African Forest Forum

A platform for stakeholders in African forestry

Forests and Climate Change Adaptation

A COMPENDIUM FOR TECHNICAL TRAINING IN AFRICAN FORESTRY

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Acknowledgements

This compendium has been developed through an organic process that initially led to the development of “Training modules on forest-based climate change adaptation, mitigation, carbon trading, and payment for other environmental services”. These were developed for professional and technical training, and for short courses in sub-Saharan African countries. The compendium provides the text required for effective delivery of the training modules; in other words, it is structured based on the training modules, but updated and strengthened based on new and emerging issues in the context of forestry and climate change adaptation and mitigation, as well as case studies from various African forestry landscapes. In this context, many people and institutions, including those from government, civil society, academia, research, business, private sector, and other communities, have contributed in various ways in the process that culminated in the development of the compendium. This has been through their inputs as reviewers, resource persons and participants to the validation of the draft documents. We wish to collectively thank all these individuals and institutions for their invaluable contributions, given that it is difficult in such a short text to mention them individually.

We also appreciate the kind financial support received from the Government of Switzerland through the Swiss Agency for Development and Cooperation (SDC) to implement an AFF project on “African forests, people and climate change” that generated most of the information that formed the basis for writing this compendium. AFF is also indebted to the Swedish International Development Cooperation Agency (Sida) for its support of another AFF project on “Strengthening management and use of forest ecosystems for sustainable development in Africa” that also provided inputs into the compendium, in addition to helping facilitate various contributors to this compendium. The issues addressed by the two projects demonstrate the interest of the people of Switzerland and Sweden in African forestry and climate change.

We are also particularly grateful to the lead authors, the contributors mentioned in this compendium and the pedagogical expert.

We hope that the compendium will contribute to a more organized and systematic way of delivering training in this area, and eventually towards better management of African forests and trees outside forests in the context of changing climate.

Preface

African forests and trees support the key sectors of the economies of many African countries, including crop and livestock agriculture, energy, wildlife and tourism, water resources and livelihoods. They are central to maintaining the quality of the environment throughout the continent, while providing international public goods and services. Forests and trees provide the bulk of the energy used in Africa. Forests and trees are therefore at the centre of socio-economic development and environmental protection of the continent.

Forests and trees outside forests in Africa are in many ways impacted by climate change, and they in turn influence climate. Hence, African forests and trees are increasingly becoming very strategic in addressing climate change, as captured in African countries' Nationally Determined Contributions (NDCs). The great diversity of forest types and conditions in Africa is at the same time the strength and the weakness of the continent in devising optimal forest-based responses to climate change. In this regard, given the role of forests and trees to socio-economic development and environmental protection, actions employed to address climate change in Africa must simultaneously enhance livelihoods of forest dependent populations and improve the quality of the environment. It is therefore necessary for Africa to understand how climate change affects the inter-relationships between food, agriculture, energy use and sources, natural resources (including forests and woodlands) and people in Africa, and in the context of the macro-economic policies and political systems that define the environment in which they all operate. Much as this is extremely complex, the understanding of how climate change affects these inter-relationships is paramount in influencing the process, pace, magnitude and direction of development necessary for enhancing people's welfare and the environment in which they live.

At the forestry sector level, climate affects forests but forests also affect climate. For example, carbon sequestration increases in growing forests, a process that positively influences the reduction in the level of greenhouse gases in the atmosphere, which, in turn, may reduce global warming. In other words, the forests, by regulating the carbon cycle, play vital roles in climatic change and variability. For example, the Intergovernmental Panel on Climate Change (IPCC) special report of 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels underscores the significance of afforestation and reforestation, land restoration and soil carbon sequestration in carbon dioxide removal. Specifically, in pathways limiting global warming to 1.5 °C, agriculture, forestry and land-use (AFOLU) are projected with medium confidence to remove 0-5, 1-11 and 1-5 GtCO2 yr-1 in 2030, 2050 and 2100, respectively. There are also co-benefits associated with AFOLU-related carbon dioxide removal measures such as biodiversity conservation, improved soil quality and local food security. Climate, on the other hand, affects the function and structure of forests. It is important to understand adequately the dynamics of this interaction to be able to design and implement appropriate mitigation and adaptation strategies for the forest sector.

In the period between 2009 and 2011, the African Forest Forum (AFF) sought to understand these relationships by putting together the scientific information it could gather in the form of a book that addressed climate change in the context of African forests, trees, and wildlife resources. This work, which was financed by the Swedish International Development Cooperation Agency (Sida), unearthed considerable gaps on Africa's understanding of climate change in forestry, how to handle the challenges and opportunities presented by it and the capacity to do so.

The most glaring constraint for Africa to respond to climate change was identified as the lack of capacity to do so. AFF recognizes that establishment and operationalization of human capacities are essential for an effective approach to various issues related to climate change, as well as to improve the quality of knowledge transfer. For example, civil society organisations, extension agents and local communities are stakeholders in implementing adaptation and mitigation activities implicit in many climate change strategies. In addition, civil society organisations and extension agents are more likely to widely disseminate relevant research results to local communities, who are and will be affected by the adverse effects of climate change. It is therefore crucial that all levels of society are aware of mechanisms to reduce poverty through their contribution to solving environmental problems. Training and updating knowledge of civil society organisations, extension service agents and local communities is one of the logical approaches to this. Also, professional and technical staff in forestry and related areas would require updated knowledge and skills in these relatively new but highly dynamic areas of work.

It was on this basis that AFF organized a workshop on capacity building and skills development in forest-based climate change adaptation and mitigation in Nairobi, Kenya, in November 2012 that drew participants from selected academic, research and civil society institutions, as well as from the private sector. The workshop identified the training needs on climate change for forestry related educational and research institutions at professional and technical levels, as well as the training needs for civil society groups and extension agents that interact with local communities and also private sector on these issues. The training needs identified through the workshop focused on four main areas, namely: Science of Climate Change, Forests and Climate Change Adaptation, Forests and Climate Change Mitigation, and Carbon Markets and Trade. This formed the basis for the workshop participants to develop training modules for professional and technical training, and for short courses for extension agents and civil society groups. The development of the training modules involved 115 scientists from across Africa. The training modules provide guidance on how training could be organized but do not include the text for training; a need that was presented to AFF by the training institutions and relevant agents.

Between 2015 and 2018, AFF brought together 50 African scientists to develop eight compendiums in a pedagogical manner, namely:

1. Basic Science of Climate Change: A Compendium for Professional Training in African Forestry 01- https://afforum.org/publication/basic-science-of-climate-change-a-compendium-for-professional-training-in-african-forestry-01/
2. Basic Science of Climate Change: A Compendium for Technical Training in African Forestry 02- https://afforum.org/publication/basic-science-of-climate-change-a-compendium-for-technical-training-in-african-forestry-02/
3. Basic Science of Climate Change: A Compendium for Short Courses in African Forestry 03- https://afforum.org/publication/basic-science-of-climate-change-a-compendium-for-short-courses-in-african-forestry/
4. Carbon Markets and Trade: A Compendium for Professional Training In African Forestry 04- https://afforum.org/publication/carbon-markets-and-trade-a-compendium-for-professional-training-in-african-forestry/
5. Carbon Markets and Trade: A Compendium for Technical Training in African Forestry 05- https://afforum.org/publication/carbon-markets-and-trade-a-compendium-for-technical-training-in-african-forestry/
6. Carbon Markets and Trade: A Compendium for Short Courses in African Forestry 06- https://afforum.org/publication/carbon-markets-and-trade-a-compendium-for-short-courses-in-african-forestry/
7. Climate Modelling and Scenario Development: A Compendium for Professional Training in African Forestry 07- https://afforum.org/publication/climate-modelling-and-scenario-development-a-compendium-for-professional-training-in-african-forestry-07/
8. International Dialogues, Processes and Mechanisms on Climate Change: A Compendium for Professional and Technical Training in African Forestry 08- https://afforum.org/publication/international-dialogues-processes-and-mechanisms-on-climate-change-a-compendium-for-professional-and-technical-training-in-african-forestry-08/

From 2019 to 2022, AFF mobilized 75 African forestry stakeholders to continue the development of the compendiums including updating, strengthening and contextualizing them with case studies, new and emerging issues in forestry and climate change in order to produce six new compendiums as follows:

1. Forests and climate change adaptation: a compendium for professional training in African forestry
2. Forests and climate change adaptation: a compendium for technical training in African forestry
3. Forests and climate change adaptation: a compendium for short course in African forestry
4. Forests and climate change mitigation: a compendium for professional training in African forestry
5. Forests and climate change mitigation: a compendium for technical training in African forestry
6. Forests and climate change mitigation: a compendium for short course in African forestry

These compendiums are being translated into French for the benefit of the Francophone African forestry stakeholders.

Another notable contribution during the period 2011-2018 was the use of the training module on “Carbon markets and trade” in building the capacity of 574 trainers from 16 African countries on rapid forest carbon assessment (RaCSA), development of a Project Idea Note (PIN) and a Project Design Document (PDD), exposure to trade and markets for forest carbon, and carbon financing, among others. The countries that benefited from the training are: Burkina Faso (35), Côte d’Ivoire (31), Ethiopia (35), Guinea Conakry (40), Kenya (54), Liberia (39), Madagascar (42), Niger (34), Nigeria (52), Sierra Leone (35), Sudan (34), Swaziland (30), Tanzania (29), Togo (33), Zambia (21) and Zimbabwe (30). In addition, the same module has been used to equip African forest-based small-medium enterprises (SMEs) with skills and knowledge on how to develop and engage on forest carbon business. In this regard, 63 trainers of trainers were trained on RaCSA from the following African countries: Angola, Benin, Burkina Faso, Cameroon, Chad, Côte d’Ivoire, Democratic Republic of Congo, Ethiopia, Kenya, Gabon, Gambia, Ghana, Guinea Conakry, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Republic of Congo, Senegal, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

In 2021 and 2022, the validated training compendiums on “Forests and climate change mitigation: a compendium for short courses in African forestry” and on “Forests and climate change adaptation: a compendium for short course in African forestry” were used to train 165 African forestry stakeholders from forestry administrations, private sectors, civil society and community based organizations from 29 African countries including 10 from Francophone (Algeria, Benin, Burkina Faso, Chad, Mali, Mauritania, Niger, Tunisia, Togo and Senegal); 15 from Anglophone (Botswana, Egypt, Ethiopia, Kenya, Gambia, Lesotho, Liberia, Malawi, Namibia, Nigeria, Rwanda, Uganda, Tanzania, Zambia, Zimbabwe) and 2 from Lusophone Africa (Angola and Mozambique).

An evaluation undertaken by AFF has confirmed that many trainees on RaCSA are already making good use of the knowledge and skills gained in various ways, including in developing bankable forest carbon projects. Also, many stakeholders have already made use of the training modules and the compendiums to improve the curricula at their institutions and the way climate change education and training is delivered. In the same vein, an evaluation done at the end of the training workshops using the compendiums for short courses indicate that the skills gained, and experiences shared were relevant to improve the capacity of trainees in developing and implementing activities, projects, programmes and policies related to forest and tree-based mitigation and adaptation in their national contexts.

These compendiums and training workshops were largely financed by the Swiss Agency for Development and Cooperation (SDC) and with some contribution from the Swedish International Development Cooperation Agency (Sida).

The development of the compendiums is therefore an evolutionary process that has seen the gradual building of the capacity of many African scientists in developing teaching and training materials for their institutions and the public at large. In a way this has cultivated interest within the African forestry fraternity to gradually build the capacity to develop such texts and eventually books in areas of interest to the continent, as a way of supplementing information otherwise available from various sources, with the ultimate objective of improving the understanding of such issues as well as to better prepare present and future generations in addressing the same.

We therefore encourage the wide use of these compendiums, not only for educational and training purposes but also to increase the understanding of climate change aspects in African forestry by the general public.

Macarthy Oyebo
Président du Conseil d’administration du AFF

Godwin Kowero
Secrétaire exécutif du AFF

Abbreviations and Acronyms

ABM	Adaptation Benefit Mechanism
AFF	African Forest Forum
AMAT	Adaptation Monitoring and Assessment Tool
APF	Adaptation Policy Framework
AfDB	African Development Bank
ASP	Assessing Scaling Potential
BR	Biennial Reports
BUR	Biennial Update Reports
CO_2	Carbon dioxide
CCA	Climate Change Adaptation
CCD	Climate Compatible Development
CIF	Climate Investment Funds
CTCN	Climate Technology Centre Network
CBA	Community Based Adaptation
CRiSTAL	Community Based Risk Screening Tool Adaptation and Livelihoods
CBA	Cost Benefit Analysis
CEA	Cost Effective Analysis
CTF	Clean Technology Fund
CVCA	Climate Vulnerability and Capacity Analysis
UK-DFID	United Kingdom Department for International Development
DIME	Development Impact Evaluation Initiative
DRM	Disaster Risk Management
EbA	Ecosystem Based Approach
EWS	Early Warning Systems
FIP	Forest Investment Programme
GIS	Geographic Information System
GIZ	German Organisation for International Cooperation
GCM	Global Climate Models
GEF	Global Environment Facility
GEFEO	Global Environment Facility Evaluation Office
GFDRR	Global Facility for Disaster Reduction and Recovery
GS	Global Stocktake
GCF	Green Climate Fund
GHG	Greenhouse Gas
INDC	Intended Nationally Determined Contributions
IWRM	Integrated Water Resource Management
IBRD	International Bank for Reconstruction and Development
ICI	International Climate Initiative
ICF	International Climate Fund
IDA	International Development Association
IEG	Independent Evaluation Group
IPCC	Intergovernmental Panel on Climate Change
LDCF/SCCF	Global Environment Facility Least Developed Countries Fund and the Special Climate Change Fund
M&E	Monitoring and Evaluation
MCA	Multi Criteria Analysis
MDB	Multi-lateral Development Bank
MEA	Multilateral Environmental Agreements
NTFP	Non-Timber Forest Products
NAPs	National Adaptation Plans

NAPAs	National Adaptation Programme of Action
NC	National Communication
NDC	Nationally Determined Contributions
OECD	Organisation for Economic Cooperation and Development
PSD	Participatory Scenario Development
PPCR	Pilot Program for Climate Resilience
PSI	Private Sector Initiative
PPP	Public Private Partnership
REDD+	Reducing Emissions from Deforestation and forest Degradation
RBM	Results Based Management
RMS	Results Measurement System
SREP	Scaling up Renewable Energy Programme
SGP	Small Grants Projects
SCCF	Special Climate Change Fund
SFDCC	Strategic Framework on Development and Climate Change
SPA	Strategic Priority for Adaptation
SPCR	Strategic Program for Climate Resilience
SDG	Sustainable Development Goals
TAMD	Tracking Adaptation and Measuring Development
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VRA	Vulnerability Reduction Assessment
WB	World Bank
WRI	World Resources Institute

Executive Summary

The Intergovernmental Panel on Climate Change (IPCC) asserts that there is unequivocal evidence that there have been unprecedented widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere over the last four decades, leading to changes in the Earth's climate. Climate change is a state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Adaptation to the changing climate and associated variability is key for survival of humans and forest ecosystems. This compendium focuses on issues related to climate change adaptation in forest and non-forest-based sectors. The document is divided into four chapters beginning with basic definitions and concepts of adaptation and includes some case studies from the African continent.

In chapter one several concepts related to climate change and adaptation are explained and discussed in detail. These include climate change, extreme events, hazards and risks, resilience, vulnerability, adaptation and maladaptation. Chapter two gives an overview of climate change and climate vulnerability in development sectors. The relationship between forests and people, forest-based adaptation strategies and financing and funding opportunities are also discussed. There are several types of adaptation, varying from those activities done before the climate event to those done after the event. Some are short term measures while others are long term. The chapter also discusses determinants of adaptation and characteristics that determine a systen's ability to adapt. Chapter three discusses importance and types of assets, resources and capital for adaptation. Chapter four discusses how forest and tree-resources respond to climate change and climate variability and the interventions of enhancing resilience of forest ecosystem to cope with impacts of climate change and variability. The chapter also highlights the role of forests in climate change adaptation, appropriate forest-based initiatives that could help forests and people to adapt to climate change and forest-based climate change adaptation interventions. The chapter concludes by assessing the challenges to climate change adaptation and how forest ecosystems services help vulnerable social systems to adapt. Chapter five introduces learners to adaptation strategies and related mechanisms from outside the forest sector. These include the significant role to other sectors such as agriculture, water, health, fisheries and coastal ecosystems, among others. Finally, chapter six deals with concepts and methods of monitoring, reporting and evaluation of adaptation practices in forestry, including adaptation measures to climate change in forestry projects. The chapter also includes methods used for monitoring and evaluation of non-forest-based adaptation options/projects to climate change and climate variability.

Compendium Overview

This compendium seeks to provide technical training for African Forest stakeholders on how to manage forests in a manner that enables them to adapt to climate change. Climate change impacts society and ecosystems in many ways including causing rising sea levels, rising temperatures, rainfall variability, droughts, floods, other extreme events and saltwater intrusions. These climate events result in food insecurity, droughts, increasing pest and disease outbreaks, destruction of ecosystems and infrastructure, migration of species and destruction of habitats. Challenges associated with climate change and climate variability require suitable adaptation mechanisms in physical, ecological, human systems. These include changes in social, behavioural, structural, physiological and environmental processes, perceptions of climate risk, practices and functions to reduce risk, and exploit new opportunities. Behavioural change is one of the key coping mechanisms for physical vulnerabilities. Notable ecological adaptation interventions include managing biodiversity and reducing desertification. Other human/social coping responses include mixed cropping, terracing, crop diversification, water harvesting and irrigation, drought resistant livestock systems, use of early maturing varieties, drought resistant crops, tree planting, adjusting of planting dates and early warning systems.

This Compendium specifically addresses both forest and non-forest-based adaptation mechanisms including the role of forests in climate change adaptation, and how forests and trees adapt to climate change. It introduces learners to the concept of adaptation to climate change, types of adaptation, assessment of forest-based adaptation mechanisms, determinants of adaptation, non-forest based adaptation options, monitoring and evaluation, impact (economic, social, biological) assessment of adaptation, as well as integration of climate change adaptation into development policies and plans. A brief description of each chapter is outlined below.

In **chapter one** several concepts, related to climate change and adaptation, are explained and discussed in detail. These include climate change, extreme events, uncertainity, hazards and risks, resilience, vulnerability, adaptation and maladaptation. Vulnerability can be biophysical (soil quality, water availability, sunlight, CO_2, temperature suitability, and, in some cases, pollinator abundance) or social (social, political, and economic environment). Climate change responsiveness is a determinant of resilience, together with risks and resources and can go beyond the risk discourse with three elements of: the extent of knowledge gains; extent of attitude change; and extent of action or practice. However, when adaptive actions cause greater vulnerability than before, directly or indirectly and/or significantly undermining abilities or opportunities for current and future adaptation, they become maladaptation. Furthermore, developing countries that are poor often face an adaptation deficit, characterised by a failure to adequately adapt to existing climate risks.

In **chapter two** we see that humans and ecosystems exposed to the extreme events are vulnerable. An overview of climate change and climate vulnerability in development sectors and the vulnerability of forests and social systems to climate change. The relationship between forests and people and forest-based adaptation strategies are highlighted. However, the vulnerability of the social or ecological system is a complex of interacting factors and depends on the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. If a system, community or society exposed to hazards can resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures, feedbacks and functions through risk management, it is resilient. Adaptation can be in several forms including being responsive, autonomous, reactive or planned adaptation. Adaptation can also be short term or long term. The main determinants of adaptive capacity are the levels of economic wealth, technology, information and skills, infrastructure, institutions, and equity. Adaptation to climate change impacts also depends on the level of awareness of the risks of climate change and the capacity of individuals/communities to adapt to it. In order to adapt, individuals and communities are therefore motivated by socio economic factors including age, level of education, household size, land tenure, heading family etc. Other factors that could influence adaptive capacity include resources to invest in adaptation, access and ability to process information, flexibility of a system to change in response to climate stimuli, willingness to change and adapt, and the ability of species to migrate or for ecosystems to expand into new zones. Vulnerability is a major factor of adaptation that is determined by adaptive capacity and potential impact (determined by sensitivity and exposure). Characeristics that influence a system's capacity to adapt, such as resilience, susceptibility, responsivess and adaptability, are also discussed.

