coastal resilience considerations. Concentrating investment in productive ocean and coastal projects and programmes helps to build long-term comparative advantages based on technological and innovation capacity.

2.4 Case study

In recent years there have been increasing efforts to use emerging technologies to assess coastal risks at different spatio-temporal scales. (See the Appendix for additional representative case studies.)

Funding development of technologies for coastal risk assessment: examples of numerical simulation models

In two projects funded by the EU Research and Innovation programme, FP7-Micore (Morphological impacts and coastal risks induced by extreme storm events) and FP7-RISC-KIT (Resilience-Increasing Strategies for Coasts – toolkit), the open-source, freeware numerical model XBeach was applied to simulate the effect of a variety of extreme storms on coasts along every European regional sea. The model was developed by research centres in the Netherlands with launch funding provided by the United States Corps of Engineers. The model was originally developed for the situation in the United States, but it has been adapted and validated to be used as a dune safety assessment tool by the Dutch Public Works Department and Waterboards and is now also broadly applied in Europe and elsewhere in the world.[29]

Different open-source models meant to compute waves in the ocean (WaveWatch III) and processes in the coastal zone (SWAN) have been developed over the years through collaborations between research institutes (Delft University of Technology, National Oceanic and Atmospheric Administration) funded by national agencies, such as the Office of Naval Research (United States) and Rijkswaterstaat (the Netherlands). In the same manner, the Weather Research and Forecasting model, a mesoscale atmospheric model used to downscale global models and investigate atmospheric features on the scale of a few kilometres, was developed at the federally funded United States National Center for Atmospheric Research. The Weather Research and Forecasting model is used for short-term forecasts and the investigation of atmospheric processes. These models are now used all over the world by scientists and engineers for short-term forecasts and also to compute future extreme scenarios that engineers use to design infrastructure in coastal zones including coastal defences, bridges, wind farms, etc.

[29] https://www.deltares.nl/en/software/xbeach/.

Knowledge-sharing of risks and technologies for risk assessments: example from the Pacific small island developing States

The UNESCO and The Pacific Centre for Environment and Sustainable Development, University of the South Pacific project "Towards climate change resilience: minimizing loss and damage in Pacific SIDS communities" was funded by the Government of Malaysia. The overall goal of the pilot project was to generate and share new knowledge and raise awareness of the loss and damage caused by the adverse impacts of climate change in five Pacific SIDS: The Cook Islands, Fiji, Samoa, the Solomon Islands and Timor-Leste. The pilot project developed and tested tools and approaches to better understand loss and damage at the community level; identified challenges in coping and adaptation; and made recommendations for follow-up interventions in both research and implementation. It also developed and tested tools and approaches to better understand loss and damage and knowledge gaps in adaptation and resilience-building.

Climate change and small-scale fisheries: the comprehensive risk management perspective

Based on three stocktakes in different regions of the world (Caribbean, West Africa and South Pacific), the German Agency for International Cooperation global programme on climate risk assessment and management for adaptation to climate change mandated a desk study which summarizes the impacts of climate change for the particular sector of small-scale fisheries and formulates general and specific regional recommendations in order to avoid, minimize and address losses and damages in the sector. The fisheries sector contributes significantly to income and food security for hundreds of millions of people, particularly in SIDS and coastal LDCs. Climate change presents key challenges for small-scale fisheries and mariculture and is projected to have significant impacts on the lives and livelihoods of people dependent on this sector. The precise magnitude of future impacts of climate change on fisheries – in particular small-scale fisheries – are still poorly understood, since they involve numerous interactions with fragile and complex ecosystems that are often already affected by other stressors such as overfishing or pollution (see figure below).

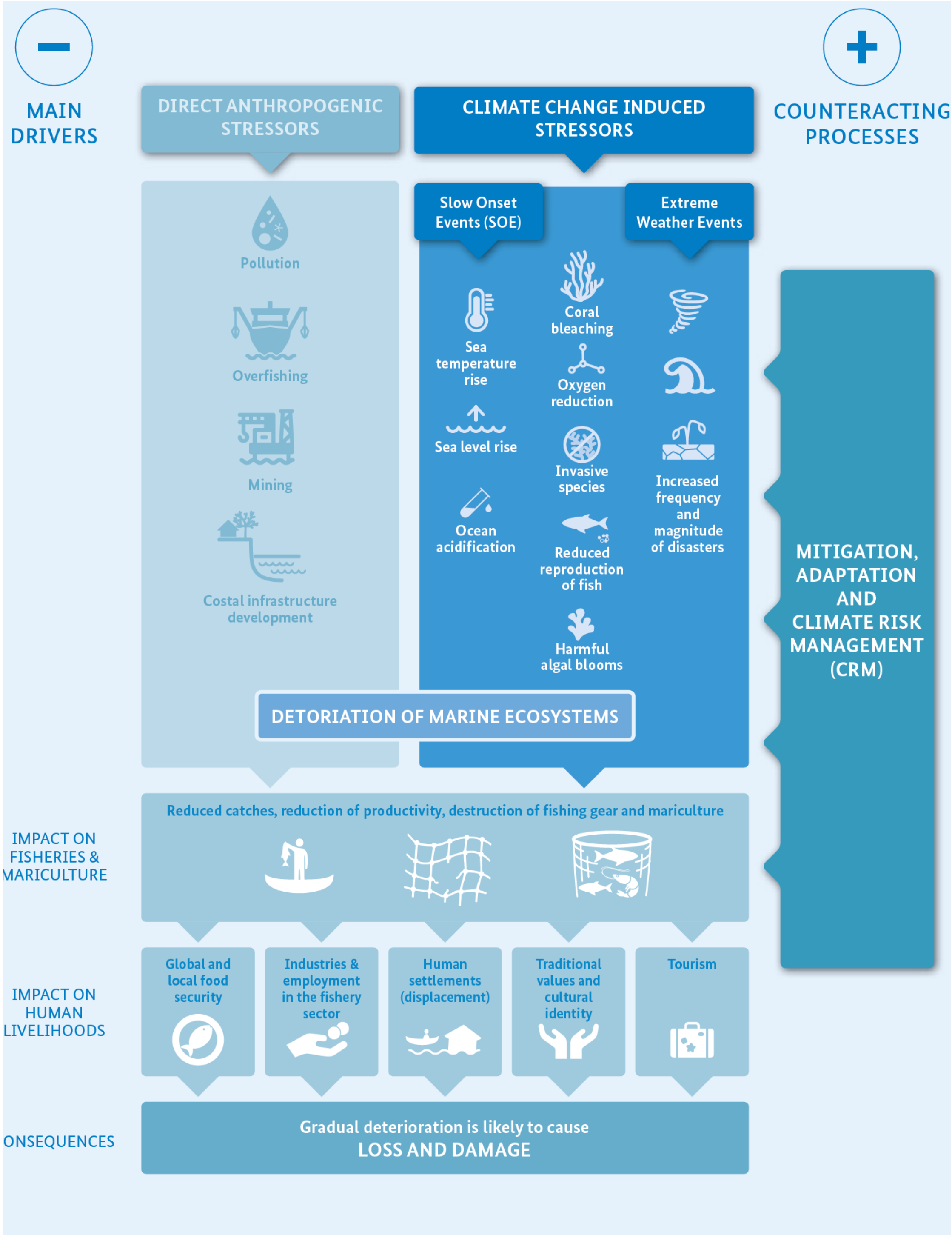

Figure 2: Impacts on the fisheries and mariculture sector in the era of climate change

Risk assessment and management for infrastructure in a changing climate: examples of projects

Extreme weather due to climate change may cause severe threats to the undisturbed functioning of critical infrastructures. In the future, these challenges could become even more demanding.

In the RIMAROCC project,[30] a common ERA-NET Road method for risk analysis and risk management with regard to climate change impacts on roads, was jointly developed by partners from Austria, Denmark, Finland, Germany, Ireland, the Netherlands, Norway, Poland, Spain, Sweden and the United Kingdom. The

[30] https://www.cedr.eu/strategic-plan-tasks/research/era-net-road/call-2008-climate-change/rimarocc-project-results/.

output was a guideline for road owners with a description of the developed method. The RIMAROCC method is a framework and an overall approach to adapt to climate change. The purpose is to support decision-making concerning adaptation measures in the road sector. It was developed in such a way that it can be easily adapted to the owner’s own risk management strategy. The main functions of the RIMAROCC method are: identification of risk factors (climate factors, asset intrinsic factors, site factors), definition of the level of acceptable risks, prioritization of assets (or components) according to the risks and estimation of effects of mitigation efforts/measures.

Another European project, INTACT,[31] addressed the challenges of the impact of extreme weather on critical infrastructures. The project brought together the best know-how and experience in Europe in order to assess risks to critical infrastructure and develop and demonstrate good practices in planning and designing protective measures as well as crisis response and recovery capabilities. The methodology was applied to cases in Finland (rural electricity distribution in extreme winter conditions), Ireland (flood risks to transport connections and essential local services), the Netherlands (port of Rotterdam transport connections under local extreme weather events), Italy (rainfall-induced landslides) and Spain (effects of drought, heatwaves and flash floods).

[31] https://cordis.europa.eu/project/rcn/185476/factsheet/en.

Chapter 3

Technologies for Coastal Zone Risk Retention

3.1 Setting the scene: key perspectives on coastal zone risk retention

Risk retention means that a country, community or organization explicitly or implicitly chooses to absorb the impacts of a (climatic) hazard if it occurs. Risk retention involves accepting risk, i.e. even if the risk is mitigated, if it is not avoided or transferred, it is retained. (UNFCCC WIM, 2019)[32]

Technologies for risk retention can take a variety of forms, including structural/engineered technologies to protect and prevent risks, mostly from sudden onset events (short term), as well as organizational and financial planning strategies. These include diverting federal budgets and establishing ex ante reserve funds for the purpose of off-setting unexpected financial claims; legal and regulatory, ecosystem-based, coordinated, cross-sectoral and regional approaches; and community-based approaches. Loss and damage from slow onset climatic processes can be addressed by such approaches as resource management, awareness- and capacity-building, land-use planning and management, contingency planning, research, development and innovation. These technologies provide measures for the protection, retention and sustainable development of coastal zones.

Projected climate change impacts include continuous slow onset processes, sudden onset events occurring with a short warning time, as well as the cascading and interacting impacts of slow onset processes and extreme events that leave little or no time for preventive evacuation of vulnerable communities and can cause large numbers of fatalities. Governments therefore increasingly need to implement adaptive management in order to manage and accommodate risks. Adaptive management can help to avoid investment losses, prevent irreversible decisions and lock-ins, and seize opportunities from the changing conditions. It encourages an integrated and flexible approach to increase resilience and reduce vulnerability by linking short-term actions and decision-making with long-term developments concerning coastal risks.

Adaptive management uses a stepwise approach in order to take cost-effective corrective actions in accordance with the future pace of climate change and regional development. For instance, it uses the adaptive capacity of economic sectors to incorporate adaptive developments or systems through policy measures, and it can apply the technique of adaptation pathways to analyse possible sequences of measures. Adaptive management supports the development of coastal risk retention by taking into account the uncertainties surrounding climate change and socioeconomic developments.

It is important that technologies for coastal risk retention take into account (i) maintaining, protecting and restoring the environment’s natural capacities to reduce the levels and duration of a hazardous event; (ii) the ability to recover; and (iii) the ability to adapt to changing conditions. In this regard, approaches that aim for risk retention consider uncertainties related to climate change, coastal development and socioeconomic growth by providing a flexible method to increase resilience to climate change and increase climate variability.

3.2 Overview of types of technologies

Hard technologies include a wide variety of structural/engineered measures, NbS, hybrid solutions, EWS, etc., which serve as adaptation measures. Soft technologies consider economic options and financial adaptation strategies, such as contingency funds, insurance, bonds and solidarity schemes, which require access to finance and market arrangements (e.g. multi-donor trust funds). Adaptive management also considers introducing adaptive developments or systems through policy measures (e.g. in the adaptive capacity of economic sectors) and applying the techniques of the adaptation

[32] The UNFCCC WIM Compendium 2019.

pathways to analyse possible sequences of adaptation measures. Organizational technologies address hazard preparedness, strengthening institutional arrangements, development planning and coastal adaptation plans/strategies, coordinated cross-sectoral and regional approaches, as well as community-based approaches, among others.

3.2.1 Hard technologies

Hard technologies vary from solutions that reduce exposure and protect exposed assets from coastal floods, such as traditional structural solutions to technologies that reduce the vulnerability of people and their goods, and NbS that promote ecosystem-based approaches and provide adaptation measures with hybrid technologies that aim to build the resilience of the natural system and coastal communities.

Structural/engineered technologies (e.g. seawalls, storm surge barriers and closure dams, dykes, TetraPods, riprap) are a crucial element in coastal risk reduction, mostly to reduce wave impact on the coast. There are many types of hard-engineered technologies and their application mostly depends on the cost of construction and maintenance, and the degree of engineering design effort required. In this sense, riprap is the common armouring on many coastlines because it requires less engineering expertise to design and construct than seawalls or revetments (Stanford Centre for Ocean Solutions, 2018). However, while hard structures are highly protective and commonly used, they offer no remedy for sediment deficiencies (e.g. due to sea level rise) or for dune erosion during conditions with high surge levels. In addition, the high cost of implementing these technologies (e.g. storm surge barriers and automated dam closures), which is further increased by maintenance needs, can make them inaccessible to many countries. Another challenge is the perceived aesthetic impact, namely, visual pollution, which can affect coastal communities. Soft measures, which are engineered methods that make use of natural resources, such as sand and dunes (e.g. artificial sand dunes and dune restoration) are therefore popular. In applying beach and foreshore sand nourishments, modern modelling and surveying techniques are used to optimize this solution and make the best use of the prevailing local physical conditions. Engineered technologies, in particular hard measures, are mostly applied along open stretches of coast and in harbours and ports in order to protect exposed assets, including industrial activities, and the recreational value of the shoreline. Coastal cities, which are an essential livelihood asset and highly exposed to the natural risks, equally require technologies for risk retention. However, the increasing pressure on space in urban areas (used for habitation and economic activities) as well as aesthetic concerns make the use of engineered technologies in cities a compromise measure. Linking flood protection to urban development through the multifunctional use of infrastructure is therefore a promising solution. There is now increasing attention being devoted to using a broader range of measures, especially nature-based approaches.

Nature-based solutions (NbS) 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.[33] Coastal ecosystems, such as mangroves, coral reefs, seagrass beds and saltmarshes, can reduce the energy of waves. Coastal vegetation in particular plays a significant role in mitigating coastal erosion and promoting sediment deposition with mangroves and saltmarshes. NbS consider the conservation, sustainable management and restoration of natural ecosystems. For example, restoring and conserving mangroves and coastal wetlands is referred to as a “green” engineering solution for building the resilience of the natural system and coastal communities (see also Chapter 4). Recently, coastal adaptation strategies are being approached in a

[33] https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions.

more holistic manner, with the co-benefits NbS bring to local communities gaining recognition. The role of NbS in adaptation and their potential role in hybrid solutions are also gaining wider recognition.

Hybrid technologies are landscape adaptation approaches that combine engineered approaches with NbS. The emphasis of these technologies is on sustainable development in densely populated coastal zones. Hybrid technologies encourage stronger integration by bringing together multi-sectoral actors, including experts in the fields of biodiversity research, engineering and landscape planning, as well as representatives of local communities and governmental agencies. Key examples that combine engineered and nature-based approaches include climate smart agriculture (e.g. local irrigation schemes) and engineered (e.g. living shorelines) and indirect measures (e.g. dams, irrigation schemes, upgraded embankments, etc.) for resilient water infrastructure. In that regard, dykes that are bordered by salt marshes require less height and enforcement; salt marsh restoration is therefore now combined with dyke design in order to provide solutions that offer added value for nature, sustainable safety and a flexible basis for future dyke adaptations, with sufficient space for additional uses, such as recreation. Hybrid NbS challenge siloed, sector-specific approaches and encourage stronger integration. When designed properly, with the aim of transcending traditional siloed thinking, these solutions offer potential multiple benefits as they not only offer solutions to mitigate climate change and sea level rise impacts, but also generate welfare and socioeconomic growth.