In **Chapter three** we learn that the socio-ecological systems need to adapt to the extreme events caused by a changing climate through strengthening their resilience. This can be achieved through accumulation of assets, resources and financial resources. There are four forms of capital that can determine how individuals and community can respond to climate change impacts, including natural, human, physical, social and financial capital. Furthermore, climate change adaptation should be mainstreamed into policies, plans, programmes and projects at all levels. Vulnerability of communities is reduced when there is engagement and coordination using various mechanisms, such as providing funding, integrating adaptation into development planning processes and sharing inter-disciplinary information. Funding for climate change normally flows through multilateral channels, within and outside of the UNFCCC financial mechanism and increasingly through bilateral, as well as through regional and national climate change channels and funds. Private sector initiatives can also support climate change adaptation through public private partnerships.

Chapter four discusses forest-based adaptation and shows that there are several ways in which forests and trees can respond to climate change and variability and these can be different depending on the type of forest and geographic location. Temperature, precipitation, carbon dioxide are important factors for plant growth and development and climate change alters optimum requirements for plant growth, which induces stress. Genetic diversity controls inter-specific competitive relationships that constitute fundamental determinants of potential species responses to change, in conjunction with mechanisms of dispersal. Climate change is likely to affect population dynamics, timing of reproduction or migration, and growth of forest ecosystem components. Under a changing climate, forest species can either adapt to climate change, migrate to suitable habitats or become extinct. When climatic conditions go beyond physiological thresholds of species or if the climatic conditions trigger insect pest outbreaks, tree mortality can occur at various levels. Forest resilience can also be linked to the resilience approach to sustainable development where capacities are built to tackle unexpected events and people interact with the biosphere (air, water and land) as one of its components rather than as external drivers of ecosystem dynamics. Management approaches that can build resilience of forest ecosystems include rehabilitation of degraded forests, forest landscape restoration, fire management, creation/expansion and adaptive management of parks/reserves, protected areas, biodiversity corridors, fire management, silvicultural manipulation, pest management, forest governance, nursery techniques and control of invasive species. Invasive species threaten biodiversity by decreasing species diversity, causing economic losses, and can affect human health and livelihoods. Invasive species can spread diseases or release allergens into the air, thus affecting human health. Forest management actions need to be adjusted to build the resilience of forests and trees to the negative impacts of climate change and build and maintain resilient landscapes. Adaptation to climate change in forest ecosystems can be enhanced by exploiting inter- and intra-crop genetic diversity for their resistance to biotic and abiotic stresses resulting from changing climatic conditions. Mixed species forests are an important option for adapting forests to unknown future instabilities such as those from climate change. The role of forest and tree resources is also discussed giving some examples of technological and socio-economic adaptation initiatives. In this chapter we also categorise challenges, gaps and barriers to adaptation. The chapter concludes by highlighting some of the initiatives for adaptation in the African continent, including national determined contributions, adaptation benefits mechanism and other African initiatives.

Chapter five discusses non-forest-based adaptation and includes sectors of agriculture, fisheries, health and sanitation, built environment, energy, transport, water and tourism. Sectoral adaptation initiatives are also highlighted. In the agricultural sector, adaptation strategies include crop diversification, agroforestry, crop rotation, minimum tillage, switching crops, rainwater harvesting, using drip irrigation, etc. All sectors are adapting to climate change through technological interventions such as early warning systems, integrated water resource management, soil and water conservation, building settlements in safe zones, better building designs and ecosystem-based approaches. In other cases, socio-economic adaptation is done through livelihood diversification, improved access to markets, use of indigenous knowledge and practices, social networks and migration. At national, regional or international levels, climate change mainstreaming occurs at all levels. At national levels, countries prepare national adaptation plans for implementation at sectoral levels. Governments coordinate with other development agencies to promote adaptation at all levels with supportive legal frameworks. Finally, the chapter discusses disaster management types and cycle. The chapter concludes by giving some case studies on non-forest adaptation.

Chapter six discusses issues of monitoring, evaluation and reporting of adaptation practices. Monitoring is an ongoing process whilst evaluation takes place at defined intervals and uses data from monitoring. Monitoring and evaluation (M&E) approaches can be community based or project/programme based. Monitoring can be of vulnerability, resilience, adaptive capacity or some indicators. Parameters considered in adaptation initiatives include vulnerability, resilience and adaptive capacity. Several methods are used for M&E, including the Global Climate Fund (GCF) adaptation performance indicators, Global stocktake, Global Environment Facility (GEF) M&E and Climate Vulnerability and Capacity Analysis (CVCA) framework. Tools for M&E include Adaptation Monitoring and Assessment Tool (AMAT), and Community-based Risk Screening Tool – Adaptation and Livelihoods (CRiSTAL) tool. The monitoring and evaluation results are reported, and feedback is gathered in the process.

Learning outcomes

To equip learners with knowledge and skills about adaptation and to design and implement climate change adaptation strategies.

Compendium objectives

At the end of this Compendium, learners will be able to:

i. Explain the concepts and factors of climate change vulnerabilities and risks.
ii. Describe the concepts of adaptation to climate change.
iii. Describe different types of adaptation to climate change.
iv. Distinguish between forest and non-forest based adaptation mechanisms/strategies.
v. Explain the determinants of adaptation to climate change in the context of forestry.
vi. Discuss national and international climate change adaptation policies and strategies.
vii. Design and assess forest-based adaptation strategies to climate change.
viii. Describe adaptation strategies and initiatives outside the forestry sector; and,
ix. Describe the monitoring and evaluation approaches to adaptation.

Chapter 1. Concepts of Adaptation

1.1 Chapter overview

This chapter introduces learners to concepts of climate change adaptation, vulnerability and associated terms such as resilience and resistance, the determinants of adaptation, forest-based adaptation, economic assessment of adaptation and the integration of climate change adaptation into development policies and plans and adaptation financing.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Define operational terms relevant to climate change adaptation.
ii. Define climate change adaptation.

1.2 Definitions and concepts of climate change adaptation

In order to understand the concepts of adaptation, it is important that you get acquainted with the meaning of some key terms and concepts used. These include climate change and climate variability, coping resilience, adaptation, vulnerability and adaptive capacity**.**

Activity 1.1 Brainstorming (15 Minutes)

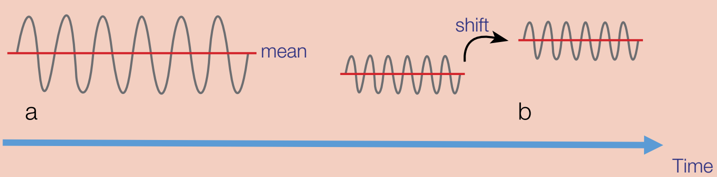
Share your views on the concepts and terminologies used in understanding adaptation to climate change.

1.2.1 Climate change and climate variability

Climate change refers to a state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period of time, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, or to persistent anthropogenic activities that affect the composition of the atmosphere or the land (IPCC 2012). Change is shown as a characteristic of the mean state.

Climate variability refers to the spatial and temporal variations of the climate around an average state at all spatial and temporal scales beyond that of individual weather events. This variability may occur due to natural processes within the climate system (internal variability) or by natural or human external stimuli (external variability) (IPCC 2012).

Which of the following represents climate change and climate variability?



1.2.2 Extreme events

According to McCarthy et al. (2001) and Sillmann et al. (2021), extreme climate events or extreme weather events are events that are unusual at a particular place and time of year. The characteristics of extreme weather may vary from one place to another in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as extreme, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season) (IPCC 2014). Evidence of changes in extremes, such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence is overwhelming and such climate extremes have been observed in every region across the globe (IPCC 2021).

Extreme events, such as heat waves and cyclones, are often embedded within broader sectoral initiatives such as water resource planning, coastal defences, and disaster management planning to facilitate adaptation to climate change (Noble et al. 2014).

1.2.3 Hazards and Risks

A **hazard** is the potential occurrence of a natural (physical event or phenomenon) or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources (UNISDR 2009). In other words, a hazard is the disruption of the equilibrium in the natural event's system (Burton et al. 1993). In this compendium, in addition to the definition given above, the term hazard refers to climate-related physical events or trends or their physical impacts as used by IPCC (2014). A Climate hazard is any physical process or event (phenomena, hydro-meteorological or oceanographic variables) that can harm human health, livelihoods, or natural resources whilst a geophysical hazard refers to natural land processes and events with potential to cause harm to human health, livelihoods, systems, or natural resources (IPCC 2014, Glantz and Pierce 2021).

Risk is a situation involving exposure to danger. It refers to the potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain (IPCC 2014). Climate related risks are created by a range of hazards. Some hazards, such as changes in temperature and precipitation leading to droughts or agricultural losses, are slow in their onset whilst others such as tropical storms and floods are more sudden events (UNFCCC 2020). Emergent risk refers to a risk arising from the interaction of phenomena in a complex system, e.g. the risk caused when there are geographic shifts in human population in response to climate change leads to increased vulnerability and exposure of populations to risk in the receiving region (IPCC 2014), such as the droughts in the Sahel region of Africa.

1.2.4 Uncertainty

Uncertainties relate to situations where it is impossible to exactly describe the state of future outcomes.

In climate change adaptation, uncertainties arise from different sources, e.g. future emissions, natural climate variability, modelling, socio-economic, behavioural and technological responses and ecological dynamics.

Uncertainty can arise from multiple causes and situations: i.e. the shortage or lack of information or abundance of information with conflicting pieces of information, measurement errors, linguistic ambiguity, or the subjectivity of opinions (econadapt-toolbox.eu).

Uncertainty is a condition characterised by indeterminacies and refers to what we cannot know for certain in terms of outcomes, effects or impacts of a particular event where the probabilities cannot be calculated (Walker et al. 2003). It is a condition where there is limited knowledge, making it impossible to accurately explain an existing situation or future outcomes. It is used when predicting future events, to check measurements already done, or to determine the unknown. Examples include growing uncertainties around extreme temperatures, spatial and temporal rainfall patterns as well as droughts, cyclones and floods (Mehta et al. 2019). IPCC (2007, 2014) showed that climate projections are built on an accumulation of uncertainties about the exact values of key physical parameters and these limit their precision for certain purposes including modelling and prediction of adaptation responses. A sophisticated suite of computerised models has been developed to help understand human impacts on climate change. These include Global climate models (GCMs) projecting climate at a coarse resolution, typically 2.5° latitude x 2.5° longitude (77 000 km^2 or larger) and Regional Climate Models (RCMs) or statistical downscaling methods zooming in on smaller areas (at resolutions as fine as 20 x 20 km), using GCMs as input. The models are used to guide practical project and program planning and analysis.

Modelling future climate based on temperature and precipitation is confronted by problems related to many causes of uncertainty, e.g. measurement errors, inadequate knowledge about the climate system, and/or subjectivity of analyst opinion (ECONADAPT-toolbox.eu).

It is important to note that overabundance of information or contradicting information can also lead to uncertainty. Three types of uncertainties are usually considered (Tröltzsch et al. 2016, Kangas et al. 2018):

Epistemic uncertainty: when there is inadequate information or knowledge for characterising phenomena.

Normative uncertainty: When there is no prior agreement on framing of problems and ways to scientifically investigate them.

Translational uncertainty: when there are conflicting or incomplete scientific findings.

The IPCC (2007), however, classifies uncertainties into 'value uncertainties' and 'structural uncertainties'. Value uncertainties arise from the incomplete determination of particular values or results and are generally estimated using statistical techniques and expressed probabilistically. Structural uncertainties arise from an incomplete understanding of the processes that control particular values or results, generally described by collective judgment of authors' confidence in the correctness of a result. In both cases, estimating uncertainties is intrinsically about describing the limits to knowledge and for this reason involves expert judgment about the state of that knowledge. Systems that are either chaotic or not fully deterministic in nature have a different type of uncertainty arising from limited abilities to project all aspects of climate change.

1.2.5 Vulnerability

Interface between Biophysical and social vulnerability

The availability of natural resources has always been important for the well-being of human systems as societies obtain most of the important resources (including food and water) from forested ecosystems (wood for timber and fuel, wild foods, fibre for clothing, medicinal plants for health care and religious purposes, as well as materials for income generating activities). Climate change together with anthropogenic activities can lead to the loss of these natural resources culminating in an increased level of biophysical vulnerability (Macchi et al. 2008).

In terms of climate change, **vulnerability** refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extreme events. It can also be a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007a). Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. The impact of climate change is determined by climate signals, to which a system is exposed and its sensitivity. Potential impacts would be realised if the system had no potential to adjust or if no adaptation measures were taken (Fritzsche et al. 2014, Abiodun et al. 2017). The potential impact is therefore, determined by a system's exposure and sensitivity. The overall vulnerability of a system may be moderated by adaptive capacity. Assessment of the potential impacts of climate change involves evaluation of the magnitude of potential effects of climate change, strictly depending on exposure and sensitivity (Fellmann 2012).

Vulnerability can be stated as either physical or biophysical vulnerability (the degree of, and sensitivity to, damage resulting from special climate-related incidents or disasters) or social vulnerability (the inability of individuals, organisations, and societies to withstand adverse impacts of multiple stressors, due partially to characteristics inherent in social interactions and institutions) (Adger et al. 2004, Thomas et al 2019). Biophysical vulnerability focuses on the nature, frequency and magnitude of the natural extreme event itself and its impacts upon a society's resources. It can also be viewed as the exposure of human systems to natural extreme events and, therefore, to hazard (Burton et al. 1993, Kling et al 2020). Biophysical resources, include soil quality, water availability, sunlight, CO_2, temperature suitability, and pollinator abundance (Myers et al. 2017). Social vulnerability is the product of the social, political, and economic environment shown by the way it structures the lives of different groups of people (Blaikie et al. 1994, Otto et al 2017). Vulnerability, therefore, expresses the complex interaction of different factors that determine a system's susceptibility to the impacts of climate change (Fritzsche et al. 2014).

The vulnerability of countries and societies to the effects of climate change depends not only on the magnitude of climatic stress, but also on the sensitivity and capacity of affected societies to adapt to or cope with such stress (OECD 2009). A community's vulnerability to climate change is, however, determined by factors linked to cultural issues, poverty, health status, political and institutional issues, environmental conditions and processes, including food and nutritional security (IPCC 2007b, Lavell et al 2012). In this regard, socio-economic systems play a role in amplifying or moderating the impacts of climate change, as moderated by social vulnerabilities associated with socioeconomic, cultural and environmental factors (IPCC 2007b). Thus, the drivers of vulnerability include the status of a country (e.g. being a small island developing state or Least Developing Country (LDC)), lack of land, isolation, high-risk location, population growth, nature and land degradation, poverty, food shortages, poor infrastructure, concentration of activities or populations in high-risk areas, low capacity, dependence on natural resources (e.g. rainfall) or economic sectors (e.g. fossil fuels) or processes (e.g. desalination for water), and a poor health sector (UNFCCC 2019).

1.2.6 Resilience

Scale is the extent and/or resolution of a process or analysis, or the level of organisation of a phenomenon or process, e.g. field, farm, region or country (ODI 2016). It can also be used as an analytical dimension of a system, e.g. spatial, temporal, jurisdictional scales (Mock et al. 2015).

For the purposes of this compendium, **resilience** is defined as a system's capability to recuperate after a disturbance. The UN office for Disaster Risk Reduction (DRR) (2009) defined resilience as, "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management." The IPCC (2001) also defined resilience as, "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure, ways of functioning, and the capacity to adapt to stress and change". In a vulnerable system, resilience decreases as vulnerability increases when faced with major disturbances such as those linked to climate change. Furthermore, the resilience of an individual in a community or ecosystem is influenced by the resilience of the wider community, which, in turn, is influenced by national governments, with the resilience qualities manifesting differently at each level (ODI 2016). The processes of resilience, vulnerability, and wellbeing must therefore be analysed from a "multi-level and multi-scale perspective" in order to identify feedback loops and complex interactions among a system's components (Mock et al. 2015).

A resilience approach to sustainable development puts emphasis on building capacities to tackle unexpected events. The approach considers that people interact with the biosphere (sphere of air, water and land) as one of its components rather than as external drivers of ecosystem dynamics. As people use various ecosystem services such as food, water, spiritual or cultural values, they demonstrate their dependence and interaction with the biosphere. A resilience thinking approach attempts to explore best management options for these interrelating systems between people and nature (social-ecological systems) to guarantee a sustainability and resilient provision of necessary ecosystem services that sustain human existence (Simonsen et al. 2015).

Further reading:

Biggs R, Schlüter M, Schoon MI. (eds). Principles for Building Resilience; Sustaining Ecosystem Services in Social-Ecological Systems. Stockholm Resilience Centre. Cambridge University Press. 978-1-107-08265-6-.

Burch SL, Harris SE. 2014. Understanding Climate Change: Science, Policy, and Practice. University of Toronto Press, Scholarly Publishing Division. Chapters 9 and 10.

1.2.7 Coping

Whereas adaptation is the more fundamental change of the system to allow for a new coping range to be established, **coping** is the short-term reaction to variability (Mertz et al. 2009, Rabaiotti and Woodroffe 2019). Acclimatisation is a form of adaptation which occurs all of a sudden through self-directed determinations (FAO 2008).

There are several possible adaptation measures. For human systems, the process involves the engagement and extensive consultation of multiple stakeholders at different levels and in multiple sectors and calls for the analysis of current threats to climate stresses and shocks, and modelling them to predict future climate impacts (CARE International 2009). The process needs an understanding of the prevailing vulnerabilities of individuals, households, and communities. Some of the adaptive measures can be preventive, whilst others respond to changes that already occurred. Some adaptive actions can be initiated by the state, others by private groups or individuals affected. Some activities occur autonomously, while others are planned.

Climate change coping strategies include activities such as taking environmentally responsible actions (this is a potent way to manage and reduce the anxiety); adopting a problem-solving attitude; cognitive re-structuring or reframing; social support-seeking; becoming more attentive to the issue, expressive coping. Other examples of coping measures include the planting of trees and crops that tolerate high temperatures or drought, crop diversification, rainwater harvesting (Kihila 2018), developing communication systems for improving risk management, etc. (UNFCCC 2010). Protecting forested land, grasslands, and wetlands requires governance mechanisms for protecting areas with large carbon stocks, where communities obtain NTFPs. Furthermore, forest protection facilitates soil and water conservation and can enhance crop production resulting in improved resilience to climate change and variability, thus building the coping mechanisms against adverse effects of climate change (Jhariya et al. 2019, López-Vicente and Wu 2019).

1.2.8 Adaptation

Adaptation to climate changes refers to adjustments in ecological, social, and economic systems in response to the effects of changes in climate (Spittlehouse and Stewart 2003)

Adaptation occurs in natural and human systems. In human systems, it refers to the process of adjusting to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, it is the process of adjustment to actual climate and its effects. Human intervention can enable adjustment to expected climate (IPCC 2012) and societies make themselves better able to cope with an uncertain future (UNFCCC 2007). Adaptation focuses on extreme weather events and when the extreme weather events add up over a longer time period, under certain circumstances they can be called extreme climate events. Notably, a weather event categorised as extreme in one region may be very normal in another (IPCC 2012).

Climate change adaptation covers all measures that prepare natural and man-made systems to survive climate change impacts with the least possible damage or are able to take advantage of the potential opportunities presented by climate change (IPCC 2001). There are a wide range of possible adaptation measures.

The adaptation process in human systems requires extensive engagement of stakeholders at multiple levels, in multiple sectors and requires assessment of existing exposure to climate shocks and stresses, and model-based evaluation of future climate impacts (CARE International 2009). Adaptation demands an understanding of the existing vulnerability of individuals, households, and communities. Some adaptive measures are preventative, while others react to changes that have already taken place. Some are initiated by the state, others by private organisations or affected individuals. Some occur autonomously, others are planned. Examples include the use of plants that can better tolerate hot temperatures in agriculture and forestry (e.g. Sahelian agroforestry parklands) (Hänke et al. 2016), the development of communication systems to improve risk management, etc. In this regard, to adapt implies maintaining or strengthening resilience against current disruptions, on the one hand, and being capable of planning for the long term, on the other (Cardona et al. 2012, Zamasiya et al. 2017). An adaptation plan needs to assess each action being considered against its potential for maladaptation.

1.2.9 Maladaptation

This is a process resulting where vulnerability to climate variability and change becomes greater than before, directly or indirectly, and/or significantly undermining abilities or opportunities for current and future adaptation. Many initiatives that have been labelled as climate change adaptation have emerged as maladaptation in both developing and developed countries due to failure to adjust adequately or appropriately to the environment or situations (Magnan 2014). Frameworks for avoiding maladaptation were discussed by Magnan (2014). Examples of maladaptation as outlined by Magnan (2014, 2016) and Chi et al. (2021) include the following:

- Adopting actions that ignore local relationships, traditions, traditional knowledge, or property rights, leading to eventual failure.
- Adaptation actions ignoring wider impacts.
- Adaptation addressing one sector but failing to account for negative effects in other sectors or values of other people.
- Adaptation actions of benefit in the short term but failing in the long-term causing a risk that go with various low-regret activities.
- Neglecting direct and/or indirect drivers of vulnerability.
- Reducing incentives to adapt and retaining traditional responses that are no longer appropriate.

The IPCC (2007) highlighted that the poorest countries often face an **adaptation deficit**, characterised by a failure to adapt adequately to existing climate risks. In order for adaptation policies to work effectively, there is a need to guard against adaptation deficits. As climate change accelerates, the adaptation deficit has the potential to rise much higher unless a serious adaptation programme is implemented.

Activity 1.2 In text Question (5 minutes)
Adaptation producing good results in the short term but failing in the longer term causes a risk that may accompany many low-regrets actions and is a form of maladaptation. Is the statement True or False? Use examples to explain your response.

Summary
In this section we were exposed to basic terminologies related to climate change adaptation and related terms. Climate change was defined as a state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer whilst climate variability shows the spatial and temporal variations of the climate around an average state at all spatial and temporal scales beyond that of individual weather events. Vulnerability is the likelihood that a system or other elements, e.g. individuals, species ecosystem and so on, can be harmed. Vulnerability is explicitly the exposure to hazards and the likely sensitivity of the system exposed to a hazard to be injured or harmed. An element that has potential to cause harm or injury is a hazard. The potential exposure to hazard is referred to as risk. Other terms discussed include extreme events, uncertainty, resilience, coping, adaptation and maladaptation. Vulnerability can be biophysical (soil quality, water availability, sunlight, CO_2, temperature biodiversity) or social (social, political, and economic environment). The process of making adjustments in ecological, social, and economic systems in response to the effects of changes in climate is called climate change adaptation. Climate change vulnerability assessment focuses on species, habitats, or systems of interest, and helps identify their greatest risks from climate change. Assessments can be impact-based or vulnerability-based. A system, community or society exposed to hazards is resilient if it is able to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. Forests are subject to a variety of disturbances that are also strongly influenced by climate change and are affected by changes in their disturbance dynamics. However, when adaptive actions cause greater vulnerability than before, directly or indirectly and/or significantly undermining abilities or opportunities for current and future adaptation, they become maladaptation. Furthermore, developing countries that are poor often face an adaptation deficit, characterised by a failure to adequately adapt to existing climate risks. We concluded by learning that maladaptation occurs when effects of activities to reduce vulnerability to climate variability and change, results in worse situations than before, directly or indirectly and/or significantly, whilst undermining abilities or opportunities for current and future adaptation.

Bibliography for further readings

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Chapter 2. Overview of climate change and climate variability impact on development sectors

2.1 Introduction

Climate impacts are manifested through various forms, among them droughts and floods that result in food insecurity, loss of ecosystem functions and loss of biotic elements which are likely to worsen as climate change progresses. Most of Africa depends on primary sectors such as agriculture and fisheries for food, fibre and income, making vulnerability to climate change evident in these climate-sensitive sectors as they are affected by rising sea levels, increasing temperatures, floods and increasingly variable rainfall (CDKN 2014). AMCEN/UNEP (2002) suggested that rainfall in Africa could decrease by 5% in 2050 and can become more variable year by year, coupled with other climatic variables such as temperature, and humidity radiation. This will in turn directly affect the productivity of agriculture, fisheries and forest ecosystems as vegetative growth, animal production and their development depend on optimum climatic conditions. Increased temperatures are expected to cause increased open water and soil-plant evaporation leading to increased potential evapotranspiration, decreased runoff and reduced soil water.

On the other hand, flooding can result in saltwater intrusion and increased contamination of drinking water, contributing to a range of health problems, including water borne diseases, like diarrhoea, intestinal worms and trachoma (Muoghalu 2014, Bello et al 2017, Liang and Gong 2017). Global warming will also cause rise in sea levels as a result of the thermal expansion of the oceans, caused by rising oceanic temperatures (Conway 2009, Ray and Shaw 2018), impacting on fisheries, aquaculture and coastal farming activities. According to the IPCC (2007), climate change can drive biodiversity loss in tropical forests and several other ecosystems with an average of 15 to 37% of species likely to become extinct by 2050. The result is a shift in vegetation composition, flowering patterns impacting vegetation landscape distribution, which has impact on biodiversity and food productivity due to its effects on pollinators. Rising temperatures increase the likelihood, intensity, sizes and frequencies of wildfire in forests, impacting on biodiversity (Brown et al. 2004, Sultan et al. 2019). In the agricultural sector, changes in rainfall patterns, temperature, CO_2, weeds, insect pests, animal and plant diseases and weeds associated with global warming affect quantity and quality of food produced (Pimentel 1993, Muoghalu 2014, Sylla et al. 2018).

Several sectors of social and economic development are affected by climate change and some of them have developed coping and adaptive strategies to ensure survival. The following sections explore how development sectors are affected by a changing climate and their associated coping mechanisms. The sectors include forestry, agriculture (crops and livestock), water, fisheries, transport, energy, health and sanitation, insurance and tourism and recreation industries.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Describe the vulnerability factors and indicators for assessing the dynamics of the main development sectors affected by climate change.
ii. Describe the vulnerability factors and indicators for assessing the dynamics of the main sectors affected by climate change.
iii. Explain the concept of adaptation to climate change in the context of
iv. forest and people
v. Critically analyse the determinants of adaptation to climate change.
vi. Describe the concepts underlying system's characteristics to adapt to climate change and variability.
vii. Explain compnents of vunerabilty.
viii. Explain factors affecting adaptive capacity.

Activity 2.1 Brainstorming (15 Minutes)

What do you think are the factors that determine the severity of climate change impacts on inidviduals and communities?

2.2 Sectorial impacts of climate change

2.2.1 Forestry sector and climate change

Forests are important for communities as sources of firewood, timber, traditional medicines, staple foods and drought emergency foods, among other benefits. A large fraction of the African population lives in rural areas and depends on forests for their livelihoods (Bélisle 2021, Bottoman 2020). Furthermore, forests, trees and shrubs provide ecosystem services such as water storage and transpiration of water required for precipitation, maintaining soil fertility, carbon sequestration and providing habitats for a diverse array of plant and animal species (Muoghalu 2014, Sannat et al. 2020).

The forestry sector is positively and negatively affected by climate change depending on location and species involved (Singh et al 2020, Kareem et al 2020). Some species will become extinct whilst others will dominate new areas or be suppressed. In most cases, climate change will be an added stress to habitats, ecosystems and species that are already threatened, especially in Africa. This is likely to cause species to migrate and habitats to be reduced (IPCC 2014). Reduction in habitats and other human-induced pressures expose up to 50 % of Africa's total biodiversity to risk (Boko et al. 2007, Buxton 2020, Krumm et al. 2020). The overexploitation of land resources including forests, soils, desertification and land degradation increase threats to biodiversity (UNDP 2006). Furthermore, attacks of forests by pests and pathogens triggered by warming temperatures, increased drought frequency, changes in precipitation and increased CO_2 concentrations affect disturbance patterns and productivity. These changes shape the world's forests and forest sector by increasing the levels of insect herbivory (Currano et al. 2008, Gossner et al. 2021). There may be positive impacts of climate change such as natural selection, succession, natural thinning and canopy gaps.

Climate change affects annual life cycle events such as migration, pollination, dispersal, blooming and reproduction. Most of these are triggered by temperature and other environmental changes. For example, a change in temperature may induce a physiological event, which may not be synchronised with other activities in the ecosystem (IPCC 2014), e.g. flowering and pollinator presence. The climate change and shifts in ecological conditions can also support the spread of pathogens, parasites and diseases, with potentially serious effects on human health, agriculture and fisheries (EPA 2017). Table 1 shows an overview of some impacts of climate change on forests.

Table 1: Impacts of Climate change on Forests

Impacts of climate change on forests (Prutsch et al. 2014)

- Changes in the lifecycles of trees (e.g. leaf fall, flowering and seed production)
- Vitality and productivity of forest ecosystems negatively affected by a combination of rising temperatures and decreasing precipitation
- CO_2 fertilisation effect and longer growing seasons may have a temporary positive impact on timber growth (if the water supply is sufficient) and could affect wood and fibre quality
- Changes in site-suitability for species - thermophilic and drought-tolerant tree species (esp. *Senegali/Vachelia* species) will propagate more widely
- Plants suffer increase in drought stress
- Appearance of non-native, drought- and heat-tolerant harmful organisms
- Greater risk of forest fires because of increased heat waves and droughts
- Potential increase in the frequency and intensity of storm events, leading to a higher risk of wind-related breakage which reduces the productivity of forests
- Late frosts negatively affect tree development
- Decrease in water availability in summer reduces survival rates of young plants
- Increased climate stress can cause destabilisation of protected forests, representing a threat to their protective functionality.
- Increasing pressure from forest pests (e.g., bark beetles, fungi)

Activity 2.2 Brainstorming (15 Minutes)
Discuss the specific vulnerability of forests, trees and people to climate change and vulnerability.

2.2.2 Climate change and the agricultural sector

Climate change is linked to insect outbreaks in Eastern Africa and this has been worsened by lack of preparedness, chronic political instability and limited capacity for the African countries (FAO 2020a, Salih et al. 2020). In 2018, two cyclones (in May and October) from the Indian Ocean created conducive breeding ground for dessert locusts, and the first-wave of infestations in East Africa was at the end of 2019, destroying 70,000 ha of farmland in Somalia and Ethiopia (Kennedy 2020). In this regard, global warming played a role in creating the conditions required for the development, outbreak and survival of the locusts (Meynard et al. 2020).

The agricultural sector is one of the sectors adversely affected by climate change and climate variability. It is the main source of food, income and employment and therefore, effects of climate change and variability has implications on global food supply. The agricultural sector supports 80 % of the population's livelihood in arid and semi- arid areas of Africa (FAO 2016a). Humans are mainly linked to land, through agriculture and forestry activities, that also have significant impact on the Earth's functional systems. Agriculture has always been a key sector targeted for adaptation and mitigation activities that address climate change issues while ensuring food security for a growing population (Cline 2007, Makate et al. 2019, Ampaire et al. 2020). Climate change affects productivity of agricultural systems through droughts, frost, floods and other extreme events such as cyclones that can damage crops, livestock and human life The impacts of climate change are more severe for those who totally depend on rain-fed activities (Ludena and Yoon 2015, Pereira 2017, Coulibaly et al. 2020). Furthermore, the African continent is expected to see an increase in crop pests and diseases in response to variations in temperature and precipitation, in addition to poor soil fertility (FAO 2009).

Agricultural production is expected to decline between 8-37% in some parts of Africa, mostly affecting small-scale farmers (Schlenker and Lobell 2010, Thornton 2011). Climatic conditions such as extremely high/low temperatures and precipitation can prevent crops from growing well although increases in temperature and CO_2 can result in increased yields of certain crops. Although rising CO_2 levels can promote growth of plants, it can reduce nutritional values of most food crops. For example, increased atmospheric CO_2 levels can reduce protein and essential mineral concentrations in some crop species, such as rice, wheat and soybeans (Myers et al. 2014, Zhu et al. 2018). Furthermore, there are many pests, weeds and fungi that thrive under the wetter conditions, warmer temperatures and increased CO_2 levels (Ziska et al. 2018). In order to adapt, developing countries need effective support based on a grounded understanding of the real drivers of marginalisation and food insecurity. A study in Kenya by Owino et al. (2020b,c) showed constraints to smallholder farmers' adaptation to climate change and the information sources that offer the highest opportunity for adoption. A study in Botswana by Moseley (2016) showed that international efforts to support climate change adaptation will have a limited effect on smallholder farming livelihoods and rural food security unless such efforts take account of political and economic constraints.

The CO_2 fertilisation effect causes a possible increase in plant growth occurring as a result of excess atmospheric CO_2 as plants use the CO_2 for growth during photosynthesis. The types of plants that are likely to benefit are those having C3 photosynthetic pathway, for example, wheat and potatoes, whereas those with a C4 pathway, such as maize, cassava, and sugarcane will not benefit. The fertilisation effect, however, varies between species and also between regions, as studies showed that about 50–70% of yield variability was attributed to crop responses to elevated CO_2 and climate (McGrath and Lobell 2013).

It is important to note that in Africa, agriculture and forestry are some of the main contributors of GHGs. This means that as we address adaptation, we must bear in mind the contribution of Agriculture, Forestry and Other Land Uses (AFOLU) to global warming and hence climate change.

2.2.3 Climate change and the water sector

The water sector will be affected differently in different parts of Africa. East Africa is at higher risk of flooding and associated infrastructure damages and health impacts whilst southern Africa is expected to have the greatest reduction in precipitation with risks of drought (Serdeczny et al. 2016, Nyiwul 2019). Water resources are therefore closely linked to climate change and are a product of the balance between amount of rainfall and snow that falls into catchment areas recharging ground water, resulting in changing groundwater tables or levels (Taylor et al. 2013) and water that is lost through evaporation. Increase or decrease in rainfall in the wet season affects other sectors resulting in significant economic impacts due to vulnerability of crops/livestock to drought or floods.

Increased evaporation and decreased precipitation can lead to decreases in available soil moisture to plants, consequently affecting crop yields and food security. MacDonald et al. (2012) showed that many parts of rural Sub-Saharan Africa depend on groundwater as the sole source of safe drinking water. Increased evaporation and variability of precipitation implies decreases in available soil moisture to plants and this eventually affects crop yields and food security. Furthermore, there will be a reduction in water yield of near-surface springs.

Too much water in the form of floods makes people vulnerable to flood risks and pollution (Prutsch et al. 2014, Bai et al. 2018, Okaka 2020). Floods can cause contamination of drinking water whilst rising temperatures can increase surface water temperature which is associated with disease transmission. Furthermore, reduced precipitation and increased evaporation can lead to reduction in water yield of near-surface springs thus affecting stream flows and availability of water (Zhang 2015, Polley et al 2017, Nkhonjera 2017).

> *Climate change impacts on the African continent will include increasing water scarcity and stress with potential increase of water conflicts in almost all its 50 transboundary river basins* (De Wit and Stankiewicz 2006).

Integrated water resource and watershed management activities in Africa have been implemented and they show the link between water resources and other sectors of development mainly the forestry sector where trees are instrumental in catchments area protection as is the case in many water towers. According to UNDP (2018), some communities in some countries in Africa have implemented watershed rehabilitation and management. These countries include Ethiopia: through integrated soil and water conservation, Rwanda: through tree planting on uncovered slopes, terracing of muddy land, water retention barriers and opening of trenches, and Zimbabwe: through building or rehabilitating low-cost adaptive infrastructure such as conservation agriculture, product diversification (i.e. aquaculture, bee-keeping), improved water and soil fertility management, confined pastures, feedlots and agroforestry. Trees in catchment areas, reduce erosion, improve infiltration and create conducive microclimate.

Further reading

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2.2.4 Climate change and the health sector

The health sector in Africa is also affected by climate change and variability because of the vulnerability of its population that varies among regions and communities due to differences in socio-economic conditions, geographical positions, existing health infrastructure, microclimates and underlying epidemiology (UNFCCC 2007, Chersich and Wright 2019, Wright et al. 2021). The impacts of climate change can be direct due to extreme temperatures or precipitation, UV related cancers and diseases and air quality (UNECA 2011). Indirect impacts of climate change to human health are those related to non-human biochemical or biological systems, e.g. crop yields, distribution of infectious diseases or social impacts resulting from climate change. Climate change also exacerbates several climate sensitive diseases such as malaria, diarrhoea and tuberculosis (Guernier et al. 2004, Mordecai et al. 2020).

Rising temperatures cause changes in geographical distribution of some disease vectors that can migrate to new areas and higher altitudes - for example, the malaria mosquito migrating to higher altitudes and exposing many people who were not previously exposed to infection especially in the densely populated areas of east African highlands (Boko et al. 2007, Bryson et al. 2020). Expected climate variability will interact with other vulnerabilities and stresses such as HIV/AIDS (already affecting lives of many), wars and conflicts (Harrus and Baneth 2005), to increase susceptibility and risk to infectious diseases (e.g. cholera) and malnutrition for adults and children (WHO 2004, Ramirez 2017, Githeko 2021).

Climate change impacts on the African continent will include increasing water scarcity and stress with potential increase of water conflicts in almost all its 50 transboundary river basins (De Wit and Stankiewicz 2006).

Forests provide direct and indirect benefits that are important for human health and wellbeing, especially for poor communities who depend on wild food and medicinal plants for their survival (Dhlamini 2019). FAO (2020b) stated that even commercial pharmaceutical products, including drugs used for prevention of diabetes, malaria, treatment of cancer, and prostate conditions, are plant based. Although some of the drugs are synthesised, some are traditional medicines. Of the traditional medicines, about 60 % are collected from the wild.

UNEP (2016) showed that about 60 % of all human infectious diseases are zoonotic, i.e., able to infect other host species and 75 % of all emerging infectious diseases originate in animals. The chances for pathogens to jump from wild and domestic animals to people has been exacerbated by global changes, including land-use change, encroachment of humans into forests and other wild landscapes, deforestation and habitat erosion, and globalisation of wildlife trade with inadequate regulation (FAO 2020c). Ebola, HIV and COVID-19 are linked to wild animals and originate from the forests (Andersen et al. 2020), for example, through loss of bat habitat through deforestation and agricultural expansion (UNEP 2016). Ebola outbreaks in West Africa have been linked to forest loss (Olivero et al. 2017). UNEP (2020b) outlined six important facts about infectious disease outbreaks and emphasised that ecosystem integrity underlines human health and development as human-induced environmental changes modify wildlife population structure and reduce biodiversity, resulting in new environmental conditions that favour hosts, vectors and/or pathogens.

2.2.5 Climate change and the infrastructure

Besides social conflicts and pollution, increased occurrence and magnitude of weather disasters continue to pose problems in settlements, infrastructure and industry. Tropical cyclones and flooding events can cause severe damage and cause loss and damage to property (Pudyastuti and Nugraha 2018). In Africa, the population in urban areas is relatively low (47%) but is likely to rise and pose more problems (Stapleton et al. 2017, Mngumi 2020, Saleh 2021). This may be worsened by people migrating from rural areas to urban areas in search of better livelihoods.