Early warning systems (EWS) are based on the operational forecasting system and often on the trend analysis and decision-support system. EWS for tsunamis have an additional functionality, as events are usually detected via seismic sensors and water level sensors located in the deep ocean (e.g. the DART system in the Pacific). The arrival time and characteristics of the tsunami are then computed with numerical models that help trigger evacuation warnings when and where relevant. For floods, there are modern EWS that are designed for maximum flexibility with respect to data import, export and processing and which provide a user-friendly software environment. Examples of such EWS include the freeware Developing a Flood Early Warning System (Delft-FEWS) software package or DHI Group’s license-based Flood Risk systems, which offer integration of real-time forecasts and data processing with an intuitive graphical user interface and visualization platform. Such advanced EWS are capable of handling and managing real-time data and workflows and executing models for dedicated forecasts and decision support, as well as producing long-term analysis of trends. Modern EWS combine the advantages of operational scheduling (e.g. data import and processing for operational forecasts) and built-in protocols to connect to external databases and internet applications, with the flexibility to run on high-performance workstations or local desktops. There are also less sophisticated, but equally important, mechanisms and technologies for EWS which can serve a dual function by saving the lives and property of local communities and engaging them in early warning information generation. In this respect, The International Centre for Integrated Mountain Development has developed a community-based flood EWS[34] which consists of an integrated system of tools and plans that are prepared and managed by communities in order to detect and respond to flood emergencies. Projects to improve EWS are focused on improving communications and weather forecasts in order to make climate change information available to communities in specific sectors, and also on designing mobile applications to facilitate communication between stakeholders and local communities.

There are international mechanisms to support developing countries in their prevention and recovery effort, such as Climate Risk and Early Warning Systems (CREWS),[35] hosted by the World Meteorological Organization secretariat. CREWS is a mechanism that funds risk-informed early warning services for LDCs, and SIDS based on clear operational procedures. Such mechanisms encourage partnerships for synergies. For example, a new partnership on risk-informed early action was launched in 2019 at the United Nations Climate Action Summit. The Global Commission on

[34] https://www.preventionweb.net/files/51370_icimodcbfews016.pdf.

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

Adaptation addresses scaling up investment in people-centred EWS under its Action Track on 'preventing hazards from becoming disasters' ([36]Within the Risk-Informed Early Action Partnership, the Global Commission on Adaptation will work with the World Meteorological Organization, the International Federation of Red Cross and Red Crescent Societies, the Global Facility for Disaster Reduction and Recovery, the United Nations Development Programme and others to systematically link investments in national hydrological and meteorological services with investments in effective people-centred early action, with a focus on increasing the number of EWS in LDCs and SIDS.

3.2.2 Soft technologies

Funding measures and financial strategies: Risk retention measures allow countries to 'self-insure' against climate change impacts and implement tools that build resilience, like social protection measures, or those that allow populations to cope in the face of climate change impacts and offset the financial burdens of doing so (UNFCCC, 2012). Economic measures include contingency funds, insurance, bonds and solidarity schemes, which require access to finance and market arrangements. Among the most common risk retention policies are social safety nets and microfinance programmes that aim to provide loans and other financial services to vulnerable people. Risk retention programmes like social safety nets contribute to efforts to reduce loss and damage from both extreme weather events and slow onset climatic processes, build resilience to climate change and help communities to cope when loss and damage cannot be avoided. In addition, international climate finance is also available through entities like the Least Developed Countries Fund, the Adaptation Fund and the Green Climate Fund. Loss and damage from the incremental changes that occur with slow onset processes, like sea level rise, require targeted, long-term approaches. Alongside climate finance, planning controls, land acquisition and planned retreat, coastal protection and engineered works are the responses available to coastal communities. The cost of implementing coastal protection measures varies (e.g. the cost of building seawalls ranges from $2,300 to $17,000 per lineal metre) and not all measures will be suitable in a given area (Banhalmi-Zakar et al, 2017).

Many of the opportunities for coastal risk retention are driven and/or supported by donors, lenders and investors, including: development banks; multi-donor trust funds (e.g. the World Bank's PROBLUE programme); special funds and programmes (e.g. the Green Climate Fund, the InsuResilience Solutions Fund); green and blue bonds; and national disaster risk agencies (e.g. the United States Federal Emergency Management Agency and National Flood Insurance Program). Many of these are new innovative financing mechanisms and facilities for coastal risk retention. The Blue Natural Capital Financing Facility (BNCFF), for example, provides funding for bankable projects and businesses with clear climate change adaptation and/or mitigation impacts. The goal is to leverage private investment opportunities into sustainable climate projects building on or including NbS. The BNCFF provides assistance to project developers, businesses, and financiers to advanceendeavours to build the blue economy. There is strong interest within the donor and finance community in ecosystem-based adaptation solutions for risk transfer and ecosystem-based conservation and rehabilitation. Quantitative adaptation benefits have been identified for a few, mainly coastal, ecosystems with wetlands (marshes and mangroves), which industry risk models have already defined as a risk-reducing feature. One pillar of the World Bank PROBLUE programme promotes cross-sectoral upstream planning to assist SIDS and coastal LDCs in developing the full potential of their blue economies. In 2019, PROBLUE funding provided USD 0.6 million for the Blue Economy Development Framework, USD 0.5 million for work related to NbS for resilience; and USD 2.1 million for financial innovation and mobilization for growing blue economies, for a total of USD 3.2 million in funding.

Adaptive management and adaptive pathways: As slow onset processes progress and given the deep uncertainty of future conditions and the many plausible climatic, ecological and socioeconomic

[36] https://gca.org/global-commission-on-adaptation/action-tracks/disaster-risk-management.

scenarios, it may be difficult to construct static adaptation options that will perform well in all scenarios over a long period of time. Adaptation pathways are therefore being designed with a number of adaptation measures/options, where a new adaptation action is activated on the basis of adaptation tipping points (i.e. the stage when an adaptation action in place is no longer able to meet the established objectives). Adaptation pathways offer the possibility of including climate change factors, infrastructure factors (e.g. functionality, equipment performance), and socioeconomic developments (e.g. service demand). Tools and methodologies are being currently developed for adaptive management (e.g. Marchau et al. 2019, Haasnoot et al. 2019, Haer et al. 2019). The Society for Decision Making Under Deep Uncertainty (DMDU)[37] develops approaches that support the design of courses of action or policies in situations of deep uncertainty and applies them to real world situations, facilitates their use in practice and fosters effective and responsible decision-making. Robust decision-making, dynamic adaptive planning and dynamic adaptive policy pathways are among the tools explored and disseminated by DMDU for decision-making under deep uncertainty; these are applicable to coastal zones facing threats that are to some degree unpredictable.

3.2.3 Organizational technologies

Coordinated integrated cross-sectoral approaches to the management of coastal zones provide frameworks for adaptive management that increase resilience to climate change and amplified climate variability in coastal zones. Integrated approaches that can be applied to comprehensive risk management of coastal zones include ICZM, MSP, marine protected areas (MPAs), integrated water resources management (IWRM), S2S management and land-use planning. For example, ICZM considers uncertainties related to climate change, coastal development and socioeconomic growth by providing frameworks for policy-based plans that prioritize climate change considerations by integrating a long-term planning horizon as well as cost-effective adaptation measures for adaptive planning and management. ICZM also brings together different users of coastal zones in order to make coordinated decisions. ICZM as an approach is being reviewed by countries and the international community as the perfect means to achieve coastal adaptation and as a comprehensive risk-management approach for resilience-building that could also minimize the negative consequences of climate impacts and socioeconomic development. Egypt, for example, is currently enhancing climate change adaptation in its North Coast and Nile Delta regions by implementing the climate adaptation ICZM Plan for the Mediterranean Coast.[38] For strengthening land management component in the ICZM, approaches such as S2S management are being considered, given upstream activities on land and rivers that can jeopardize coasts and intensify the impacts on coastal zones. S2S embraces system-wide thinking and acknowledges the interdependencies of flows and services throughout river basins, deltas, estuaries, coastlines, nearshore and sea.