Climate change and variability will also affect physical infrastructure and the housing sector as a result of higher frequency of tropical cyclones and heavy rainfall that will affect the capacities of rainwater and waste-water systems such as gutters and sewage treatment plants (Pudyastuti and Nugraha 2018, Crick et al. 2018). The increase or reduction in temperatures requires changes in the design of housing to improve heating and cooling systems. Furthermore, there are chances of increased heat stress and deteriorating indoor conditions due to higher concentrations of pollutants inside buildings or sealing/insulation measures. Green infrastructure (e.g. green roofs, urban parks and porous pavements) can improve storm water management and reduce flood risk in cities, and can moderate the heat-island effect, as well as providing some co-benefits for mitigation (Noble et al. 2014, Basyouni 2017). The practice of urban/social forestry can go a long way in reducing impacts of heat island stress and thus positively impact human health.

2.2.6 Climate change and the transport and energy sector

Chinowsky et al. (2015) and Feikie et al. (2017) showed that climate change impacted road infrastructure in Malawi, Mozambique, South Africa and Zambia require more than US$596 million to maintain and repair roads as a result of damages directly related to temperature and precipitation changes from potential climate change through 2050. Climate change impacts caused US$151.4 million damages in Kenya (Njogu 2021). The unpaved roads are susceptible to increases in precipitation.

Transportation systems are crucial for ensuring the efficient distribution of food, energy, and trade, as well as facilitating movement of workers and consumers to access their jobs and markets respectively (Pudyastuti and Nugraha 2018, Faiyetole 2019). The transport sector encompasses road, rail, air and marine transport and it is a significant enabler of most business activities as virtually all other sectors rely on transport infrastructure. Roads for example, signify a lifeline for economic, agricultural and ecological livelihoods, together with other indirect benefits such as access to education, healthcare, credit, political participation, etc. (Twerefou et al. 2015, Fuentes-Lillo 2021). Roads passing through geographic locations can be few, making each road critical for access to services and other areas. Climatic events such as high temperature, storms, heavy rains, cyclones, hurricanes and sea-level rise can destroy transport infrastructure including roads, bridges, ports and airports (Pudyastuti and Nugraha 2018, Lane et al. 2020, Njogu 2021). Extreme events present an expensive hazard to road infrastructure in terms of degradation, required maintenance, and potential reduction of the road lifespan resulting from climatic impacts (Schweikert et al. 2014, Roy and Alam 2020). Higher temperatures soften and expand pavements, creating rutting and potholes and warping of rail tracks. In this regard the risks of climate change to roads threaten the associated development, economic growth, and socio-economic benefits of infrastructure expansion (Chinowsky et al. 2015, Nkonya et al. 2018, Chakwizira 2019).

In the energy sector, fossil fuels, including oil, coal and natural gas provide between 70 and 90% of global energy consumption (Darwishi et al. 2016, York and Bell 2019). The energy sector is among the greatest contributors to emissions through their combustion, which releases GHGs and other pollutants (IPCC 2011, Abdollahi 2020). However, the sector is also impacted by climate change as the increase or decrease in temperature leads to more energy requirements for cooling or heating. The reduction in rainfall affects power generation whilst abundant rainfall is associated with interruptions in power supply, e.g. due to trees falling on power lines creating disruptions (Pudyastuti and Nugraha 2018, Boadi and Owusu 2019).

2.2.7 Climate change and the tourism sector

Tourism is a social, cultural and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes. Activities in the tourism sector are in the form of leisure and recreational travel, including coastal and beach tourism (UNWTO 2018). Climate change affects the tourism sector as conditions of heat, rainfall, snow or extreme events can harm tourists or prevent them from visiting. Climate change affects tourism assets, such as biodiversity, glaciers, coral reefs and cultural heritage sites, apart from the fact that tourism itself can cause an increase in resources degradation (Lemelin et al. 2012, Pandy 2018, Scott et al. 2019). Sea-level rise and more acidic oceans will threaten coastal tourism infrastructure and natural attractions. Rising temperatures will shorten winter sport seasons and threaten the viability of some ski resorts. Climate change will lead to changes in biodiversity due to shifting ecological zone either becoming too wet or dry thus, affecting eco-tourism (Nicholls 2014, Sintayehu 2018). Changing precipitation will affect water availability and affect holidays which are scheduled for favourable weather conditions.

Extreme weather events are likely to become more common, disrupting travel and damaging infrastructure, and insurance is likely to become more expensive or even unavailable (Nicholls 2014).

Climate change affects the demand for, and availability of, energy and water for the tourism sector. Some organisations, such as Conservation International, have supported the development of nature-based tourism to alleviate poverty and conserve biodiversity (Conservation International 2016).

Activity 2.3 Revision
Explain how climate change impacts affect different sectors of development.

Summary
In this section we have learnt that all social and economic development sectors are affected by climate change and its variability. The African continent is dependent on primary sectors such as agriculture, forestry and fisheries for food, fibre and income, making vulnerability to climate change evident due to the sensitivity of the sectors to climate change. These sectors are affected by rising sea levels, increasing temperatures, floods, cyclones and increasingly variable rainfall.

2.3 Vulnerability of forests and social systems to climate change

Forests are vulnerable to changing climate, but they can also be important for humans and ecosystems to adapt to climate change. Forests as means of climate change adaptation is shown when forests become key in adaptation of societies to climate change by providing ecosystem services, reducing social vulnerability and contributing to human well-being (Seppälä et al. 2009, Staal et al. 2020). Forests affect rainfall interception, infiltration, evapotranspiration and groundwater recharge. They regulate base flows during dry seasons and peak flows during rainfall events, services that are important for improving people's adaptation to climate variability and change. Furthermore, forests prevent erosion and landslides by stabilizing the soils and further reducing negative impacts of climate hazards on infrastructure, water supplies and settlements. Forested watersheds regulate water and protect soils to reduce climate impacts (Pramova et al. 2012, Ellison et al. 2017, Wei et al. 2018). Deforestation and forest degradation exacerbate the effects of climate change.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Describe the vulnerability factors and indicators for assessing the dynamics of the main sectors affected by climate change.

ii. Explain the concept of adaptation to climate change in the context of forest and people.

Activity 2.3 Brainstroming (10 Minutes)

Explain the link between deforestation and human livelihoods.

Climate related disturbances influence the structure, composition and functions of forests (Dale et al. 2001, Sonwa 2018, Pfeifer et al. 2018). The changes in the function or structure of natural ecosystems and planted forests due to climate related hazards or events, adversely affect productive functions of forest ecosystems, which subsequently can also impact local economies (Weiskopf et al. 2020). Forests are exposed to several disturbances that are strongly linked to climate and are expected to increase susceptibility of forests, depending on their frequency, duration, intensity and timing. Climate change will also change the disturbance patterns of native forest insect pests and pathogens and facilitate the establishment and spread of alien pest species.

On the other hand, forests need to adapt to climate change because it is one of the main drivers of forest growth and development. Forests are affected by any changes in their disturbance dynamics (Seppälä et al. 2009, Kulakowski et al. 2017). Direct impacts of climate change on trees in natural or planted forest ecosystems include destructions/deaths after a flood or drought event, increased fuel loads (including carbon induced growth), extended fire seasons/prolonged dry season, and increased forest fire activity (Mortsch 2006, Luo et al. 2018). Storms can cause severe windfall attracting pest insect populations, for example, bark beetle (*Ips typographus*) outbreaks in Europe. Forests also need human interventions for reduction of negative climate change impacts.

Furthermore, when forests are disturbed, biodiversity is also disturbed. Climate change related stress threatens biodiversity conservation in several ways (Table 2). Forest fires are likely to

Table 2: Impacts of climate change on biodiversity

Impacts on biodiversity (Prutsch et al. 2014)

- Lifecycles of plants and animals are changed (e.g., migration and breeding behaviours, foliage, flowering)
- Facilitation of the establishment of non-native species
- Thermophilic species can be propagated
- Cold-sensitive and moisture loving species can be displaced
- Gene pool depleted due to population failure, leading to reduced adaptive capacity
- Ecosystem functions adversely affected, e.g. protective functions of forests
- Aquatic ecological communities, especially fish ecology affected by increase in temperature
- Alterations in aquatic vegetation caused by increased temperatures
- Increased desiccation of wetlands and marshes.
- Species composition in ecosystems changes (e.g., predicted shifts in distribution limits towards the north and higher elevations)
- Limited adaptive capacity threatens biodiversity

be more intense due to factors stated above but the ecological impacts of forest fires vary with forest types, climatic and geographical regions, coupled with other disturbances (agriculture, encroachment or fragmentation and infrastructure development, grazing, harvesting fuelwood and other Non-Timber Forest Products (NTFPs), illicit felling, invasive species, and numerous other pressures). The ability of forests to withstand and recover from the different stresses depend largely on how the disturbance pressures are managed (Heikkilä et al. 2010, Stevens-Rumann et al. 2018, Piper and Paula 2020).

Activity 2. 4 Revision (10 minutes)
Describe the relationship between humans, ecosystems and climate.

2.3.1 Vulnerability assessments

Vulnerability assessment entails a practice of identifying, measuring and ranking the vulnerabilities of a system. Climate change vulnerability assessment focuses on species, habitats, or systems of interest, and helps identify their greatest risks from climate change **impacts. Results of the assessments are usually used to inform decision makers and to support processes of adaptation. The recommended adaptive measures aim to enhance the ability to resist or avoid harmful consequences of climate change (OECD 2009**, Schilling et al 2020). Units of analysis for vulnerability assessments are based on places, institutions and people (Figure 1). The central concern of vulnerability assessment is to protect people from the adverse consequences of present climatic variations and dangerous climate change. People depend on resources (land, water, ecosystems) and are organised into socio-economic groups (whether organisations, sectors or institutions).

Assessment for social-ecological systems is based on two main approaches: *impact-based approaches* that start with the assessment of potential impacts of climate change on forests or forest dependent people under different climate scenarios, and *vulnerability-based approaches* that start with assessment of social sensitivity and adaptive capacity to respond to stresses and, if necessary, this information can be combined with impact studies (Kelly and Adger 2000, Khan et al 2019).

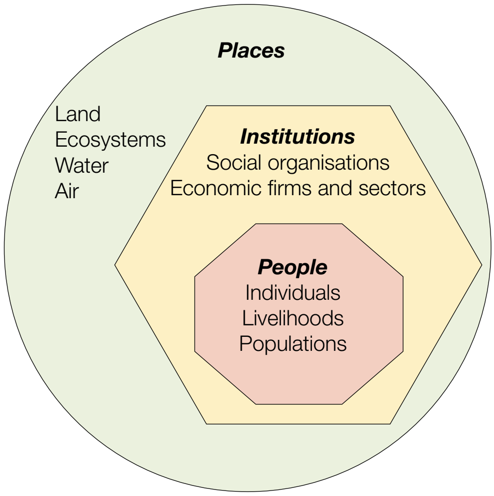

Figure 1. Units of analysis for vulnerability assessments (Downing and Patwardhan 2002).

The vulnerability-based approaches determine vulnerability based on existing capacity instead of using any predicted future impacts (Ribot 2009, Karimi et al. 2021). Fritzsche et al. (2014) and, Karimi et al. (2021) showed that vulnerability assessments fulfil the purposes of:

- Identifying current and potential hotspots,
- identifying entry points for an intervention, and
- tracking changes in vulnerability and monitoring and evaluation of adaptation.

Summary

We have learnt that socio ecological systems need to adapt to the extreme events caused by changing climate by coping and strengthening their resilience. Humans and ecosystems exposed to the extreme events are vulnerable. The vulnerability of the social or ecological system is a complex of interacting factors and depends on the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. Climate change related impacts affects forest ecosystems and the biodiversity they contain. The effects on biodiversity will also affect humans who rely on forests for timber and non-timber forest products.

2.4 Adaptation to impacts of climate change and climate variability

We have learnt that climate change adaptation is the process of adjusting to current or expected climate change and its impacts/effects, along with mitigation. Climate change impacts have been demonstrated through rising sea levels, increased temperatures, rainfall variability, floods, droughts, saltwater intrusion etc. We have already learnt how climate change affects different sectors of development. In order to survive, humans and ecosystems need to adapt and cope with climate change. Adaptation shows how individuals, communities and nations strive to moderate and cope with the impacts of a changing climate and its variability. In this section, we discuss the types and determinants of adaptation, characteristics of a system's capacity to adapt, adaptation and development and related financing mechanisms.

Learning outcomes

By the end of this session, the learner should be able to:

i. Explain the determinants of adaptation to climate change.
ii. Describe the concepts underlying a system's characteristics to adapt to climate change and variability.
iii. Relate forest-based climate change adaptation into development policies and plans.
iv. Explain adaptation financing mechanisms relevant to the forestry sector in Africa.

Activity 2.5 Brainstorming (10 minutes)

Describe the approaches used to adapt to climate change in your country.

2.4.1 Types of adaptation

Adaptation can take place before, during and after future events that may be expected as a result of climate change. IPCC (2001) distinguishes several types of adaptation: anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation. Measures taken now in anticipation of climate change are anticipatory whilst those taken in response to current extreme events are reactive. Adaptation during climate change has been described as gradual, stepwise and short-term.

Article 6 paragraph 8 of the Paris agreement states that *"Parties recognise the importance of integrated, holistic and balanced non-market approaches being available to Parties to assist in the implementation of their nationally determined contributions, in the context of sustainable development and poverty eradication, in a coordinated and effective manner, including enhancing public and private sector participation in the implementation of nationally determined contribution and enabling opportunities for coordination across instruments and relevant institutional arrangements" (UNFCCC 2015).*

The Paris Agreement (2015) established, for the first time, a global adaptation goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal". The goal provides additional context for vulnerability assessments and adaptation actions by governments and other actors. Although the Paris agreement encourages Parties to strive towards achieving their targets for reducing greenhouse gas emissions as specified in their Nationally Determined Contributions (NDCs), there is evidence that adaptation efforts are also recognised. The GHG emissions are mainly from sectors of energy supply, industry, transport, waste, buildings, agriculture, land use and forestry (UNFCCC 2019). All sectors of development are expected to adapt to the impacts of climate change, with some activities done before and others done after a climate change event. Several types of adaptation are implemented to cope with climate change impacts and will be discussed in the following sections.

Anticipatory adaptation

Adaptation that takes place before impacts of climate change are observed is described as anticipatory, preventive, proactive, or long-term. Anticipatory adaptation is more likely to reduce the long-term damage, risk and vulnerability due to climate change as it involves long-term decision-making, which improves the ability to cope with future climate change (IPCC 2007a). Periodic assessment and risk management strategies help make this response the most effective. Decisions for anticipatory adaptation incorporate flexibility, discounting future costs and benefits and projecting future conditions. In the short term, activities focus on managing climate variability whilst in the long-term they address both the present and the future, e.g. ecosystem conservation (World Bank Group nd). For example, local authorities can prevent construction of houses in areas prone to flooding in the long term, build flood resistant houses, raise floor level of houses above expected flood levels, use flood resistant materials for construction or using a combination of these (Cement Concrete & Aggregates Australia 2011). Or, forestry authorities can ban logging on fragile areas/slopes as a control measure against landslides. Aerial seeding in hard to access areas can also be done to regenerate degraded areas to assure service functions of the forests.

> Anticipatory adaptation and decadal climate projections can potentially enhance flexibility in adaptation planning, allowing communities to adequately respond to climate variability and other challenges, as well as reduce chances of maladaptation in responding to climate challenges in the context of multiple and reinforcing stresses and shocks (Nyamwanza and New 2016).

Stern (2007), Weitzman (2007) and Zhang and Welch (2021) advocated for the use of low and declining discount rates to assess climate-sensitive decisions that involve intergenerational trade-offs at the global level. Some aspects, such as investments with environmental or health impacts are not ordinarily considered in discounted value frameworks because they require spontaneous responses.

Autonomous adaptation

This refers to adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems (Adhikari et al. 2011, Mersha and van Laerhoven 2018). Also referred to as spontaneous adaptation, it is usually unplanned consequential adaptation of both natural and human systems (IPCC 2007a, Malik et al. 2010, Pecl et al. 2019). Autonomous adaptation includes widely considered initiatives by private actors instead of governments, thus it is related to private adaptation, and planned adaptation to public adaptation. Autonomous adaptation is often overlooked in international and national efforts to manage the impacts of climate change (Fazey et al. 2010).

Autonomous adaptation is driven by how environmental change and resource scarcity present livelihood risks, and market or welfare changes in human systems rather than physical risks alone. It might include practices such as altering agricultural inputs and cropping cycles, introducing water-managing technologies, or diversifying economic activities (Malik et al. 2010, Khalil et al. 2020). Activities can be based on pre-existing ‘risk-management or production-enhancement activities’, but which have substantial potential to offset negative climate change impacts and take advantage of positive ones (Fazey et al. 2010, Singh et al. 2020).

Reactive adaptation

This is adaptation that takes place after impacts of climate change have been observed and it is described as corrective. Extreme events will be a feature of climate change in the future, suggesting importance of improving responses to similar events in the present. Reactive adaptation reduces vulnerability, increases resilience and strengthens adaptation capacity. Responsive adaptation activities, interventions or adjustments can be categorised into processes that aim at creating or enhancing; (i) resilient and improved livelihood outcomes, (ii) resilient and productive ecosystem conditions, and (iii) supporting governance conditions. For example, after a destruction of houses by a cyclone, all houses could be upgraded to new stronger building standards/codes that local people are familiarised with and/or receive practical training on (Sousa-Silva et al. 2018, Chatiza 2019).

Private and public adaptation

Private adaptation is initiated and implemented by individuals, households or private companies only for their benefits. Private adaptation is usually in the actor's rational self-interest (IPCC 2001, Mitter et al. 2018). An example could be the constructing of small weirs by individuals to ensure water availability during a dry spell. There is also some private adaptation with public benefit when an individual or business initiates an activity that is of benefit both to that individual or business but also to the public more broadly. For example, runoff and erosion control can maintain the viability of the field whilst reducing the impact on the environment. Public adaptation is initiated and implemented by governments at all levels and is usually directed at collective needs (IPCC 2001, Amare 2021).

Tree planting activities on an individual small plot may help the landowner get microclimate benefits. However, on aggregate, many small farms combined practicing any form of community forestry can have a large impact on the environment of an area and thus contribute to private and public adaptation.

Planned adaptation

Planned adaptation is adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state. It involves deliberate, anticipatory interventions at different levels and across sectors (IPCC 2001, Fazey et al. 2010). According to Füssel (2007), planned adaptation is the use of information about present and future climate change to review the suitability of current and planned practices, policies and infrastructure. In forestry, planned adaptation can involve redefining forestry goals and practices in advance in view of climate change-related risks and uncertainties. At the community level, planned adaptation may include diversification of forest- and non-forest-based income sources, better local governance of forest resources and capacity building for monitoring and coping with possible calamities of unprecedented extent. Within the industrial forest sector, planned adaptation may involve the inclusion of bioenergy as a product or the promotion of wood products for their low carbon footprint.

At national and global levels, planned adaptation can include timely monitoring and reporting systems and the development of tools for vulnerability assessments and adaptation planning (IPCC 2001, Mersha and van Laerhoven 2018). To deal with environmental issues, countries are embracing green growth and circular economy. Adoption of green growth strategies and technologies in forestry can be seen as part of planned adaptation.

Activity 2.6 Revision

Using examples, explain types of adaptation.

Summary

In this section we learnt that forests are important for ecosystem health. When forests are disturbed by climate change, they cannot be able to provide the services that they normally give. Disturbances caused by climate change affect the survival of humans and ecosystem components. All sectors of development are expected to adapt to the impacts of climate change, with some activities done before and others done after a climate change event. There are several types of climate change adaptation, including responsive, autonomous, reactive, or planned, private or public adaptation. Adaptation can also be short term or long term. Planned adaptation can involve redefining goals and practices in advance in view of climate change-related risks and uncertainties.

2.5 Determinants of adaptation

2.5.1 Introduction

In the previous section we learnt about types of adaptation. The main determinants of adaptive capacity include the levels of economic wealth, technology, information and skills, infrastructure, institutions, and equity. Adaptation to climate change impacts depends on level of awareness of the risks of and the capacity of individuals/communities/ecosystems to adapt to it. This can be enhanced through provision of relevant information to the vulnerable population about the risks and consequences of climate change. The later involves technical developments and government support. In this section we will learn about socio-economic determinants of adaptation.

Learning outcomes

By the end of this session, the learner should be able to:

i. Critically analyse the determinants of adaptation to climate change.
ii. Describe the concepts underlying system's characteristics to adapt to climate change and variability.

Activity 2.7 Brainstroming (10 Minutes)

What are some of the socio-economic factors that determine capacity of one to adapt to climate change?

2.5.2 Socio economic determinants of adaptation

Socio-economic factors affect the capacity and efficiency of one to adapt. Adaptation deficit occurs when there is failure to adapt effectively to existing climate risks largely affected by socio-economic determinants such as age of household head, gender, education level, access to credit, among others (Deressa et al. 2009, Othniel and Resurreccion 2013, Ludena and Yoon 2015, Belay et al. 2017, Enimu and Onome 2018, Mequannt et al. 2020). These are explained below:

Households' heads age - depending on locality, there are several views of effects of household head's age on adaptation. Some studies found that as household head age increased willingness to adopt adaptation strategies decrease whilst others found a positive association of age with adaptation to climate changes. Older farmers may be more conservative and more risk-averse compared to younger farmers, resulting in a lower likelihood of adopting new technologies by the older generation.

Gender – similar to age of household head, gender has no universal response. In Nigeria, male household heads took adaptation measures better than their female counterparts. This difference was influenced by the fact that male headed households were often considered to be more likely to get information about new technologies and take on risk more than households headed by women. On the other hand, households headed by women are more likely to take up climate change adaptation methods, which can be attributed to willingness of women to change their livelihood strategy in an effort to support their families.

Household size - increased family size and age of household head had a detrimental impact on the farmer's adaptive capacity. Farmers are more vulnerable when their families are big because a unit increase in the household size reduces the likelihood of responding to climate change. This is because a big family has high consumption demands, putting a great strain on little resources available during drought periods. As a result, some families may be compelled to transfer some of their work force to non-farm activities in order to make ends meet.

Educational level - there is a strong relationship between educational status of household head and the probability of adopting adaptation measures. This implies that the number of years spent schooling, by the head of household will result in a higher likelihood of adapting to climate change.

Farming experience - farming experience positively relates to the probability of adopting adaptation measures. More years of farming experience lead to greater likelihood of adopting adaptation measures. Most farmers in African countries have observed and experienced long-term increased temperatures, declining and change in precipitation patterns and increases in drought frequencies as a results of climate change. They are likely to develop intricate and complex systems based on first-hand knowledge on weather and climate variability, as well as climate change over time.

Membership of cooperative - belonging to a cooperative increases the likelihood of adopting adaptation as members of such have high awareness of climate risks and better adaptive capacity. Membership can also help to sensitise the farmers on ways of adapting to effects of climate change.

Access to credit - credit provision solves financial constraints of farmers enabling them to invest in adaptation technologies. Access to credit increases the likelihood that farmers will take up adaptation innovations such as diversification and buying feed supplements for livestock. In the case of forestry, farmers are likely to buy fast maturing improved tree seedlings for planting if they have acesss to credit.

Farm/herd size - farm size determines the diversity of activities that can be done, with larger farms promoting diversification. Diversification improves access to market and basic food and improves resilience to climate shocks compared to farmers who practice either crop or livestock production only. Small land size and limited resources to enhance diversification makes farmers more vulnerable to climate risks.

Household income and poverty – developed nations are better able to adapt than developing countries because they have resources to invest and offset the cost of adaptation. Poverty reduces adaptive capacity. There is a positive relationship between farm income and adoption of soil conservation practices, use of different crop varieties and adjustment in planting date in combating climate change effects. Diversification of income sources may be a good strategy to reduce resource dependency and vulnerability of individuals at the household level but can also increase vulnerability by reducing specialties and entrepreneurial innovations for promoting the produce outside local areas by increasing the cost of production.

Access to weather information and extension services - awareness and perceptions of changes in climatic conditions shape responses to risks associated with a changing climate. Knowledge about climate change increases the probability of adaptation. Improved extension services that provide technical support on agriculture, on farm forestry and climate change services will significantly reduce vulnerability to climate risk. Farmers need to be educated on the vulnerability of specific species/crops and the appropriate species/crop mix, including drought-resistant breeds/crops and appropriate trees on farm so that they can adopt appropriate practices to minimise the adverse impact of climate change. Information on rainfall and temperature can have significant positive impact on the likelihood of using the information for use of different crop varieties.

Other determinants are tenure status, access to market, social identity, fixed assets, ethnicity, social status and equity.

Activity 2.8 In Text Question(s) (10 Minutes)

1. Explain any four socio-economic determinants of climate change adaptation.
2. Discuss how the following factors affect an individual or community's capacity to adapt to climate change:
   i. access to markets,
   ii. social identity,
   iii. fixed assets,
   iv. ethnicity and social status,
   v. infrastructure, and
   vi. institutions.

Summary

In this section we learnt that there are several socio-economic determinants of climate change adaptation. The main ones include levels of economic wealth, technology, information and skills, infrastructure, institutions and equity. Adaptation to climate change impacts also depends on level of awareness of the risks of climate change and the capacity of individuals/communities to adapt to it. In order to adapt, individuals and communities or groups are influenced by social factors, including age, level of education, household size, land tenure and family head. Other factors that can influence adaptive capacity at societal level include, availability of resources to invest in adaptation, access and ability to process information, flexibility of a system to change in response to climate stimuli, willingness to change and adapt. When it comes to non-human species, adaptive capacity will include the ability of species to migrate or for ecosystems to expand into new zones.

2.6 System characteristics that influence a system’s propensity to adapt

2.6.1 Introduction

The vulnerability of countries, societies and ecosystems to the effects of climate change depends not only on the magnitude of climatic stress, but also on the sensitivity and capacity of affected societies to adapt to or cope with such stress, access to health services and existing ecological conditions. Social and natural systems are supported by characteristics which make them resilient and therefore, able to withstand the impact of climate change. In social systems, vulnerability is affected by factors associated with poverty, social class and status of health and nutritional levels (IPCC 2007a, Lavell et al. 2012). This section discusses some of these characteristics in some detail, including vulnerability and its components of potential impact and adaptive capacity, resilience, susceptibility, responsiveness and adaptability.

Learning outcomes
By the end of this session, the learner should be able to:
i. Explain compnents of vunerabilty.
ii. Explain factors affecting adaptive capacity.

Activity 2.9 Brainstorming (10 minutes)
Explain the factors that determine the capacity of a system to adapt to climate change?

2.6.2 Vulnerability

Following the definition of vulnerability in section 1.2.5, here the attempt is to address the extent to which a natural or social system is susceptible to sustaining damage from climate change. The vulnerability of a community is affected by social vulnerabilities associated with poverty, social class and status of health and nutritional levels (IPCC 2007a, Lavell et al. 2012, Ofoegbu et al 2017). Smit and Wandel (2006) and Yohannes et al. (2020) stated that when extreme events or more extreme variability go beyond the coping range, the adaptive capacity might be surpassed, and the system becomes threatened. Furthermore, vulnerability is limited to adaptive capacity of a system that is strengthened or weakened by its sensitivity and exposure to the climate impact (Figure 2).

Vulnerability = potential impact (sensitivity x exposure) – adaptive capacity

Resilience is shown when ecosystems can shift greatly from their previous state and still return to pre-disturbance conditions.

Resistance is shown in ecosystems that are better at resisting change than others, and therefore have high resistance (Isling 2016).

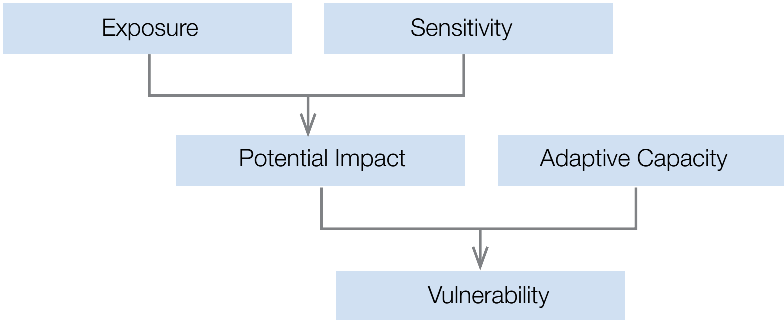

Figure 2. Components of vulnerability (IPCC 2007a, Fellmann 2012)

Potential impacts

Climate change has consequences which have an impact on natural and human systems. The impacts can be potential effects or residual impacts, depending on the form of adaptation. Potential impacts are those impacts of climate change that affect human (e.g. health, agriculture, tourism, etc.) and natural (e.g. biodiversity, water resources, soil, etc.) systems. These are all the impacts that may occur under a particular projected climate change, without considering adaptation (McCarthy et al. 2001, Norwegian Red Cross 2019). They are represented by the extent of damage to natural and human systems being either direct or indirect, negative or positive, tangible or intangible, long or short-term (Usman et al. 2013). Assessment of the potential impacts of climate change involves evaluation of the magnitude of potential effects, strictly depending on exposure and sensitivity.

Other forms of climate change impacts

Residual impacts are those that would occur after adaptation.

Aggregate impacts are the total impacts summed up across sectors and/or regions. The aggregation of impacts requires knowledge of (or assumptions about) the relative importance of impacts in different sectors and regions. Measures of aggregate impacts include, for example, the total number of people affected, change in net primary productivity, number of systems undergoing change, or total economic costs.

Market impacts are those linked to market transactions and directly affect gross domestic product (GDP, a country's national accounts), for example, changes in the supply and price of agricultural goods.

Non-market impacts are impacts that affect ecosystems or human welfare but are not directly linked to market transactions - for example, an increased risk of premature death.

Source: IPCC 2001

Exposure

Exposure to climate vulnerability represents the presence of ecosystems or species, people and resources (economic, infrastructure, cultural or social resources) in areas or places that might be adversely affected by a changing climate. Exposure indicators can consist of biophysical factors such as drought, heavy rains, high temperatures and rising sea level. According to IPCC, climate change impacts will remain as long as the probability of occurrence of extreme weather events over time remains (IPCC 2007a, Ayodotun et al. 2019). An indirect effect may include damages caused by an increase in the frequency of coastal flooding due to sea level rise.

Sensitivity

Sensitivity to climate change refers to the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. An example of a direct effect may be in the form of a change in crop yield in response to a change in the mean, range or variability of temperature whilst indirect effects may include damages caused by an increase in the frequency of coastal flooding due to sea level rise. Positive effects may include increases in crop growth resulting from increased rainfall whilst the negative effects are associated with death of plants or animals following a drought (IPCC 2007b). The degree of a system's sensitivity to climatic hazards depends not only on geographic conditions but also on socio-economic factors such as population and infrastructure (Fronzek et al. 2019; UN Task Team on Social Dimensions of Climate Change 2011).

Sensitivity to climatic stress is higher for processes and activities that are climate-dependent, such as agriculture and coastal resources. Components of sensitivity include changes in disturbance regimes (e.g., fires, pests and disease), in tree level processes (e.g., productivity), in species distribution, in site conditions (e.g., soil condition). Indicators of sensitivity can encompass geographical conditions, land use, demographic characteristics, and industrial structure such as dependency on agriculture and extent of industrial diversification (Ludena and Yoon 2015, Evariste et al. 2018). In forestry, sensitivity can imply the degree to which growth, health, structure and composition of the forest are altered by a variation in climate and changes in stand structure (e.g., density, height). However, forest ecosystems vary in their sensitivity and response to climate change because of complex interactions among organisms, disturbance and other stressors (Malhi et al. 2020).

Sensitivity shows the extent to which a species or system is positively or negatively and directly or indirectly affected by climate change or variability. Change in crop yields in response to changes or variability of temperature is an example of a direct effect whilst damage caused by an increase in the frequency of coastal flooding when sea level rises is an example of indirect effect. Positive may include increases in crop growth resulting from increased rainfall whilst the negative is associated with death of plants or animals following a drought (IPCC 2007b). Sensitivity to climatic effects increases with dependence of processes and activities on climate, e.g. fisheries, agriculture, forestry and certain coastal activities that support livelihoods. A sensitive system can be affected by even small alterations of climate. In this regard, sensitivity can reflect how the system can respond to climate effects and the extent to which the changes in climate might affect the system in its present form (IPCC 2001).

Geographic conditions (Fronzek et al. 2019) and socio-economic factors determine the sensitivity of a system to climate related hazards (UN Task Team on Social Dimensions of Climate Change 2011). Indicators of sensitivity can include geographic circumstances, land management, demography and industrial/economic activities, e.g. extent of industrial diversification and dependency on rain-fed agriculture (Ludena and Yoon 2015). In forestry, sensitivity can imply the degree to which forest growth, health, structure and composition are altered by a variation in climate.

Adaptive capacity

Adaptive capacity describes the ability of a system to cope with climatic extremes and its ability to transform to match climate change, reduce potential damages, exploit opportunities, or manage the circumstances. It includes the ability of institutions, humans and other organisms to adjust to potential damage, by taking advantage of opportunities, or to responding to consequences (Millennium Ecosystem Assessment 2005, Siders 2018). Adaptive capacity to climate change depends on physical resources, access to technology and information, varieties of infrastructure, institutional capability and the distribution of resources. Indicators for adaptive capacity comprise economic capability, physical infrastructure, social capital and institutional capacity, etc. Economic capability represents the economic resources available to reduce climate change vulnerability. Adaptive capacity includes human resources and technological alternatives (Yohe and Tol 2002, Dube et al. 2020). The capacity to adapt and cope with climate change depends on a multitude of socio-economic factors that are generally complex in developing countries, especially in rural communities. These factors include level of education, wealth status, access to information, governance, institutions, technology and skills, access to resources, infrastructure, political influence and kinship networks (Smit and Wandel 2006, Ofoegbu et al. 2017). Abdul-Razak and Kruse (2017) and Owino et al. (2020b) showed that economic resources, technological capacity and awareness/training were the most important and most relevant adaptation options for smallholder farmers in Ghana.

In natural systems, Beever et al. (2015), Nicotra et al. (2015) and Thurman et al (2020) showed that adaptive capacity of species and populations in an ecosystem is a combination of evolutionary potential, life-history traits, dispersal ability and phenotypic plasticity, that are influenced by behavioural, genetic, epigenetic and acclimation processes. However, it is also possible to identify organisations able to manage ecosystems or lead communities in implementing adaptation projects that eventually decrease vulnerability to impacts of climate change.

The provision of ecosystem services plays an important role in facilitating adaptation of social systems through the provision of regulatory (regulation of water, climate and diseases) support services (biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling and provisioning of habitat), provisioning (direct and indirect use values, e.g. food, medicines etc) and cultural services (non-use values). The linkages between ecosystem services and vulnerability to climate change are shown in Figure 3.

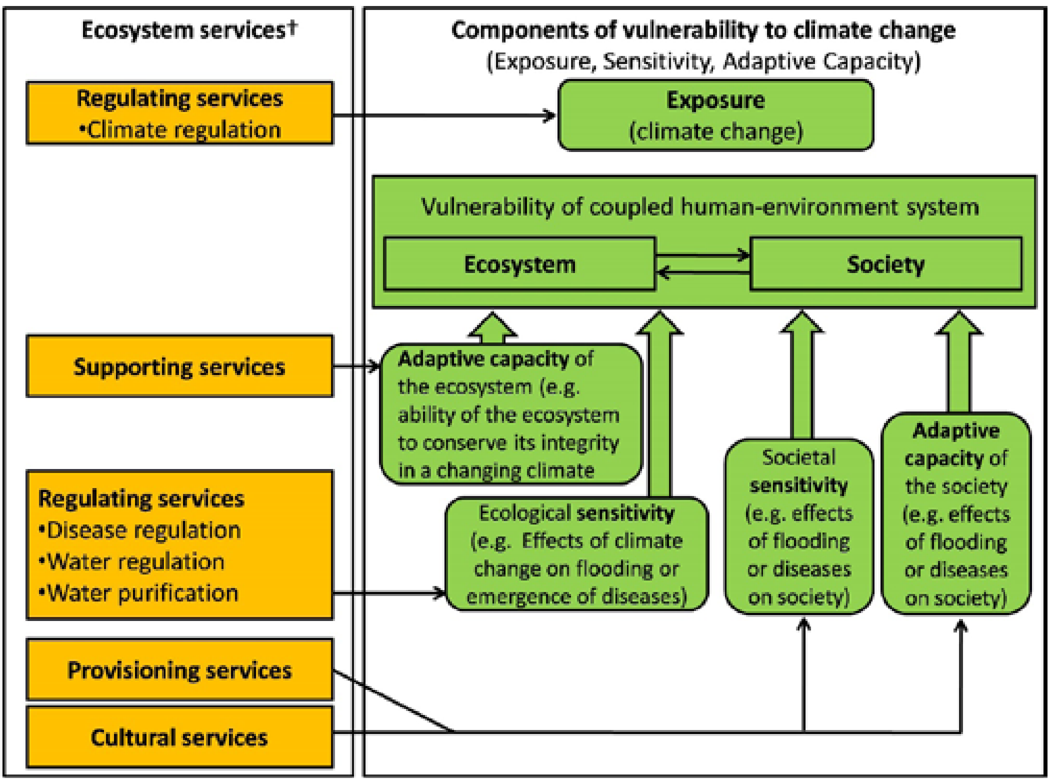

Figure 3. Ecosystem services and their links to vulnerability to climate change (Locatelli et al. 2008, van de Geest et al. 2019)

In Africa, poverty not only makes people vulnerable, but also limits their choices as natural disasters such as floods can overwhelm poor households, destroying their ability to cope. If crops fail, subsistence farmers have few or no alternative means to provide food for their families. The socio-economic impacts of extreme climate events, therefore, arise from the interaction between natural conditions and human factors such as land use and land cover changes and the demand for and use of water. Excessive water withdrawals can also exacerbate the impact of extreme events such as droughts (Tadesse 2010, Anyu and Dzekashu 2020).

Furthermore, adaptive capacity can reflect the intrinsic qualities of a system that make it more or less capable of adapting (e.g. the cooperative relationships between species in an ecosystem, or the relative abundance of shaded parks in urban areas). In human systems, adaptive capacity can reflect the presence of effective leaders and organisers in a community It can also reflect the abilities of an organisation responsible for managing ecosystems or leading a community to collect and analyse information, communicate, plan and implement adaptation strategies that ultimately reduce vulnerability to change impacts (Giordano 2014, Ndhleve et al. 2017). Giordano (2014) and Muronzi and Mukarwi (2019) added that adaptive capacity can be affected by the following factors:

- Availability of resources to finance adaptation.
- Access and skill to manage information.
- System's flexibility to adjust in response to some climate stimuli.
- Preparedness to cope, adjust and adapt to risks.
- Capacity of ecosystems to expand into new zones or of species to migrate.

Adaptation measures vary according to the way climate change is described, the sector or exposure unit that is adapting, the manner and timing of adaptation, and the adaptation capacity. There are potentially many adaptation measures that can be adopted in response to climate change (Smit et al. 2001, Sharifi 2020). Local vulnerability measures must take into account scale, dynamics and diversity of societies in order to convey information on diverse natural environments and heterogeneous socio-economic structure at multiple scales. The three (scale, dynamics and diversity) are elucidated below.