Policies, legal and supporting mechanisms: For managing coastal risks in a comprehensive manner, various global agendas encourage the use of integrated approaches.

The United Nations General Assembly emphasizes the importance of using integrated, cross-sectoral approaches, such as ICZM, MSP and MPAs, for developing and implementing effective adaptation measures that enhance coastal resilience.[39] Coastal and marine planning and management are addressed by a number of United Nations agencies, funds, programmes and departments, which are mandated to provide support to countries in managing coastal zones. This support comes in a form of policy guidance and efforts to develop the coastal management capacities of countries. With regard to land areas, Parties to the transboundary water conventions, the United Nations Economic Commission for Europe Water Convention and United Nations Watercourses Convention have recognized the important connection between transboundary rivers and coastal zones. There are a number of policies and legal and regulatory mechanisms available aimed at helping countries in the

[37] See: http://www.deepuncertainty.org/.

[38] See: http://iczmplatform.org/storage/documents/V3RA2ZpELMDhSV15pZaMLysgeH3Y6ZuumzcQqtZn.pdf

[39] General Assembly resolution 71/312.

process of developing and implementing integrated cross-sectoral approaches for adaptive management at the regional and national levels.

The Protocol on ICZM in the Mediterranean[40] is an example of a regional legal instrument that supports countries in the Mediterranean basin to better manage coastal zones in the light of climate change. The European Commission (EC) is one of the Parties to the ICZM Protocol that also implements the EU MSP Directive[41] in order to establish a framework for MSP with land–sea interactions in all European sea basins.[42] The importance of integrated approaches is recognized globally, with many initiatives being carried out in Africa. To assist and to accelerate MSP processes globally, IOC-UNESCO and EC have developed a Joint Roadmap including the Maritime/Marine Spatial Planning Initiative. International efforts to implement integrated approaches around the world are making climate adaptation, adaptive planning and resilience-building efforts more effective in coastal zones. The Coastal Zone Management Act in Belize is an example of legislation that establishes a legal framework for coastal zone management using cross-sectoral integration and coordination of resilience-building management while applying ecosystem services valuation and MSP approaches.

Capacity-building plays an important role in the process of development and implementation of adaptive and integrated cross-sectoral approaches in coastal zones. In that regard, the United States has been carrying out the Coastal Resources Management Program, a pioneering initiative that works with developing countries around the world to advance the practices of ICZM. ICZM, MSP, S2S and other platforms for integrated approaches (e.g. UNEP Priority Actions Programme/Regional Activity Centre, European MSP Platform, Action Platform for Source-to-Sea Management, Caribbean Community Climate Change Centre Regional Clearinghouse Database), centres for practical support (e.g. the Pacific Climate Change Centre), trainings by UNESCO-IOC and institutes (e.g. in ICZM, MSP, IWRM, adaptive planning), training tools (e.g. CoastLearn) and regional projects (e.g. OURCOAST) deliver a wealth of knowledge-driven assistance mechanisms to countries and capacity-building to stakeholders and communities for the development and implementation of much-needed integrated approaches, which today largely are informed by the perspective of holistic management (sea–land) and climate mitigation and adaptation planning. Partnerships are strengthening these efforts (e.g. the Ocean and Climate Initiatives Alliance, the Global Ocean Forum, the Pacific Ocean Alliance, the Marine Regions Forum).

Approaches for local communities: Community-based adaptation aims to implement climate change adaptation measures in tandem with development goals, using bottom-up processes to enhance community capacity, while also ensuring contextual suitability and local acceptance of the projects launched. Such practices aim to identify local-level knowledge, including technological innovations, and strengthen and replicate this knowledge to promote effective adaptation. As a long-term, adaptive and reflective process, community-based adaptation is an ever-evolving process and many projects have now been established, particularly in Asia and Africa. Activities at the regional level play an important role in creating an enabling environment for comprehensive risk management and for involving local communities. For example, Interreg is a pan-European programme that aims to help local governments develop and deliver better policy for local communities by creating opportunities for sharing solutions. Several Interreg projects on coastal risk management and adaptive planning topics have developed practical tools and methodologies for local communities. For example, the Innovative Management for Europe’s Changing Coastal Resource[43] project produced the online learning portal “Coastal Adaptation - practical approaches to adapt to coastal

[40] http://paprac.org/iczm-protocol.

[41] Directive 2014/89/EU.

[42] The European Sea Basins: Atlantic, the North Sea, the Mediterranean Sea, the Black Sea, the Baltic Sea.

[43] http://www.imcore.eu.

climate change for coastal communities";[44] the SUSTAIN[45] project created a fully implementable policy tool to help coastal communities to promote sustainability; the FRAMES[46] project addresses the shared territorial challenge that ongoing climate change results in increasing sea levels and extreme rainfall patterns for areas and communities; and the LAND-SEA[47] project promotes an integrated approach towards improving policies for sustainable management.

Coastal risk preparedness: Coastal risk preparedness includes EWS and notifications, coastal hazard mapping, evacuation procedures, emergency preparedness, community preparedness, flood-proofing and regulatory techniques (e.g. land use, development moratoria, overlay zones, rebuilding and redevelopment restrictions). Coastal hazard mapping provides information and raises awareness of where a flood is expected to take place and comprises important input for land-use planning and/or emergency management. Detailed coastal hazard mapping, thanks to advances in geospatial technology (see Chapter 2), provides important information for preparing evacuation plans as part of EWS and also plays a role in local capacity-building. Community preparedness critically enables people to respond to forecasted risks and hazard warnings and minimizes the adverse consequences of a hazard.

Flood-proofing concerns maintaining or increasing the resilience of built environments, and even adapting the function of edifices. Techniques can involve efforts to elevate, wet flood-proof, dry flood-proof, provide barrier systems and implement backup measures. Measures to flood-proof buildings include elevating 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 a building watertight); and wet flood-proofing (implementing a design that allows floodwaters to freely enter the house, but minimizes the impact by reducing structural damage due to the force of the water). Also, the choice of land use can reduce the impact of flooding; land use includes the measures and mechanisms by which people have adapted their way of living and their livelihood to regular or incidental flooding, such as building houses on raised land (mounds) or on poles, growing flood resistant crops, diversifying livelihoods, etc. One example of regulatory flood-proofing measures is development moratoria, which are temporary prohibitions on development in a location while planning or studies are completed. This gives local communities time to effectively and comprehensively undertake planning measures while maintaining the status quo. In addition, rebuilding and redevelopment restrictions encompass a broad range of regulatory tools local governments can use to place progressive restrictions on structures when they are rebuilt and renovated. These tools are useful where redevelopment is undesirable, such as in areas that are currently in flood zones or predicted to be impacted by future sea level rise (Ocean Solutions, 2018).

3.3 Opportunities and challenges

Technological opportunities today

Technologies for the reduction and retention of risk in coastal zones, including structural/engineered measures, financial measures, policy and capacity-building, provide numerous economic and social benefits by protecting infrastructure and communities from climate risks, loss and damage. Furthermore, integrated cross-sectoral approaches to the management of coastal zones offer frameworks for adaptive management that increase resilience to climate change. Implementation of these technologies can also benefit ecological systems by building with nature. Implementing NbS and/or landscaping options as part of multifunctional measures encourages stronger integration by bringing together multi-sectoral actors. These solutions have potential multibeneficial effects: offer

44 http://www.coastaladaptation.eu/index.php/en/.
45 http://www.sustain-eu.net/index.htm.
46 https://northsearegion.eu/frames/.
47 https://www.interregeurope.eu/land-sea/.

solutions to mitigate climate change impacts; generate both direct and indirect socioeconomic benefits; social welfare and economic growth; driver for new coastal resilience projects.