Scale refers to critical analysis of relative magnitude of reference such the local, national, regional or global scale (Ludeña et al. 2015, Crane et al. 2017). The assessment at the local scale becomes critically important not only because of the bio-physical environmental differences of locations, but also because of the socio-economic contextual differences at the local level. Furthermore, within a country or region, heterogeneity of socio-economic contexts such as institutions, population, social network and culture, may affect the local vulnerability to climate change (Carina and Keskitalo 2008, Segnon et al. 2020). **Dynamics** considers the assessment taking a dynamic point of view (Frank et al. 2011, Nyairo et al. 2020). Global vulnerability studies on climate change using static proxy variables such as annual GDP may ignore the dynamically changing coping capability at the local scale over a period. Individual perception and accumulated knowledge of climate change that evolves over time results from learning through the past experiences of households' response to climate change, their attitudes, values and cultural norms (Ludeña et al. 2015, Crane et al. 2017). **Diversity** considers dealing with micro level units of analysis such as household or community ecosystem, where it becomes feasible to capture the diversity of the natural environment of communities and their socio-economic heterogeneity (Acosta-Michlik and Espaldon 2008, Segnon et al 2020).

2.6.3 Resilience

Communities become resilient when they can efficiently, and in time, absorb, resist and recover from the impacts of hazards while preserving or restoring identity, critical basic structures, feedbacks and functions (UNISDR 2009). A resilient ecosystem has the capacity to withstand disruption and restructure while going through change to remain basically with the same state, in a manner that allows for the persistence of system functions (Walker and Salt 2006, Fentaa et al 2019). Resilience can be "engineering resilience” or “ecological resilience”. Engineering resilience is associated with the ability of a system to return to a more-or-less pre-disturbance condition with the assumption of only one steady state known as the equilibrium dynamics (Holling 1996, Yousefpour et al 2020). For example, if there is increased drought conditions, resilient forest ecosystem components can recover from drought stress, with little or no alterations of species composition. Ecological resilience is the capacity of a system to absorb impacts before reaching a threshold where the system is modified into a different state. Such systems have more than one stable state where resilience becomes the measure of the capacity of the forest ecosystem to tolerate stress (e.g. prolonged drought) before being converted into a different vegetation ecosystem such as bushland or grassland. However, the systems may experience several other different but stable forest states where new species compositions, provides most or all the goods and services that were supplied by the initial state (Holling 1996, Hart et al 2019).

In southern Africa, bush encroachment in forest areas is expected to increase due to increased concentrations of atmospheric CO_2 that is associated with increased woody plant cover (Archer et al. 2011). This is because elevated atmospheric CO_2 concentrations reduce transpiration rates in plants, increasing soil water availability and the competitive dominance and productivity of deep-rooted plants, such as trees and shrubs (Bond and Midgley, 2000).

Biggs et al. (2015) and Salgueiro-Otero and Ojea (2020) identified seven resilience principles critical for fostering resilience in social-ecological systems:
- Maintenance of diversity and redundancy.
- Management of connectivity.
- Management of slow variables and feedbacks.
- Fostering complex adaptive systems thinking.
- Encouraging learning.
- Broadening participation.
- Promotion of polycentric governance systems.

A resilient forest ecosystem can withstand (absorb) external pressures and return to its pre-disturbance state over time if disturbance is reduced. The ecosystem maintains its taxonomic composition, ecological structure and processes. However, biological and ecological resources in the ecosystem affect its resilience and include: (i) species diversity (ii) genetic variability within species, and (iii) regional species and ecosystem pools. The size of forest ecosystems (usually, the larger and less fragmented, the better), and condition and character of the surrounding landscape also affect their resilience (Thompson et al. 2011, Albrich et al. 2020).

Therefore, maintenance and restoration of forest biodiversity increases forest resilience to anthropogenic pressures and becomes an essential ‘insurance policy’ and safety net against anticipated climate change impacts (Thompson et al. 2011). The diversity at molecular level within a species, within a forested community, or across a landscape and bioregion represent manifestations of biological diversity at various scales. In this regard, biodiversity initiatives should be considered at all scales (stand, landscape, ecosystem, bioregional) and including all elements (genes, species and communities). When biodiversity increases in planted and semi-natural forests, resilience capacity is enhanced and often also productivity (Walker 1995, Bodin and Wimen 2007, Sayer et al. 2017).

When resilient ecosystems respond to a disturbance, they follow a successional pathway, which reverts the ecosystem to its pre-disturbance structural and functional state. This usually occurs in forests that are dominated by small-scale disturbances. A disturbance can be sufficiently severe to restructure an ecosystem within a short period (i.e. decades), or over long term (i.e. centuries). Forests can also resist some environmental variations, e.g. weather patterns over time. It is possible to have very resilient ecosystems that have low resistance to a particular disturbance. However, most well-developed forests, especially primary old forests, are both resilient and resistant to changes (Holling 1973, Levin 2015, Behera et al. 2018).

Factors like redundancy (niche overlap between species) and modularity (interconnectedness of a system's components) are also important in determining an ecosystem's resilience (Levin 2015, Aquilué et al. 2020). Resistance occurs when the capacity of an ecosystem makes it able to absorb disturbances and remain largely unchanged (Isling 2016). The concept of resistance is linked to the concept of stability because a forest ecosystem remains within a range of variation around a specified ecosystem state in response to minor perturbations. Stability shows the ability to maintain a dynamic equilibrium over time while resisting alteration to a different state. A stable ecosystem persists when it has the capacity to absorb disturbances and remain largely unaffected over long periods of time (Thompson et al. 2009, Albrich et al. 2020). The presence of multiple species in a plant community can stabilise ecosystem processes if the species vary in their responses to environmental fluctuations. If abundance of one species increases, it can compensate for the decreased abundance of another. Biologically diverse communities are also more likely to contain species that confer resilience to that ecosystem because as a community accumulates species, there is a higher chance of any one of them having traits that enable them to adapt to a changing environment (Cleland 2011, Lister et al. 2019).

Resilience is shown when ecosystems can shift greatly from their previous state and still return to pre-disturbance conditions.

Resistance is shown in ecosystems that are better at resisting change than others, and therefore have high resistance (Isling 2016).

2.6.4 Susceptibility to climate change and its impacts

Maintaining tree species biodiversity in an area reduces the susceptibility of the area to disease. For example, the evergreen sclerophyll oaks (e.g. holm oak/*Quercus ilex*, cork oak/*Q. suber*, *Q. coccifera*, developed morphological traits that reduce their susceptibility to wildfire in terms of increased resistance as opposed to increased resilience), as an alternative survival mechanism. The thick bark of cork oak protects the cambial layer from moderate intensity fires, increasing the probability of tree survival. If the fire is sufficiently intense to burn the aboveground vegetation, dormant buds will be activated and regenerate new shoots and sprouts following the fire (Thompson et al. 2009, Rainsford et al. 2020).

2.6.5 Responsiveness

Climate change responsiveness is a determinant of resilience, together with risks and resources. Responsiveness can go beyond the risk dialogue and has three elements: the extent of knowledge gains; extent of attitude change; and extent of action or practice. Responses to climate change are mainly either mitigation of GHGs or adaptation. Mitigation and adaptation activities improve resilience of vulnerable systems and reduce potential damages that can arise from climate change and climate variability (IPCC 2014, Sharifi 2020). The National Research Council (2010) listed several options and strategies for responding to climate change, including the following:

- Limiting greenhouse gas (GHG) emissions to slow the rate and extent of climate change.
- Taking adaptation initiatives that reduce potential damages from climate change impacts.
- Expanding research and development to provide better low-carbon options for the national and global economy.
- Scientific understanding about climate change and its impacts improved to enable better and informed decision making.
- Reducing GHG emissions.
- Reducing short- and long-term vulnerability to climate change.

- Reducing energy costs and exposure to the volatility of energy costs.
- Facilitating future response to governmental or other regulations targeting reduction in GHG emissions.
- Establishing economic leadership and promoting economic development in green technology sectors.
- Promotion status of environmental leadership.
- Regional, national and global investments in low-carbon technologies.
- Sharing best practice measures for adapting to climate change.

2.6.6 Adaptability

Adaptability is a feature of a system or of a process that shows the capacity of actors to influence resilience. In ecology, adaptability reflects the ability to cope with unexpected environmental disturbances. It is largely a function of the social component made up of individuals and groups that act to manage the system (Berkes et al. 2003, Dardonville et al. 2020). It is measured by the ability to either control the trajectory of the system (change precariousness), change the processes in response to dynamics at other scales (panarchy response) or change the topology of the stability landscape (latitude and resistance). Adaptability is characterised by volatility, uncertainty, complexity and ambiguity (VUCA) (Mack and Khare 2016). It can be at individual, interpersonal or team/group level.

Individual adaptability is reflected by behaviour change resulting in improved outcomes. Motivation is a strong factor for individuals to adapt as those who are constantly seeking ways to improve their performance become more adaptable. Interpersonal adaptability is driven by one's own initiative and not externally imposed by the demands of one's environment, or by an external unexpected event. Team adaptability is emergent and evolves over time, the dynamics of which are influenced by the complexity of the task being faced. The team adaptability can be continuous, incremental, forecastable, or unpredictable and disruptive. In the process they can be cognitive, affective, motivational, or behavioural modifications (National Academy of Engineering 2018).

Transformability is the capacity to define and create new stability landscapes by introducing new components and ways of making livelihoods, thereby changing the variables of the state, and sometimes the scale, defining the system.

Activity 2.10 Revision (10 Minutes)

1. Explain some characteristics of a highly resilient ecosystem.
2. List biological and ecological resources that affect a system's resilience.
3. Explain the linkages between adaptive capacity in social systems and ecosystem services.

Summary

In this section we have discussed the characteristics/factors that influence the capacity of a system to adapt to climate change and variability. Vulnerability of a system to climate impacts is a product of potential impacts (sensitivity and exposure) and adaptive capacity. Resilience is the capacity of a socio ecological system to withstand (absorb) external pressures and return, over time, to its pre-disturbance state whilst resistance is the ability for an ecosystem to remain unchanged when being subjected to a disturbance. The socio-ecological systems become resilient when they are able to timely and efficiently absorb, resist and recover from the impacts of hazards while preserving or restoring identity, critical basic structures, feedbacks and functions. The resilience of an ecosystem is affected by its biological and ecological resources such as species diversity, genetic variability within species, and regional species and ecosystem pools. Climate change responsiveness is a determinant of resilience, together with risks and resources beyond the risk. Responsiveness has three elements based on the extent of knowledge gains, extent of attitude change, and extent of action or practice. Climate change is expected to increase the susceptibility of forests to disturbances, coupled with the frequency, intensity, duration and timing of the disturbances. The presence of multiple species in a plant community can stabilise ecosystem processes if the species vary in their responses to environmental fluctuations. Adaptability is a feature of a system or of a process that shows the capacity of actors to influence resilience. In ecology, adaptability reflects the ability to cope with unexpected environmental disturbances whilst in social systems, adaptability is largely a function of the social component made up of individuals and groups that act to manage the system. Adaptability is essentially a situation characterised by volatility, uncertainty, complexity and ambiguity.

Chapter 3. Assets, resources and capital for adaptation

3.1 Introduction

Vulnerability of communities is reduced when there is engagement and coordination using various mechanisms, such as providing funding, integrating adaptation into development planning processes and sharing of inter-disciplinary information (Least Developed Countries Expert Group (LDCEG) 2012).

Learning outcomes

By the end of this session, the learner should be able to:

i. Describe assets and resources for climate change adaptation.
ii. Apply different tools for prioritising adaptation options.
iii. Explain considerations of mainstreaming climate change adaptation.
iv. Relate forest-based climate change adaptation into development policies and plans.
v. Explain adaptation financing mechanisms relevant to the forestry sector in Africa.

Activity 3.1 Brainstorming (10 minutes)

What is the relationship between wealth status and adaptive capacity?

The success of adaptation depends on the individual farmers' agility to respond to external pressures, fluctuations and stresses. The concept of sustainagility defines activities that allow the individual's agility to be sustained. The concept augments the sustainability because the two determine whether existing systems can survive or not. Sustainability at any point of complexity (e.g. from farming system to that of livelihoods) can be related to the sustainability of individual constituents, or on the agility to find and fit in new components.

Sustainagility is "the properties and assets of a system that sustain the ability (agility) of agents to adapt and meet their needs in new ways" (Jackson et al. 2010).

3.2. Forms of capital

Carney (1998) and Gott et al. (2019) showed that the resource base for sustainagility can be viewed in the light of the five types of capital, with partial but incomplete options for exchange between capital types: natural, social, physical, financial and human (van Noodwijk et al. 2001, Godwin 2003) (Figure 4). Bailey et al. (2019) studied communities in Eswatini and found that in times of drought, social and natural capital increased access of communities to other resources and opportunities which facilitated adaptation.

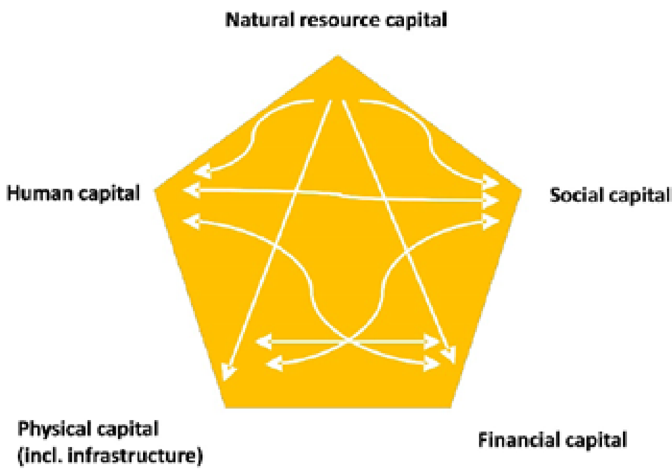

Figure 4. Types of capital affecting development and capacity to adapt (van Noordwijk et al. 2001).

All five forms of capital are either directly or indirectly influenced by climate change. Apart from capital, adaptation in agroecosystems affects sustainagility and sustainability in addition to other internal and external mechanisms related to capital (Jackson et al. 2010). It is therefore important to strengthen the five capitals in order to increase coping capacities to variable and extreme weather events while holistically improving community livelihoods (Carney et al. 1998, Gott et al. 2019).

Box 3.1 Case studies from Africa

In Ethiopia, small holder farmers adapt to climate change by using several measures such as planting alternative crops which are understood to be heat or drought resistant (Bailey et al. 2017). Additionally, social capital and community networks operate in diverse ways to serve as critical resources for adaptation to drought. Wuepper et al. (2017) also showed that households with greater social capital tend to be more specialised, implying that diversification and informal insurance were substitutes in the mitigation of risk in Ethiopia. In another study, Paul et al. (2016) found that social capital and the capacity to collectively deal with climate change adaptation were positively associated whilst also working in Ethiopia.

In Southern Africa, people and communities have always adapted to climate variations through adaptive actions linked to their resources and their accumulated knowledge and experience of past weather patterns making them able to react and recover from climate extremes, such as floods, droughts and hurricanes (Armitage and Plummer 2010). Community Based Natural Resource Management initiatives have contributed to enhanced climate change adaptation actions by communities in Malawi (e.g. the Kam'mwamba Community Integrated Natural Resource Management and Use Project in Malawi), Mozambique (e.g. Tchuma Tchato), Namibia (e.g. the Mayuni Conservancy) and Zimbabwe (e.g. Masoka CAMPFIRE Programme) (Chishakwe et al. 2012).

Natural capital can be defined as the world's stocks of natural assets, including geology, soil, air, water and all living things. It is important for reducing the vulnerability of communities. Most African communities depend on natural resources for critical resources making them more vulnerable to climate shocks and stresses, such as drought, than those that are not dependent on the environment (Guerry et al. 2015). In most cases, the resources are readily available and do not require extensive knowledge or training to exploit them (Belay et al. 2017).

Human capital includes the skills, knowledge and experience possessed by an individual or population, viewed in terms of their value or cost to an organisation or country. It can be increased through improving education and skills to broaden opportunities for profitable and stable livelihood options. Social capital is critical for strengthening livelihood strategies by broadening opportunities and narrowing the gap between support from external groups and that from internal links. Wuepper et al. (2018) found that smallholder farmers in Ethiopia used social capital and income diversification as substitutes in their risk management. However, social capital can be affected by social and political networks, with social barriers to communication within and between communities requiring physical capital, such as basic infrastructure of power, roads, bridges and means of communication. This facilitates greater access to resources and networks, transforming communities and improving their wellbeing (Mbukwa 2014). Tibesigwa et al. (2014) added that adaptation actions created by social capital are often more feasible and successful than those driven by other types of capital. Social capital can be built through programmes that are participatory in nature, such as participatory forest management or community-based natural resources management. In this regard, social capital provides more diversified livelihoods that have greater ability to withstand stresses and allow greater access to other types of capital (Cassidy and Barnes 2012). Box 3.1 shows examples of benefits of social and natural capital.

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In economics, **physical capital** represents one of the three primary factors of production as it is the apparatus used to produce goods and services. Physical capital represents the tangible man-made goods that help and support the production process. It is about access to and quality of local infrastructure and physical assets and is positively associated with food security and agricultural adaptation (Mbukwa 2014).

Financial capital is based on regularity, level and diversity of household incomes. For adaptation strategies, diversification of income facilitates engagement or investment in other livelihood activities. Households with greater financial capital have greater access to information and opportunities and are often less risk averse, enabling adaptation (Deressa et al. 2009). Activities that can reduce vulnerability include soil and water management to reduce soil erosion and siltation, improving yields and diversifying crops and animals to fill seasonal gaps in food supply, afforestation and forest restoration/conservation and diversifying incomes through utilisation of available non-timber forest products and other employment (FAO 2004).

Activity 3.2 Revision
Explain the difference between natural and physical capital or assets

Summary
In this session we have learnt that the success of adaptation depends on the agility of individuals to respond to external pressures, fluctuations and stresses and are hinged on five types of capital that have partial but incomplete options for exchange between them, viz.: natural, social, physical, financial and human. All five forms of capital are either directly or indirectly influenced by climate change. Vulnerability of communities is reduced when there is engagement and coordination using various mechanisms, such as providing funding, integrating adaptation into development planning processes and sharing inter-disciplinary information.

Further reading: Chishakwe N, Murray L, Chambwera M. 2012. Building climate change adaptation on community experiences: Lessons from community-based natural resource management in southern Africa. IIED London. Available at: 22073490 (osti.gov).

3.3 Adaptation financing mechanisms

Adaptation financing can be through individual or private sector, national, bilateral or multilateral mechanisms. Climate funds normally flow through multilateral channels, within and outside of the UNFCCC financial mechanism and increasingly through bilateral, as well as through regional and national climate change channels and funds (Bird et al. 2017). Bird et al. (2017) added that the climate finance architecture is complex and is always evolving to support mitigation and/or adaptation. They include: the Adaptation Fund (AF); Forest Investment Programme (FIP); Forest Carbon Partnership Facility (FCPF); Clean Technology Fund (CTF); Global Environment Facility (GEF); Least Developed Countries Fund (LDCF); Pilot Programme on Climate Resilience (PPCR); Scaling Up Renewable Energy Programme (SREP) and Special Climate Change Fund (SCCF). Implementation is through public, private or public/private partnerships and implemented through UN agencies or Multilateral Development Banks (MDBs) or as multilateral implementing agencies or accredited National Implementing Entities.

Learning outcomes

By the end of this session, the learner should be able to:

i. Describe some types of financing mechanisms for adaptation projects.
ii. Describe implementation modalities for climate finances.

Activity 3.3 Brainstorming (10 minutes)

Describe forms of adaptation financing that you are firmiliar with.

3.3.1 Private sector financing

Climate change poses several risks to vulnerable communities and businesses around the world. The private sector has different motives from the public sector for investing in adaptation and they often act without any public support but can complement public adaptation activities on the ground including in priority sectors such as water and agriculture.

> A Public-Private Partnership is "a long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility' (Carter et al. 2014).

Stronger public-private partnerships can serve as an important vehicle for enhancing climate resilience while at the same time creating business opportunities. In addition to the private sector funding, the UNFCCC has a centralised platform to support private-sector investment for adaptation activities called the Private Sector Initiative (PSI), which is supported by the Nairobi Work Programme (NWP) and focuses on addressing impacts, vulnerability and adaptation to climate change. The initiatives represent private adaptation interventions all over the world and cover a variety of businesses and sectors such as: water, insurance, food and agriculture, consultancy, environmental management, infrastructure and transportation, tourism and the financial sector (Biaginia and Millaer 2013, Ng'Andwe et al. 2017, Popoola et al. 2020). Private companies are implementing actions to reduce risks to their business operations, as well as investing in adaptation action in vulnerable regions in a sustainable and profitable manner (UNFCCC 2012). Initiatives include:

- Searching for new market opportunities and expanding.
- Developing climate friendly goods and services.
- Cost saving initiatives.
- Risk reduction measures, including physical operations.
- Climate proofing of the supply chain.
- Enhancing their corporate social responsibility.

The initiative provides a platform for businesses to contribute to a strong and effective response, in a sustainable and profitable manner both in their own adaptation efforts and, importantly, in those of the most vulnerable countries and communities around the world. The PSI combines the capacity of the private sector to innovate and produce new technologies for adaptation, and its financial leverage to form an important part of the multi-sectoral partnerships required between governmental, private and non-governmental actors. Some initiatives are implemented by multinationals (e.g. Allianz, Anglo American, Nestlé, GlaxoSmithKline and Siemens), others by small to medium sized enterprises (e.g., Banka Bioloo, Ignita), research institutes (Acclimatise, Ecofys), non-profit organisations (EWV, Fonkoze) and public-sector owned companies (Network Rail, ÖBB). For example, in Egypt, Allianz worked in collaboration with Planet Finance, Surety Fund and a number of European reinsurers to develop a pilot project offering death and disability insurance to more than 30,000 customers. These operate throughout the world with some pilot projects with private-sector involvement in Africa (UNFCCC 2020a). International insurance companies are also involved to some degree in climate finance in Africa. Public–Private Partnerships (PPPs) are initiated and co-financed by multilateral or bilateral organisations such as the World Bank, GIZ, (DfID) or USAID (Troilo 2011).

3.3.2 National level financing

Some governments in Africa finance adaptation and adaptation technologies, such as water supply, research, agricultural interventions or building dams. These activities are often not allocated to adaptation but are within the wider government budget for the agricultural, biodiversity or forestry sectors. Some countries, such as Benin, Ethiopia, Mali, Rwanda and South Africa have dedicated national climate change funds with some climate action programmes partly funded through national budgets whilst other proposed national climate funds in their climate change strategies and action plans (Bird et al. 2017). One of the first national environment and climate change investment funds in Africa is the Rwanda Green Fund (FONERWA) which invests in public and private projects that drive transformative change (UNFCCC 2021).

» The Rwanda Green Fund (FONERWA) invests in sustainable wealth creation and poverty reduction by providing strategic financing that accelerates Rwanda's commitment to building a strong climate resilient and green economy.
» The Fund has raised approximately USD 40 million for strategic climate resilience investments and has created more than 137,500 green jobs, provided more than 57,500 households with improved access to off-grid clean energy and protected 19,500 ha of land against soil erosion.
» Funding proposals are approved based on careful evaluation to ensure their return on investment contributes to Rwanda's climate resilience.

Source: UNFCCC (2021).

3.3.3 Bilateral level financing

Bilateral donor governments and their agencies contributed an additional USD 2.4 billion, on average, in 2015-16 for adaptation finance. Some key bilateral players have established dedicated climate initiatives to support the development and implementation of climate-change mitigation and adaptation activities internationally. Some, such as the French government, have integrated related sub-programs into existing dedicated climate or environmental initiatives (Tippmann et al. 2013). They mostly apply specific, dedicated climate-change/environmental project selection and general investment criteria. These include co-funding, expertise, management and financial capabilities of implement-ting organisations. The main bilateral climate initiatives and programs are:

- International Climate Initiative (ICI), Germany.
- French Global Environment Facility (FGEF), France.
- International Climate Fund (ICF), UK.

- Hatoyama Initiative/Fast-Start Financing (FSF), Japan.
- African Adaptation Fund (Japan-UNDP)

The Africa Adaptation Programme (AAP) was launched in 2008 by the UNDP in partnership with the United Nations Industrial Development Organisation (UNIDO), the United Nations Children's Fund (UNICEF) and the World Food Programme (WFP) and with US$92.1 million support from the Government of Japan. The AAP was established under the Japan-UNDP Joint Framework for Building Partnership to Address Climate Change in Africa, which was founded at the Fourth Tokyo International Conference on African Development (TICAD) in May 2008. Support was given over a 3-year period to enhance the adaptive capacity of the 20 AAP countries, promoting early adaptation action and laying the foundation for long-term investment to increase resilience to climate change across the African continent (Helmore 2013).

3.3.4 Multilateral level financing

There are twelve multilateral implementing entities with only three housed in Africa, viz., the African Development Bank, UNDP and UNEP. Multilateral development finance institutions provide global public finance for adaptation, with about US$ 8 billion, or 36% of the total adaptation finance tracked in 2015/2016. By the end of 2018, the Clean Development Mechanism (CDM) had also provided about US$ 200 million to the Adaptation Fund over its lifetime (Micale et al. 2018).

The **Green Climate Fund (GCF**) under UNFCCC is considered as the main potential mechanism for international climate finance. It complements many of the existing multilateral funds, such as the Global Environment Facility (GEF), the Adaptation Fund (AF) and the Climate Investment Funds (CIF). GCF support for forestry is to increase resilience and enhance livelihoods of the most vulnerable people, communities and regions, increase health and wellbeing of people, enhance food and water security, and improve ecosystem resilience and services. The fund also supports formulation of NAPs in developing countries and helps in technical capacity building and strengthening institutional frameworks. Furthermore, GCF supports projects which foster paradigm-shifts aiming for a 50/50 balance between mitigation and adaptation finance (Green Climate Fund 2020).

GEF established the Strategic Priority on Adaptation (SPA) in 2001, with USD 50 million under SPA of which US$ 5 million was dedicated to piloting community adaptation initiatives through the Small Grants Programme (SGP). The GEF Trust Fund and its SPA support activities addressing adaptation while generating global environmental benefits. The Trust Fund comprises the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF) with the SCCF partly designed to fund adaptation activities, which increase resilience to the impacts of climate change and focusing on adaptation responses mainly in the sectors of water resources, agriculture, land, health, infrastructure development, disaster preparedness, fragile ecosystems and coastal zones (UNFCCC 2007). GEF supports country needs and priorities, providing flexibility for combining NAP technical assistance and capacity-building with NAPA financing targeting actual adaptation investments for implementation. Through the LDCF alone, a total of USD 41.7 million was approved for the LDCs' NAPs as of 30 June 2017. Since the establishment of GEF in 1991, 343 adaptation projects were funded with over USD 1.6 billion in grant financing provided through the LDCF, SCCF and SPA programme whilst more than US$ 7 billion was mobilised from other sources (UNFCCC 2019). As of July 2017, about 80 % of adaptation funding had targeted LDCs, Small Island Developing States (SIDS) and African states. Box 3.2 shows examples of projects funded through adaptation fund in Africa.

Box 3.2 Examples of projects funded through adaptation funds in Africa

A total of 27 projects in 29 African countries have been funded through the adaptation fund since June 2010 with a total grant allocation of US$ 204.5 with some US$ 45.5 million allocated food security, US$ 39.9 million to water management projects and US$ 36.3 million for agriculture projects, with non targeting forestry. Some of the projects funded by the adaptation fund include:

» Integrating Flood and Drought Management and Early Warning for Climate Change Adaptation in the Volta Basin", implemented by the WMO in Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo.

» Promoting Climate-Smart Agriculture in West Africa, implemented by the West-African Development Bank to reduce the vulnerability of farmers and pastoralists to increase climatic risk, which undermines the level of food security, income generation, and the supporting ecosystem services of poor communities in Benin, Burkina Faso, Ghana, Niger and Togo.

» Restoring marine ecosystem services by rehabilitating coral reefs to meet a changing climate future, implemented by UNDP in Mauritius and Seychelles.

» Adaptation to coastal erosion in vulnerable areas implemented by Centre de Suivi Ecologique in Senegal and reducing vulnerability and increasing resilience of coastal communities in the Saloum Islands (Pandy and Rogerson 2021).

» Reducing vulnerability to climate change in Rwanda through community-based initiatives implemented by the Ministry of Environment in Rwanda.

» Pilot rural desalination plants using renewable power and membrane technology implemented by Desert Research Foundation of Namibia (DRFN) in Namibia (US$ 5 million).

Other countries funded include Ethiopia, Ghana, Guinea-Bissau, Kenya, Lesotho, Mali, Mauritius, Morocco, Sierra Leone, South Africa and 17 more (Adaptation Fund 2019).

The **Climate Investment Funds (CIF)** were established in 2008 as one of the largest global fast-tracked climate financing instruments with $7.6 billion approved to provide grants, concessional loans, risk mitigation instruments and equity in 72 developing and middle-income countries through leveraging significant financing from the private sector, multilateral development banks (MDBs) and other sources. Five MDBs – the African Development Bank (AfDB), European Bank for Reconstruction and Development (EBRD), Asian Development Bank (ADB), Inter-American Development Bank (IDB) and World Bank Group (WBG) - support the implementation of CIF-funded projects and programs. CIF include two key programs: the Clean Technology Fund (CTF) and Strategic Climate Fund (SCF) (CIF 2019).

Clean Technology Fund (CTF) (about $4.9 billion with 85 projects) promotes scaled-up funding for demonstration, distribution and transfer of low-carbon technologies that have substantial potential for long-term savings of GHG emissions. Projects supported are mainly in three sectors: Power (reducing carbon intensity through renewable energy and highly efficient technologies), Transport (focus on efficiency and modal shifts) and Energy efficiency in industry, buildings and agriculture. The fund is administered by the World Bank and finances one regional programme and 12 country programmes (CIF 2018).

Private sector investment for climate change action can also be supported through CIF. Since 2009, CIF has allocated $2.3 billion to private sector projects in clean technology, climate resilience, sustainable forestry and energy access programs in CIF countries. The funds are disbursed through national and regional investment plans under two dedicated funding mechanisms, the Dedicated Private Sector Programmes and Private Sector Set-Aside (CIF 2018).

The **Strategic Climate Fund (SCF)** supports three programmes:

- **Forest Investment Program (FIP)** providing scaled-up financing for readiness reforms and public and private investments to support developing country efforts for reducing emissions from deforestation and forest degradation, with about \$740 million. It also finances programmes addressing underlying causes of deforestation and forest degradation and overcomes problems that hindered progress of past efforts. African countries that have benefited from the fund include Burkina Faso, Cameroon, Congo Republic, Cote d'Ivoire, Ghana, Mozambique, Rwanda, Tunisia and Zambia (CIF 2019).
- **Pilot Program Climate Resilience (PPCR)** became the first operational programme under SCF in 2008, aiming to initiate and demonstrate ways of integrating climate risk and resilience into main development planning, and enhancing other ongoing initiatives. The PPCR supports fourteen developing countries in advancing their transformational climate actions. About \$1.2 billion has been invested in pilot programmes (ibid).
- **Scaling Up Renewable Energy Program (SREP)** invests c. \$740 million to demonstrate economic, social and environmental feasibility of low carbon development pathways in developing countries` energy sector. It creates new economic opportunities and increases energy access by producing and using renewable energy. For example, Guyana's Low Carbon Development Strategy of 2009, which focused on payments for preserving its rainforest through the REDD+ mechanism, expected payments to fund clean energy (particularly hydropower), develop village economies, support flood-related adaptation and strengthen health care and education (Pharo 2015). African countries that benefited from SREP include Benin, Ethiopia, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Sierra Leone, Tanzania, Uganda and Zambia (CIF 2019).

Activity 3.4 Revision

1. Outline some of the adaptation financing mechanisms that can be applied at regional level.
2. Give examples of bilateral and multilateral funding mechanisms.

Summary

In this section we learnt that funding for climate change normally flows through multilateral channels, within and outside of the UNFCCC financial mechanism and increasingly through bilateral, as well as through regional and national climate change channels and funds. Private sector initiatives can also support climate change adaptation through public private partnerships. Multilateral funds include Green Climate funds, Climate Investment Funds and Strategic Climate funds. The GCF complements many of the existing multilateral climate change funds, such as the Global Environment Facility (GEF), the Adaptation Fund (AF) and the Climate Investment Funds (CIF). Strategic Climate Fund supports three programmes: Forest Investment Programme, Pilot Program Climate Resilience and Scaling Up Renewable Energy Program. Under CIF we have Clean Technology and Strategic Climate Funds.

3.4 Mainstreaming climate change adaptation into development policies, plans, programmes and projects

3.4.1 Introduction

In the previous section we learnt that there are different ways for funding adaptation initiatives. The finding follows stipulated processes and procedures, and they require alignment of activities with national development agendas. While all societies to some extent have adapted or are adapting to the adverse effects of climate change, in most cases, the capacities to adapt to emerging variabilities and the rapid changes are significantly different causing a need for policy support for adaptation needs (UNDP-UNEP 2011). The achievement of national development goals is broadly affected by climate change through its impacts on health, livelihoods and economic development. Adaptation policies or strategies should therefore be mainstreamed into broader development policies because climate change is a cross-cutting issue. In this section we discuss issues related to mainstreaming of climate change adaptation into development activities.

Learning outcomes

By the end of this section, the learner should be able to:

i. Explain considerations of mainstreaming climate change adaptation.
ii. Explain approaches used in mainstreaming climate change adaptation into development.
iii. Explain characteristivs of good policy approaches.
iv. Outline objectives for forest-based adaptation initiatives.

Activity 3. 5 Group discussion (10 minutes)

What is the meaning of mainstreaming climate change adaptation?

3.4.2 Mainstreaming climate change adaptation into development processes

Mainstreaming climate change adaptation is a process that considers the consequences of climate risks in all areas of national development and includes integration of adaptation considerations into policymaking, budgeting and implementation processes at the national, sector and subnational levels (UNDP 2004, UNDP-UNEP 2011). The development processes should be adjusted to accommodate disaster/climate change preparedness, mitigation, avoidance, response and recovery measures for addressing climate risks. In this regard, adaptation becomes embedded into resolutions of multiple sectors relative to the nature of the intervention, its temporal and spatial scales and its institutional context. Coordination and engagement across the multiple levels is often critical for enhancing adaptation efforts and providing opportunities for promoting transformational change. Mainstreaming can be at any level - local, sectorial, national, regional or international levels.

Policy makers and responsible planners or managers in sectors such as agriculture, water resources and costal zones that are mostly affected by climate change disasters, should anticipate and incorporate the future climate change impacts in their sectoral plans (Least Developed Countries Expert Group 2012). At national level, policy makers must consider potential impacts in different sectors and make policy decisions across sectors. National policy making considers all the existing policies (and actions), so that in the end vulnerabilities to climate change are not increased, and this eliminates issues of maladaptation to climate change. Furthermore, adaptation deficits should also be addressed (Niang et al. 2014). An example of such would be a case where the agricultural sector neglects development and natural resource management efforts in marginal areas (e.g. causing deforestation and forest degradation) or if there are no markets for agricultural products.

There are other sectors where mainstreaming may be required at regional level. Some examples are river basins such as Zambezi valley and Nile or major drought prone areas such as the Sahel. The programmes can focus on most appropriate initiatives at regional level, e.g. East Africa, West Africa, southern Africa or South Asia. The regional level is also the smallest scale (at least at present) at which potential climate change impacts under different scenarios can be effectively modelled (Christensen et al. 2007, Nursey-Bray et al. 2020).

At the global level, climate change actions need cooperation of the global community of nations to act together under the UNFCCC along with other development-oriented efforts. For example, attaining many of the SDGs may be affected by climate events and socio-ecological capacities to adapt (Ansuategi et al. 2015). International cooperation is also needed for developing innovative funding mechanisms. International policy responses and funding created under the UNFCCC and Kyoto Protocol assist more vulnerable nations that lack adequate capacity to adapt to climate change. The international policies facilitate conformity by Parties and are being integrated into appropriate regional and national policies (Least Developed Countries Expert Group 2012), e.g. on sustainable forest management, climate change adaptation and mitigation, and biodiversity conservation.

Adaptation actions vary with circumstances, although a project-based approach to adaptation planning and financing may not yield the scale of results necessary for long term adaptation. The best could be formulation of national adaptation policies or climate change strategies using cross-cutting, integrated policy approaches. Vij et al. (2017) analysed climate adaptation policy approaches and their characteristics, and they identified five approaches and four key adaptation policy characteristics. Approaches include Scenarios, Strategic (spatial) planning, Robust Decision Making (RDM), Adaptation pathways and Adaptive Governance. These approaches facilitate mainstreaming of climate change into development. Table 3 describes the five approaches under the UNFCCC and their characteristics. The approaches include adaptation pathways method, ecosystem-based adaptation (EBA), community-based adaptation (CBA), livelihoods and economic diversification as well as risk-based approaches.

Good adaptation policy approaches should have the following characteristics:

- flexible,
- scalable,
- considers uncertainties,
- resilient,
- incremental or gradual change,
- time oriented,
- local, national or international scale,
- experimental and responsive.

Table 3. Policy approaches to adaptation.

Approach	Description
Adaptation pathways method	» prioritises the management of existing risks » develops a set of long-term adaptation pathways from which to choose » can use models
Ecosystem-based adaptation (EBA)	» nature-based solution that uses ecosystem services to reduce vulnerability » involves a range of stakeholders aligning their needs to planning outcomes and » forges partnerships for implementation.
Community based adaptation (CBA)	» emphasises the importance of engaging local communities, especially vulnerable groups and people, in the adaptation process
Livelihoods and economic diversification	» creates an environment that enables people to shift to additional sources of incomes while maintaining a certain level of living quality
Risk-based approaches	» focuses on reducing the identified risk and vulnerability. » approach includes four steps: 1. Identification of relevant risks; 2. Characterisation of those risks; 3. Selection of policy options to address the risks; 4. Feedback to respond to developing risks.

(Source: UNFCCC 2019)

Frameworks used by developing countries for planning and implementing their responsive adaptation include National Adaptation Programme of Action (NAPA), Community Based Adaptation Approach (CBA), Adaptation Policy Framework (APF) and Ecosystem-Based Adaptation Approach (EBA) (UN climate change secretariat 2019). Effective climate change adaptation should therefore incorporate potential impacts into ongoing strategies and plans at sectoral and national levels (Huq et al. 2003, Yoseph-Paulus and Hindmarsh 2018). When the planners and managers are equipped with appropriate methodologies and tools, they should be able to incorporate climate change issues into their normal planning at minimum costs.

National adaptation responses should be formulated as part of broader development policies, including areas not exactly linked to climate change. Integration of national adaptation plans into national development planning processes and strategies will help reduce vulnerability to the adverse effects of climate change (UN climate change secretariat 2019). The process of mainstreaming climate change adaptation is an iterative multi-year and multi-stakeholder process integrating climate change into policymaking, budgeting, implementation and monitoring processes at all levels (national, sector and subnational). This entails collaborating and networking with government and non-governmental actors, to include climate change impacts on human well-being, pro-poor economic growth, and achievement of the SDGs (UNDP-UNEP 2011).