Benefits can be maximized when climate change technologies are implemented proactively and there are opportunities to shift from an established strategy of retroactive implementation to more proactive management. This requires building capacity to integrate coastal hazard preparedness and climate change adaptation; proactive coastal adaptation measures that aim to safeguard/enhance the resilience of coasts; and the integration of socioeconomic activities and the natural dynamics of coastal zones into such processes. This approach has the potential of linking risk management, regional development, and planning and governance, and requires greater involvement of governmental agencies in the process and better integration of climate technologies into policies and sectors.

Technological challenges today: an adaptive approach to comprehensive risk management

Comprehensive risk management of coastal zones requires consideration of compounded uncertainties, including the natural variability of climate change, its impacts and slow climatic onset processes, scientific uncertainties, including the interaction of slow and sudden-onset events, and socioeconomic uncertainties. While some of these uncertainties can be reduced over time (e.g. by boosting scientific capacity), many will remain irreducible, at least in the short term, and will only dissipate when the future outcomes, based on the political and technological choices made and their impact on climate, materialize (Depoues et al, 2019). Furthermore, although climate models and hydro-meteorological forecasts are becoming increasingly precise and we have an increasing understanding of the ocean–climate system, there will always be a measure of uncertainty related to the natural variability of the ocean and climate (see Chapter 2).

Therefore, current decision-making processes relating to the comprehensive risk management of coastal zones depend on technologies for adaptive management that integrate various risks and the uncertainties surrounding them, prioritize adaptability and robustness in management choices and aim to scale up adaptation and resilience-building. Yet uncertainty is often used as a pretext for inaction. Many sectors find it difficult to consider technologies for decision-making that would apply decision-making framework with alternative approaches and adaptive management.

Technological challenges today: governance for comprehensive risk management

The complex nature of climate change poses unique challenges for institutions responsible for mitigation and adaptation efforts (Mahon et al. 2019; Shakya et al. 2018; Agrawal et al. 2009). The current arrangements are inadequate; in particular, the required knowledge is lacking to develop and implement the institutional reforms needed (UNFCCC NWP, 2019).

Effective local adaptation and comprehensive risk management of coastal zones require responsive governance from local institutions which are often constrained by limited technical and managerial capacity, poor linkages with institutions at the national, regional and international levels, inadequate systems for gathering and disseminating information, and unclear mandates and conflicting priorities from other levels and agencies of government. There are clearly major challenges to the critical task of building institutional capacity to enhance resilience to climate change.

Technological challenges today: holistic approach to comprehensive risk management

Increasing the effectiveness of any one particular technology depends on its implementation within the broader integrated approach and its prioritization during the participatory planning process. This increases the likelihood of a given measure to perform to the proper level of risk retention in the face of a multitude of environmental and socioeconomic factors. Comprehensive risk management should incorporate a holistic consideration of both sea and land areas, taking into account public uses, with coordination across institutions and sectors, and integrating governance and management of land, freshwater, coastal zones and marine areas and their resources. There are a number of integrated cross-sectoral planning and management approaches for sea- and land-sides (see section 3.2.3, e.g. ICZM, IWRM, MSP, S2S), and national plans and policies on adaptation and mitigation actions commonly encompass these approaches. However, land activities and impacts are still largely disconnected from coastal/marine considerations. Many countries have identified a need for enhanced coordination in their climate actions: a large majority of reviewed nationally determined contributions (NDCs) included components linked either to water and coastal management or to land-use planning. NDCs also indicated that estuaries, delta, and wetland systems may require increased consideration in climate adaptation and mitigation planning.

Increased understanding of the complexities of freshwater, delta, coastal zones and marine areas and their intrinsic links to land-based activities is required for comprehensive risk management in coastal zones and for strengthening the blue and green economies. Climate change brings demands a more holistic approach to strengthening the blue and green economies. In this regard, while the need to integrate S2S assessments into climate mitigation and adaptation planning processes is currently recognized, it is still to be met. Beyond that, applying S2S in climate adaptation and mitigation actions requires funding that focuses on a long-term, holistic strategy that builds system resilience, alongside efforts to reach sectoral targets.

Technological challenges today: financing and funding for comprehensive risk management

In light of sudden onset events and the wealth of assets exposed to climate change hazards, in the first instance, Governments largely choose structural/engineered solutions to reduce loss and damage and protect coastal communities in the short term. Given the relatively large cost of coastal protection projects, local and national governments can be equally reluctant to provide funding for them, fearing that this may establish a precedent that could become unfeasible if, in the light of climate change impacts, such projects should become necessary across large stretches of coastline. There is increasing recognition that identifying funding to meet the expenditure requirements of coastal protection plans is beyond the capacity of the current finance structures of local governments (Banhalmi-Zakar et al, 2017). With regard to slow onset events, NbS offer cost-effective alternatives and are complementary to structural engineered infrastructure, often in hybrid solutions. Financing for NbS is challenging and there are some, though very limited, insurance incentives for conservation and restoration; however, NbS are generally not well understood by the insurance industry as they are often perceived as being too difficult, too slow and not offering many benefits (Beck et al, 2019). Integrating NbS considerations into the insurance industry therefore remains a challenge. Furthermore, many Governments subsidize coastal risk, which creates incentives for greater coastal development; loss of ecosystems then progresses and the opportunities for private insurance decrease. There are, however, opportunities to expand integration by better incorporating risk reduction and NbS benefits in bonds (green and social impact bonds).

Long-term, consistent financial support and sustainable funding for the long-term financing of coastal adaptation are the key challenges. Some countries have not included such sustainable funding in their national strategies. In financial practices, it is no easy task to take climate risks – both transition risks and physical risks – into account (Depoues et al, 2019). Other challenges include applying innovative financial tools for adaptation, mobilizing national public funding to support integrated policies and getting climate financing to reach civil society organizations and communities at the local level.

The improvement of technologies for retention of coastal risk is a continuous process and requires experience-sharing across regions. Sharing knowledge and practices more systematically will help address the challenges of implementing climate-resilient technologies for comprehensive risk management in coastal zones.

3.4 Case study

Frameworks and methodologies

As part of a technical assistance project,[48] the United Nations Conference on Trade and Development has developed a methodology to assist transport infrastructure management and other relevant entities in SIDS in identifying priorities for adaptation and 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 the facility, local and national level. The methodology is transferable, subject to location-specific modification, and suitable for use in 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 aims to identify 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 of how to conduct the assessment. The framework allows for flexibility based on the available data, stakeholder engagement and other relevant factors.[49] Some of the major lessons learned are listed by category below:

- *Data availability*: data collection efforts take time; many SIDS lack baseline data; site visits to facilities and interviews with local stakeholders are essential *('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 and should share their success stories; there is a need for regional cooperation, and to build a knowledge-base and community of practice around vulnerabilities.
- *Implementation*: organizational 'best practices' can increase resilience, and vice versa; adaptation activities should be mainstreamed 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.

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[48] SIDSport-ClimateAdapt.unctad.org.

[49] For full details, see UNCTAD (2017) Climate Risk and Vulnerability Assessment Framework for Caribbean Coastal Transport Infrastructure (pp. 59-73); 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

"Resilience is the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions" (A special report of the IPCC, "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation")[50]

The aftermath of natural disasters comprises fatalities, huge economic losses and devastating damage to coastal zones. Coastal resources such as mangroves, wetlands and coral reefs suffer extensive damage. The severing of communities and the trauma associated with this are among many of the social issues that affect human well-being, while the environmental damage hampers the rebuilding of livelihoods. A lesson learned from such disasters is that impacted countries and communities are often much better equipped to use recovery, rehabilitation and reconstruction methods when they have taken actions to strengthen their recovery capacity and the effectiveness of decision-making instruments prior to the onset of a disaster (UNISDR "Build Back Better", 2017). In that regard, the United Nations and international organizations have been calling for local capacity for coping with disaster to be recognized as essential.

In the adaptation context, resilience includes both the ability to recover from a hazardous event and the opportunity to improve or 'adapt forward' (UNFCCC WIM, 2018). Resilience features strongly in three global agendas: in the climate change adaptation component of the Paris Agreement, enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction in the 2030 Agenda for Sustainable Development and the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR). Notably, the Paris Agreement articulates in resilience-building the need for adaptation forward in addition to rehabilitation and building back better. Coherence and synergies of these agendas can facilitate enhancing adaptation actions, as well as options for supporting the implementation of specific actions, including by integrating adaptation with efforts to achieve the SDGs and implement the Sendai Framework. These synergies are also required to downscale to the national and local levels in order to effectively respond to climate change challenges by averting and minimizing loss and damage in coastal zones.

The process of recovery and rehabilitation aims to build long-term resilience against disasters in a resident local community. This process provides an opportunity for adaptation and building back/forward better in order to reduce the future impact of disasters and ensure the community is better prepared. This requires efforts at the policy level in particular. Recovery and rehabilitation in coastal zones provide opportunities to more effectively integrate risk reduction and preparedness technologies into development planning. Such measures will help to reduce the impacts of future hazardous events and disasters. Recovery also provides opportunities for institutional strengthening of disaster risk management activities.

4.2 Overview of types of technologies

Loss and damage refer to economic and non-economic losses (social, cultural, health) during various time scales (sudden extreme and slow onset events) that have already occurred or are projected (UNFCCC WIM). The complex nature of loss and damage requires different technologies for climate change resilience development, coastal recovery and rehabilitation (i.e. for restoring coastal communities,

[50] https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/.

infrastructure, ecosystems, and livelihoods following a disaster). Recovery and rehabilitation happen over multiple time scales, and priorities may shift as a situation progresses.

4.2.1 Hard technologies

Restoration: The long-term recovery in coastal zones is increasingly seen as related to the protection and rehabilitation of coastal ecosystems (Spalding et al, 2014). Coastal ecosystems can suffer extensive damage and loss following a disaster and can be severely affected for years to come (SROCC, 2019). Current efforts are focused on the recovery and rehabilitation of coastal ecosystems in the light of their capacity to protect coasts. For example, the 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. Mapping of ecosystems is important to such restoration efforts; the Mangrove Restoration Potential Map,[51] for example, provides global and national overview figures on mangrove restoration potential for climate mitigation and adaptation, and also offers identification of national and local priority areas for mangrove restoration based on both potential ecosystem services gains and/or other socioeconomic benefits. Restoration may include, but is not limited to, hard substrates, eelgrass seed planting and the addition of spawning stocks.

Typically, restoration projects include a mix of techniques aimed at restoring distinctive coastal and marine habitats and each project has a different set of ecological objectives. For example, replanting mangroves can be difficult once they have been removed and often requires placing revetments or the use of bamboo breakwaters to ensure that young trees can survive long enough (Rasmeemasmuang and Sasaki, 2015). Innovations can support these efforts (e.g. electro-mineral accretion, powered by solar panels that floats on water). Different approaches are currently being explored to encourage the uptake and survival of coral species through artificial reefs, while restoration can play a role in reclaiming wetland with a view to harness its ability to absorb water and buffer against changing conditions to serve a mediating function. Techniques may include land purchases and breaching and excavating levees for tidal marsh restoration. Additionally, restoration of 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.

In recent years, coastal adaptation strategies have been approached in a more holistic manner that includes NbS and hybrid solutions. This enables the establishment of partnerships to enhance restoration initiatives, actions and capacity-building, such as the InsuResilience Global Partnership,[52] the International Partnership for Blue Carbon,[53] Engineering with Nature,[54] the Living Shorelines Academy,[55] the Global Mangrove Alliance,[56] Save Our Mangroves Now,[57] the Reef Resilience Network[58] and the Coral Triangle Initiative. More partnerships are expected in view of the upcoming United Nations Decade on Ecosystem Restoration 2021-2030, which aims to promote the massive scaling up of the restoration of degraded and destroyed ecosystems as a proven effective climate action.

Data-collection platforms: Recovery and rehabilitation efforts aim to restore public services and create conditions for socioeconomic activities. Short-term recovery often involves responding to 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 in communities and municipalities. Technology can play an important role in collecting data to provide information 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 to disasters and

[51] https://www.iucn.org/theme/forests/our-work/forest-landscape-restoration/mangrove-restoration/mangrove-restoration-potential-mapping-tool.

[52] https://www.insuresilience.org.

[53] https://bluecarbonpartnership.org.

[54] https://ewn.el.erdc.dren.mil/atlas.html.

[55] https://www.livingshorelinesacademy.org/index.php.

[56] http://www.mangrovealliance.org/.

[57] http://www.mangrovealliance.org/save-our-mangroves-now/.

[58] https://reefresilience.org/.

emergencies. KoBoToolbox (Pham and Vinck, 2019) is an example of one of a large number of platforms that can assist in data collection during recovery. It facilitates the 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 useful when communication systems are affected by the disaster.

Development of emergency measures: An effective and efficient emergency response depends on adequate hazard preparedness, which includes planning for various emergency hazard scenarios, simulation exercises, demonstrations and drills as well as training and education. Good coordination and management of organizations and activities are essential for containing a disaster and minimizing loss of life and injury during and after the event. Assistance and stimulus measures for businesses can also be planned to quick-start economic recovery. Migration in the context of both sudden extreme and slow onset processes is also considered in the technologies (approaches and measures) for risk management and climate adaptation. For instance, strategies on how to enhance EWS are useful in the nexus between migration, urbanization, and daily mobility (Birkmann et al. 2013; OECD, 2018).

4.2.2 Soft technologies

Financial measures: The repair or reconstruction of damaged infrastructure after extreme weather events is often funded through the national Government's disaster relief and recovery arrangements. The financial burden of hazard impacts may be relieved somewhat by relief funds and insurances. Many countries have some form of disaster insurance coverage. These insurance systems differ widely between countries in their treatment of risk. Insurance against floods is 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 programmes are likely necessary to realize the benefits to recovery, and 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. There are models that assess socioeconomic resilience to natural disasters of an economy. For instance, Hallegatte et al (2016) presented such a 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 of flood risk management has also been 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.

Assessment frameworks for resilience-building: In order to assess adaptation and resilience-building efforts as well as to understand diversity of hard technologies, uncertainty and long-term outlooks, frameworks are being developed and implemented (e.g. in affected regions). In that regard, the 'Rebuild by Design' initiative,[59] an assessment framework implemented in a region affected by Hurricane Sandy, was developed to design plans for more resilient and adaptive development that incorporate a long-term vision of how to adapt to climate change and socioeconomic development (Kind et al, 2014). The framework considers economic, social and environmental long-term perspectives (climate scenarios), the financial feasibility of solutions, and funding and financing solutions that enhance financial feasibility. Such frameworks can be applied to different settings, including hurricane-affected regions and the low-lying deltas (Delta Program, 2012).

4.2.3 Organizational technologies

International mechanisms for resilience-building: International initiatives enhances the use of policy and regulation tools relevant to coastal risk under climate change, and more such tools have been introduced in recent years. Of particular significance are the UNFCCC 2010 Cancun Adaptation Framework, and the Sendai Framework for Disaster Risk Reduction. Other initiatives such as the "Build Back Better" by the

59 http://www.rebuildbydesign.org.

Sendai Framework/UNDRR and "Build Back/Forward Better" by Climate Change Adaptation/UNFCCC emphasize that the recovery, rehabilitation and reconstruction phase (which should be planned before a disaster occurs), should integrate disaster risk reduction into development measures, making nations and communities resilient to disasters. International organizations support these ambitions and their implementation at the regional and national levels. In this regard, the Global Facility for Disaster Reduction and Recovery has expressed an interest in providing funding and technical assistance for climate resilience projects as well as other disaster risk reduction work that will also directly contribute to adaptation and sustainable development projects that are in line with the global agendas. Another example is the Global Commission on Adaptation, which though its action track on 'Preventing hazards from becoming disasters' addresses actionable targets aim to strengthen national social protection systems and the coherence of disaster management and adaptation policies.

Translating international goals and policy into concrete actions on the ground at the national level often falls to regional organizations. For example, they identify good practices, including mechanisms for multi-stakeholder engagement in regional ocean/climate governance through tools like the Caribbean Community (CARICOM) Regional Framework for Achieving Development Resilient Climate Change (2009-2015) and the CARICOM Regional Comprehensive Disaster Management Strategy (2014-2024). In the Pacific region, the Regional Technical Support Mechanism provides advice on strategic approaches and technical assistance on climate change, facilitates rapid access to technical and advisory services, and aims to, through that process, create or strengthen national capacity to effectively respond to climate change and disaster risk reduction. Regional and national initiatives to promote blue economies are being implemented to support resilience-building in coastal communities. In Caribbean and Pacific SIDS, such approaches are based on the principles of sustainability, inclusiveness and resilience in economic development.

Recovery and rehabilitation outcomes depend heavily on the existence of such programmes and mechanisms that support recovery, whether by providing human, financial or other resources, or by promoting, informing and, as necessary, mandating risk-aware, climate-adaptive, and development-focused recovery goals. For this, national-level disaster recovery frameworks provide the structure and context required by stakeholders active in recovery planning and operations.

Support for local communities: New international partnerships aim to support Governments in integrating climate risks and extreme events into social protection policies in order to help low-income communities recover more quickly following disasters and strengthen social protection programmes to prioritize those most vulnerable to climate change.[60] Together with UNDRR and the International Federation of Red Cross and Red Crescent Societies, the Global Facility for Disaster Reduction and Recovery and other partners, the Global Commission on Adaptation will support 50 countries in developing coherent regulatory frameworks on climate change and disasters and a common implementation agenda for their disaster risk management and climate change adaptation policies, with the overall goal of helping local communities around the world to adapt to new climate extremes. At the regional level, the Southeast and Caribbean Disaster Recovery Partnership (SCDRP)[61] aims to strengthen the capacity of the region's coastal communities, economies and environment to recover from coastal storms by connecting disaster recovery practitioners from the public, private and civil society sectors and providing a platform for training, resources and relationships to help coastal communities bounce back. Regional capacity-building and education organizations and networks, such as the Galápagos Alliance, the Caribbean Natural Resources Institute and Reef Resilience Network, are important for providing support to local communities.

Approaches for local communities: The need to build long-term resilience against disasters among resident communities is a key consideration of the recovery process. Local coping capacities are critical to the recovery of coastal communities and coastal zones. Skills development training, community support and health care are important activities to consider within recovery process targeting households. Innovations

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[60] https://gca.org/global-commission-on-adaptation/action-tracks/disaster-risk-management.

[61] https://www.scdrp.secoora.org.

and best practices to develop and apply participatory tools and methods to document the local and traditional knowledge of coastal communities (e.g. to develop community adaptation plans) have been identified, and efforts are being made to integrate this knowledge into scientific systems and decision-making. The use of participatory three-dimensional modelling is a good example of how this can be done. Capacity-building through a combination of targeted methods, such as training of trainers, mentoring, coaching, action learning, fostering communities of practice and peer exchanges can foster change on the ground. Participatory tools have been developed in order to implement community-based approaches in conjunction with ecosystem-based approaches, which serve to facilitate vulnerability assessments and local adaptation planning and action. For example, the Locally-Managed Marine Area Network (LMMA)[62] is a group of practitioners involved in various community-based marine conservation projects around the globe, primarily in the Indo-Pacific, who have joined together to learn how to improve management efforts. Using an LMMA approach, some coastal communities are reviving methods that were used traditionally in their culture for many generations, sometimes blending them with modern techniques for best results. By addressing stressors to local coastal zones, these communities are able to improve the resilience of their communities to the growing effects of climate change.

Ecosystem-based approaches to adaptation in coastal communities can include the conservation, sustainable management and restoration of coastal ecosystems. These approaches can increase community resilience and food security, safeguard and improve coastal biodiversity, and simultaneously contribute to climate mitigation through the storage of blue carbon (UNFCCC NWP, 2019).

Methods to increase the participation of all societal actors, including minorities, integrate their experiences and consider their needs in coastal adaptation processes, are being developed; these are directly relevant to some adaptation measures, such as NbS. One such example is the Mangoro Market Meri programme,[63] is a platform led by women for women across Papua New Guinea (and supported by The Nature Conservancy), which aims for the sustainable management of mangroves in the service of education and awareness, food security, income-generating opportunities, storage of ‘blue’ carbon and the protection of coastal communities from sea level rise and storm surge.. Potential economic opportunities include building local markets for sustainably harvested mangrove products, such as shellfish and mud crabs (short term); exploring the potential for ecotourism (medium term); and preparing to engage in blue carbon markets (long term).

4.3 Opportunities and challenges

Technological opportunities today

The United Nations and international organizations recognize that building resilience enables a system, 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, restoration and rehabilitation of its essential basic structures and functions. Global agendas enhance the use of policy and regulation tools relevant to coastal risk under climate change and such tools have been increasingly introduced around the world in recent years. International organizations support these ambitions and their translation to the regional and national levels. International programmes and mechanisms support recovery and rehabilitation 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. Such programmes and mechanisms are complemented with national-level disaster recovery frameworks. The frameworks provide the structure and context required by stakeholders active in recovery planning and operations. New international partnerships aim to support Governments in integrating climate risks and extreme events into social protection policies in order to help low-income communities recover more quickly following disasters and strengthen social protection programmes to prioritize those most vulnerable to climate change. Innovative participatory tools are being developed in order to implement community-based approaches in conjunction

[62] http://lmmanetwork.org.

[63] http://naturesleadingwomen.org/women/papua-new-guinea/.

with ecosystem-based approaches, which serves to facilitate vulnerability assessments and local adaptation planning and action.

International organizations, governments and local communities are increasingly recognizing the urgent need to prevent and reduce vulnerability and recognizing the subsequent need to build resilience. A key aspect of the recovery process is the need to build long-term resilience against disasters in resident communities. In this regard, building local coping capacities is critical to the recovery of coastal communities and coastal zones.

Technological challenges today: mechanisms and incentives for implementation of technologies

Technologies for risk prevention, retention, rehabilitation and recovery are being increasingly developed in coordinated efforts; however, they require mechanisms and incentives for implementation, where governance, institutional settings, system approach and financing are important driving forces. In this regard, prevention and resilience-building are recommended by the United Nations global agendas: Climate Change Adaptation (the Paris Agreement), Disaster Risk Reduction (the Sendai Framework) and SDGs (the 2030 Agenda).

To prevent future tragedies and ensure progress towards climate adaptation and sustainable development, Governments are encouraged to implement the goals and targets as agreed in the global agendas. This requires, however, that national adaptation plans and disaster risk recovery plans to be coherent with and link to the global agendas. Detter harmonization of these global agendas could facilitate the development of more comprehensive approaches for resilience-building, rehabilitation and recovery within coastal risk management frameworks beyond 2030.

A common opportunity associated with recovery and rehabilitation is the notion of 'building 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), demonstrates, in a case from Sri Lanka, how efforts to build back better did not result in changes to the underlying structural vulnerabilities and created hazards, despite the policy narrative and support for the concept.

Strengthening institutional arrangements and policies and using the frameworks for coordinated interactive governance and action for technologies, such as restoration, could support efforts to building back/forward better in coastal zones. In this regard, agendas related to restoration, such as the United Nations Decade on Ecosystem Restoration 2021-2030, could serve as a framework to scale up the restoration of degraded and destroyed ecosystems in order to address the climate crisis and encourage incorporating NbS into adaptation and development planning as part of a strategy to meet climate adaptation goals.

Technological challenges today: local empowerment for comprehensive risk management

Local or regional disaster management committees and their cooperation with climate change adaptation committees are essential to helping communities to prepare before, during and after disasters, since the organization of international and national responses usually takes time. For example, improving the economic status households and communities enhances their resilience by enabling them to recuperate more quickly following a disaster.

Coastal hazard preparedness measures, including EWS and community preparedness, are essential for prevention and are encouraged. In this regard, Governments develop such measures alongside policies that play a role in helping communities to maintain resilience in the face of climate change impacts. However, it is important that projects like EWS or other technological interventions are identified as needs in countries' national adaptation plans, NDCs or national DRR plans. While countries often have policies in place to address climate change adaptation at the national level that include plans for disaster management at the local level, local governments could be more empowered to provide input on the policies they are required to implement.

Climate change adaptation and risk reduction efforts are integral to avoid loss and damage, particularly in SIDS and LDCs. However, loss and damage can overwhelm the ability of individuals and households to cope and adapt (Warner and van der Geest, 2013). 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 often there is insufficient help from government agencies to identify and implement appropriate solutions. Often the insurance cover against natural hazards cushion the negative consequences. Studies indicate that in the LDCs, between 90 and 94 per cent of the population lacks access to insurance products, with the 6 to 10 percent that is covered being comprised of mostly households in the middle- to upper-income range (Reinhard, 2008; ADB, 2009; Khan et al, 2013).

Though some loss and damage can be avoided through climate change adaptation and DRR efforts, there will be residual loss and damage, which makes it important to adopt and implement a range of risk management technologies as part of a comprehensive risk management strategy to build the resilience of physical and socioeconomic systems in coastal zones. Therefore, investing in DRR technologies focused on prevention and preparedness, while also ensuring effective emergency response, reconstruction and rehabilitation, is crucial for addressing residual loss and damage. In addition, investing in prevention needs to be part of a long-term strategy and receive continued political support in order to be effective.

Technological challenges today: involving, leveraging, accelerating and upscaling

The impact of disasters on people's lives and livelihoods is generally much more dramatic in vulnerable areas and poorer developing countries. A key challenge is mainstreaming of slow onset processes into sectoral policies and plans and incorporating local and indigenous knowledge into risk management efforts in coastal zones. Strengthening the engagement of local communities and the use of local and traditional knowledge in national policy development and planning (e.g. involving women's groups and indigenous peoples) can bolster national adaptation efforts. Engagement of local people could be supported by sharing knowledge on participatory governance, particularly regarding scaling out -achieving scale- and scaling up -institutionalising in policies etc. to strengthen enabling environments.

Often, however, the importance of community-based adaptation in coastal zones is not properly acknowledged and the substantive engagement of stakeholders is not ensured. Involving indigenous peoples and women and integrating local knowledge into technologies, e.g. restoration, could benefit adaptation efforts, and these local experiences in building capacity to deepen and scale out efforts could be scaled up and replicated *vis-a-vis* organizational strengthening. In this regard, those most vulnerable to the impacts of climate change and those on the front lines of adaptation, who will have to radically change their lifestyle, could be more involved in the adaptation planning process and the creation of their own solutions, appropriate to their local context and needs, whilst building community solidarity. Effective communication of local knowledge to influence adaptation policy and practice is critical and needs to target all levels of governance and sectors (UNFCCC NWP, 2019).

The Paris Agreement recognizes that a different approach is needed for long-term impact and calls for capacity-building that is, "country-driven, based on and responsive to national needs, and foster[s] country ownership", and that is "an effective, iterative process that is participatory, cross-cutting and gender-responsive."

There is an urgent need to act, share knowledge and experience, and leverage, accelerate and upscale the needed interventions. In this regard, Governments and institutions have the primary responsibility of creating the right prevention and recovery strategies by establishing regulatory and incentive-based mechanisms to ensure resource allocation.

4.4 Case study

Achieving coastal resilience after disasters: trends in the early twenty-first century and future considerations

When a tsunami hit the Aceh region of Indonesia in December 2004, the Indonesian Government planned to rebuild cities and villages 2 kilometres from the coastal line, creating a setback that would act as a buffer. At the same time, different actors, including international agencies, non-governmental organizations and private firms, provided financial support and material assistance to rebuild coastal zones, which conflicted with the national planning policies. Facing these pressures, the Indonesian Government then had to adjust the overall rebuilding trajectory and shift its strategy to allow rebuilding in coastal zones (Pardede and Munandar, 2016). Instead of dictating the rebuilding policy in a top-down fashion, Badan Rehabilitasi dan Rekonstruksi NAD-Nias, or Agency for the Rehabilitation and Reconstruction of Aceh and Nias, the Indonesian government agency in charge of rehabilitation and reconstruction, required field actors (International NGOs and philanthropic organizations) to develop community plans for approval. Through this process, community needs were discussed and included in the rebuilding plans that considered social and economic aspects. This decentralization of decision-making was possible due to the concomitant institutional changes taking place in the country’s governance, which was shifting from a strong central structure to more decentralized structure. The devastated coastal zone in the Aceh region was transformed into a vibrant area; a mix of old residents and a large number of newcomers remade or made their home there. Communities that were relocated to areas far from the redeveloped coastal downtowns show signs of distress including high vacancy and turnover rates.

The Tohoku region of Japan was devastated by the tsunami caused by the 2011 Great East Japan Earthquake. Immediately after the event, the national Government took on planning for the rebuilding of the affected coastal zones. The rebuilding strategy had the principal goal of protecting communities from future tsunamis and called for regulation of coastal inhabitation through community relocation or elevation of coastal lands that are at risk from a tsunami 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 programmes, no significant changes were evident across the affected areas throughout the rebuilding process (Iuchi and Olshansky, 2018). Furthermore, key rebuilding actors – national, regional and local governments as well as government contractors – continued to make key decisions without adapting and modifying much of the original plan. Eight years after the event, almost no residences are found in areas identified as being at high-risk in the event of a tsunami in contrast with coastal regions in other countries that have experienced large-scale disasters, where rebuilt areas remain at high risk. Communities targeted for relocation are living in the new sites, most of which are located on hillsides or inland and are solely residential. Relocated communities are predominantly made up of elderly residents, exacerbating the aging population that existed before the disaster. Tsunami risk has reduced with community relocation and the reconstruction of coastal levees.

After Typhoon Yolanda (also known as Haiyan) struck the Leyte region of the Philippines in November 2013, coastal communities saw buildings decimated. Storm surge exceeding 5 metres swept away almost all structures, including evacuation centres and schools. During the rebuilding process, national and local governments ultimately supported the adoption of a 40-metre no-dwelling zone in order to avoid future damage and loss, particularly as there was speculation that the impacts would be exacerbated by sea level rise. While the national Government initially took the lead in developing resilient rebuilding policies, the local governments gradually became the central actors responsible for planning and making decisions regarding the local rebuilding processes. This shift took place naturally as the Philippines’ governance has long been decentralized. If decided, localities would aim to keep coastal zones uninhabited as the initial land-use plan specified. To do so, the local governments continued to work with private sector organizations, including non-governmental organizations and religious groups, to relocate communities away from coastal hazards (Iuchi and 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 ongoing, but many affected residents are re-establishing themselves 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 viable to live in. Gradually, the relocation sites are fulfilling life needs, but many people still prefer to be active in the coastal areas. Members of relocated communities still rely heavily on coastal economic activities that have re-emerged after Typhoon Haiyan, even though the risk of storm surge continues to be high.

These cases portray different governance and rebuilding strategies that create distinct 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 when rebuilding, especially ways to foster livelihoods, is essential when choosing engineering-based hazard mitigation solutions. Furthermore, having local key decision makers, such as local governments, in the driving seat, is crucial. Local actors are better placed to create locally contingent definitions of resilience and incorporate local needs into policies.