Mainstreaming adaptation into development, therefore, requires the main development actors (governments, international development funding agencies, NGOs, local communities, etc.) to increase awareness on potential impacts of climate change and to mainstream according to normal activities. The framework for mainstreaming consists of three components where the stakeholders are important throughout the process.

Framework for mainstreaming climate change adaptation

1 Setting the stage for mainstreaming by understanding the linkages between climate change and national development priorities and understanding the governmental, institutional and political contexts that inform efforts to define pro-poor adaptation outcomes. Find entry points into development planning and make the case for adaptation mainstreaming.

2 Mainstreaming climate change adaptation into policy processes through its integration into ongoing policy processes, such as a national development planning or sectoral strategies, based on country-specific evidence (i.e., vulnerability, impact and adaptation assessments, socio-economic investigations and pilot projects).

3 Meeting the implementation challenge by ensuring that climate change adaptation is mainstreamed into budgeting and financing, implementation and monitoring, and mainstreaming should be a standard practice.

(Source: UNDP-UNEP 2011)

National policies aiming at promoting forest-based adaptation to climate change should be based on various objectives including the following:

- Reducing non-climatic threats to forests such as fragmentation, land use change or degradation from unsustainable harvesting practices. Eliminating maladaptation policies by identifying other policy instruments that increase forest vulnerability, e.g. incentives to biofuels or other crops competing with forest lands.
- Design policies that encourage large-scale decision making for the management of forests or, more generally, biodiversity. It may be best to consider landscape approaches when designing and implementing forest adaptation measures (Spathelf et al. 2018).
- Climate change should be explicitly considered as a driver of change to conservation policies (Killeen and Solórzano 2008, Scarano 2017). For example, designing of national systems for protected areas and biological corridors considering vulnerability of the protected ecosystem and the role of corridors for facilitating migration of species under different scenarios of climate change (IUCN et al. 2004). Furthermore, the policies should promote forest adaptation information sharing and create monitoring systems to assess impacts of climate change on forests. Communities should be main actors targeted for awareness campaigns and information dissemination.
- Forest policies should stimulate forestry sector partnerships (locals, private sector, governmental agencies, scientists from natural and social sciences, conservation and development NGOs, international forestry agencies).
- Financial and institutional capacities limit adaptation options at the local scale (Agrawal 2008, van Diemen 2019, Gbegbelegbe et al. 2018), and policies should, therefore, include the strengthening of local institutions through funding and capacity building.

Further reading

UNCC secretariat 2019. Various approaches to long-term adaptation planning. Adaptation Committee. Bonn. Available at: variousapproaches .pdf (unfccc.int)

Activity 3. 6 Group discussion (10 minutes)
In your own country, how is climate change adaptation mainstreamed into national, sectorial, subnational policies and regional forest policies?

3.5 Practical examples- Case studies of adaptation to climate change in the context of forestry and other related sectors

Zambia's SCRALA Project 2018-2025

Zambia got support of USD$137 million (2018-2025) from the Green Climate Fund (GCF), under the UNDP and its partners (FAO and WFP) to respond to one of the key outcomes of the Zambian government's Seventh National Development Plan, focusing on poverty and vulnerability reduction whilst contributing to economic diversification and job creation to strengthen climate-resilient food security for 3 million smallholder farmers, mostly women, youth, and marginalised groups. The project on Strengthening climate resilience of agricultural livelihoods in agro-ecological regions I and II in Zambia (SCRALA) addresses the entire value chain and provides the initial trigger for poor and vulnerable farmers to shift to a resilient trajectory for agricultural livelihoods. The project also responds to Zambia's climate change strategies and Nationally Determined Contributions - commitments to reduce GHG emissions and strengthen resilience to climate change (www.adaptation-undp.org).

Benin- Mali - UNDP supported agroforestry

The project involved 210 women in Benin supported through the LDCF aiming at improving soil fertility. About 108,380 trees/shrubs were planted in 160 ha of agroforestry plots. In Mali, the LDCF also supported agroforestry with the objectives of soil fertility improvements and soil erosion management practices using the Zai method and stone bunds (UNDP 2018).

Ethiopia and Zimbabwe

The SCCF funding also supported watershed management projects in Ethiopia and Zimbabwe. Activities included soil and water conservation, conservation agriculture, building/ rehabilitating low-cost adaptive infrastructure, rainwater harvesting, product diversification (e.g. bee-keeping), intensification, drought-resistant crops, confined pastures, feedlots, improved livestock diets, drip irrigation, integrated pest and weed management (ibid).

Activity 3.7 Revision (10 minutes)

1. What are some of the considerations of mainstreaming climate change adaptation?
2. Explain approaches used in mainstreaming climate change adaptation into development.
3. List characteristivs of good policy approaches.
4. Outline objectives for forest-based adaptation initiatives.

Summary

In this section we have learnt that climate change adaptation should be mainstreamed into development activities. Mainstreaming climate change adaptation can be at any level: local, sectorial, national, regional or international. At global level, climate change actions need cooperation of the global community of nations to act together under the UNFCCC along with other development-oriented efforts. For example, attaining many of the SDGs may be affected by climate events and socio ecological capacities to adapt. Policy makers and responsible planners/managers in sectors such as agriculture, water resources, energy and infrastructure and coastal zones should anticipate and incorporate future climate change impacts in their sectoral plans because they are mostly affected by climate change disasters. Forests are vulnerable to changing climate, but they can also be important for humans and ecosystems to adapt to climate change. Adaptation policies or strategies should, therefore, be mainstreamed into broader development policies because climate change is a cross cutting issue. Long term policy approaches under the UNFCCC can be planned to use any of the five approaches: adaptation pathways method, ecosystem-based adaptation, community based adaptation, livelihoods and economic diversification as well as risk-based approaches. We concluded the section by highlighting some case studies from the African continent.

Further reading

African strategy on climate change 2014. Draft African Union strategy on climate change. AMCEN-15-REF-11. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/20579/AMCEN_15_REF_11_Draft_African_Union_strategy_on_climate_change_English.pdf?sequence=1&amp%3BisAllowed=

UN Climate Change secretariat 2019a. Various approaches to long-term adaptation planning Adaptation Committee. Bonn. Available at: variousapproaches .pdf (unfccc.int).

Chapter 4. Forest-Based Climate Change Adaptation

4.1 Chapter overview

While forests are affected by climate change, they also play a key role in adaptation to climate change. Forests support species to adapt to changing climate patterns and sudden climate events, for example by providing species refuge and migration corridors. They indirectly support economies to adapt to climate change by reducing the costs of climate-related negative impacts. Forest ecosystems also provide goods and services during extreme events (droughts and floods) and are key assets for reducing vulnerability to the effects of climate change. This chapter introduces learners to forests' responses to climate change, the role of forests in adaptation to climate change, resilience of forests and people to climate change, forest-based adaptation mechanisms and strategies, ecosystem-based adaptation, forests and livelihoods, indigenous coping and adaptation mechanisms and strategies, and challenges with climate change adaptation. For instance, planting trees and SFM can aid the protection of soil and land against detrimental impacts of flooding. Also, forests can be used to rehabilitate degraded land and maintain water quality by trapping sediments, taking up nutrients and immobilizing toxic substances. Adaptation strategies that promote SFM and better community-based forest management have the potential to not only protect land and people from some of the harmful effects of rising global temperatures, but also to provide opportunities for greater, more sustainable rural development and poverty alleviation through income generation and employment opportunities. The chapter concludes by looking at challenges and barriers to forest-based adaptation.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Explain how forests and tree-resources respond to climate change and climate variability.
ii. Discuss interventions for enhancing resilience of forest ecosystems to cope with impacts of climate change and variability.
iii. Describe the role forests play in climate change adaptation.
iv. Identify appropriate forest-based initiatives that could help forests and people to adapt to climate change.
v. Design and develop forest-based climate change adaptation interventions.
vi. Assess the challenges and barriers to climate change adaptation.
vii. Describe the role of forest ecosystems services in the adaptation of vulnerable social systems.

Activity 4.1 Brainstorming (10 Minutes)

How does climate change affect forest ecosystems?

4.2 Forests and tree resources response and resilience to climate change

4.2.1 Introduction

Building resilience of forests can be internal or external. Internal capacity entails the physiological and other responses made by the plant to changing climate conditions. External capacity entails the management activities that conserve and maintain forest ecosystem services. Management approaches to build resilience of forest ecosystems include rehabilitation of degraded lands, landscape restoration guided by six principles of landscape restoration, SFM actions to prevent degradation and disappearance of forests guided by seven thematic elements of SFM. In this section we learn about responses and resilience of forests and tree resources under climate change.

Learning outcomes

By the end of this session/lecture, the learner should be able to:

- Explain how forest and tree-resources respond to climate change and climate variability.
- Discuss interventions enhancing resilience of forest ecosystem to cope with impacts of climate change and variability.
- Explain guiding principles for landscape restoration.
- Analyse the applicability of thematic elements of SFM.

Activity 4.2. Brainstorming (15 minutes)

Discuss how forest and tree resources respond to impacts of climate change and variability.

4.2.2 Forest and tree resources response to climate change

There are several ways forests and trees respond to climate change and variability and these vary depending on the type of forest and geographic location. We have learnt that biological diversity in forest ecosystems can stabilise ecosystem functions when there are environmental fluctuations. There is variation among species responses to such fluctuation which is an essential requirement for ecosystem stability, due to the presence of species that can compensate for the function of species that are lost (Cleland 2011). In responding to climate change, forests and trees adjust their photosynthesis and respiration rates, phenology, frost and drought tolerance, soil organic matter and mineralisation rates and some species migrate or go extinct (Saxe et al. 2002, Lézine et al. 2019). The impacts of water stress depend on water conservative traits protecting vulnerable xylem transport system and these dictate patterns of leaf display in seasonally dry tropical forests (Vinya et al. 2019).

Warmer temperatures increase rates of virtually all chemical and biochemical processes in plants and soils in a similar way if substrates are available, up to a point where enzymes disintegrate. Temperature affects photosynthetic processes associated with light by altering the pigment content, the apparent quantum yield or photochemical efficiency of Photo System II and photo inhibition (Saxe et al. 2002, Smith et al. 2020). Korner and Basler (2010) and Avtar et al. (2020) showed that vegetation phenology is a sensitive indicator of ecosystem responses to climate change. Vegetation phenology is considered more constrained by minimum rather than maximum temperature regimes in different ecosystems (Jolly et al. **2005**, Daham et al. 2019). This is because minimum temperatures in spring and autumn are particularly important drivers in increasing growing season and subsequent vegetation growth (Hwang et al. 2018). Projected increase in temperatures will have significant impacts on rates of soil organic carbon (SOC) decomposition and will enhance nutrient mineralisation and availability (Saxe et al. 2001, Biswas et al. 2021).

Activity 4.3 Revision (10 minutes)
Explain how forest and tree resources respond to impacts of climate change and variability.

Further reading

Saxe H, Cannell MGR, Johnsen Ø, Ryan MG, Vourlitis G. 2001. Tree and forest functioning in response to global warming. New Phytologist 149: 369-399. https://doi.org/10.1046/j.1469-8137.2001.00057.x

Biswas DR, Ghosh A, Ramachandran S, Basak BB, Bhattacharyya R, Biswas SS, Moharana PC. 2021. Decay kinetics of enzymes as influenced by manuring under varying hydrothermal regimes in a wheat–maize cropping system of subtropical cambisols in India. Journal of Soil Science and Plant Nutrition 21(2): 908-921.

4.3 Forest and tree resources resilience to climate change

We have learnt about the impacts of climate change and climate variability to the forestry sector, and how forest and tree resources respond to climate change. In this section we focus on how to build resilience of forest ecosystem to climate change. Resilience of forest ecosystems can be strengthened by human interventions implemented at local or landscape level while considering the socio-ecological system. Forest management is key to supporting the recovery mechanisms of forest ecosystems (Thompson 2011, Ibáñez et al. 2019). There are many international initiatives created to quick start forest restoration, including rehabilitation of degraded forests (e.g. Bonn Challenge, AFRI100, etc.) through forest landscapes restoration, and adaptation actions in forest management, including application of SFM and participatory forest management.

Learning Outcomes

By the end of this session, the learner should be able to:

i. Explain factors that facilitate forest and tree resilience.
ii. Understand the international initiatives for rehabilitation and restoration of degraded lands.
iii. Describe activities that promote forest landscape restoration.
iv. Describe adaptation actions in forest management.

Activity 4.4. Brainstorming (10 minutes)

Explain how one can rebuild the resilience of forest ecosystems to respond to the impacts of climate change.

Adaptation measures in forestry depend on a variety of related factors, such as forest type, management goals, climatic threats and the non-climatic pressures. Forest ecosystems can be altered by global climate changes, as biophysical rates and physiological tolerances of species are likely to be exceeded (Thompson et al. 2009, Bravo-Oviedo et al. 2018). There is therefore a need to restore or maintain the resilience of a forest by manipulating the biological and ecological resources as an important societal climate change adaptation measure.

Biological and ecological resources that determine the resilience of a forest ecosystem to changing environmental conditions include:

- species diversity, including that of micro-organisms,
- diversity of genetic traits within populations of species and pool of species and ecosystems at regional level, and,
- extent of forest ecosystems covers with larger and less fragmented being better than fragmented and small in addition to the character and condition of neighbouring landscape.

(Thompson et al. 2009)

There are different methods or interventions carried out globally aimed at enhancing resilience of the forest ecosystem to respond to the challenges of climate change and climate variability. Some of these include, but are not limited to, the following:

a) Rehabilitation of degraded forests.
b) Forest landscape restoration.
c) Adaptation actions in forest management.
d) Urban forestry.
e) Watershed management.

The following sub-sections provide key highlights on how each of the identified interventions/ methods/ measures contribute to resilience of the forest ecosystem responding to the impacts of climate change and variability.

4.3.1 Rehabilitation of degraded forests

Development models that improve human well-being without damaging the environment are needed to curb problems associated with deforestation, fragmentation, desertification, water shortages, biodiversity loss and climate change, among others (Besseau et al. 2018). An international governance environment comprising international laws is also required. The activities are supported by international law, including in the agreements sealed at the United Nations Earth Summit in Rio de Janeiro (1992), the Convention on Biological Diversity (UNCBD), the United Nations Convention to Combat Desertification (UNCCD) and UN Framework Convention on Climate Change (UNFCCC) and the sustainable development goals (SDG) 15 (protection, restoration and promotion of the sustainable use of terrestrial ecosystems, sustainably managed forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss) (UN 2015).

Some of the existing development frameworks are the World Business Council for Sustainable Development (WBCSD) and the Global Landscapes Forum (GLF). Others are the Great Green Wall (GGW) and the African Forest Landscape Restoration Initiative (AFRI100). WBCSD advocates for land degradation neutrality and encourages a business case for halting land degradation (WBCSD 2015). GLF is the major global knowledge-led platform on integrated land use, dedicated to achieving the SDGs and Paris Climate Agreement through a holistic approach for creating productive, prosperous, equitable and resilient landscapes (Besseau et al. 2018). The GLF activities are based on five cohesive themes: food and livelihood initiatives, landscape restoration, rights, finance and measuring progress. Degraded landscapes affect livelihoods and wellbeing for some 3.2 billion people across the world, costing 10 % of the global economy (IPBES 2018). The global landscapes community made a target to restore more than 2 billion ha of degraded land worldwide, an area greater than South America (WBCSD 2015). The initiative requires annual investment by private and public sectors of up to $350 billion (WRI 2014).

A target was made by world leaders to intensify restoration efforts by supporting the world's largest restoration initiative to bring 150 million ha of degraded landscapes into restoration by 2020 (The Bonn Challenge). The leaders meeting in New York in 2014 called for the restoration of an additional 200 million ha by 2030, a target that was incorporated into the Bonn Challenge (Besseau et al. 2018). This was supported by the New York Declaration on Forests, which outlined other ambitious goals, including elimination of deforestation from agricultural commodity supply chains and strengthening forest governance. The GGW in Sahel and Sahara Initiative received at least 14 billion US$ in new funding in 2020 to fast track efforts to restore degrading land, save biological diversity, create green jobs and build resilience of the Sahelian people (UNCCD 2020). The GGW covers up to 156 Mha in 11 African countries (Burkina Faso, Chad, Djibouti, Eritrea, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal and Sudan).

Other initiatives include the AFRI100, or the African Forest Landscape Restoration Initiative, that targets to restore 100 million ha of degraded landscapes by 2030 (FAO 2020a, Mansourian and Berrahmouni

2021). Twenty-nine countries have pledged to restore about 125 million ha since the effort was launched in 2015. Seven of the country restoration commitments have areas over 5 million ha each, including Ethiopia (15), Sudan (14.6), Cameroon (12), Mali (10), DRC (8), Tanzania (5.2) and Kenya (5.1). Other countries include: (Benin (0.5), Burkina Faso (5), Burundi (2), Chad (3.5), Central African Republic (1.4), Cote d'Ivoire (5), Ghana (2), Guinea (2), Liberia (1), Madagascar (4), Malawi (4.5), Mozambique (1), Niger (3.2), Nigeria (4), Republic of Congo (2), Rwanda (2), Senegal (2), South Africa (3.6), Eswatini (0.5), Togo (1.4), Uganda (2.5) and Zimbabwe (2). The remaining countries had target areas below 5 million ha (AUDA-NEPAD 2020).

The initiative is supported by nine financial partners and 12 technical partners. Support includes the World Bank Africa's Climate Business Plan ($1 billion) and nearly $540 million from private investors (WRI 2015). Continental dialogues to support the initiative chronicled through the 2016 Kigali Declaration on Forest Landscape Restoration in Africa; the 2017 Lilongwe Call for Action; and the 2018 joint Funding Strategy for Central African Forests Commission countries (IUCN 2020).

Further reading
Mansourian S, Berrahmouni N. 2021. Review of forest and landscape restoration in Africa. Accra. FAO and AUDA-NEPAD. https://doi.org/10.4060/cb6111en. Available at: Review of forest and landscape restoration in Africa 2021 (reliefweb.int)

4.3.2 Forest landscapes restoration initiatives

Forest and Landscape Restoration (FLR) was initiated in 2003, by the Global Partnership of governments, organisations, research institutes, communities and individuals aiming at restoration of degraded forests and their surrounding landscapes. Forest and landscape restoration aims at reversing the degradation of soils, agricultural areas, forests, and watersheds to regain their ecological functionality. FLR is defined as a process aimed at regaining ecological functionality and enhancing human well-being in deforested or degraded land-scapes. Forest landscape restoration contributes to SDGs 1 ("no poverty"), 6 ("clean water and sanitation") and 15 ("life on land") while encompassing inter-nationally agreed commitments on forests, biodiversity, climate change and desertification (UN 2015). The Global Restoration Council supports the efforts of the Partnership by securing strong, long-term commitments. Forest and landscape restoration has emerged as a key element in strategies to meet this challenge, encompassing our efforts to address land management, biodiversity conservation and climate change. Through the SDGs and other agreements, the international community is committed to managing the earth's natural capital in a more sustainable path. There is need for increased Global Ambition on Ecosystem Restoration (IISD 2018).

Restoration activities in Africa
Ghana – restoration efforts that includes establishing commercial teak plantations and reintroducing native tree species having planted 190 450 ha between 2002 and 2015 (Foli 2018).

Madagascar - restoration of the Fandriana-Marolambo landscape has included planting 800,000 indigenous trees and establishing new economic activities including pig rearing, essential oils, fruit trees and beekeeping.

Niger and Ethiopia - low-cost "Farmer Managed Natural Regeneration" has yielded significant benefits. Re-growing indigenous trees and shrubs from stumps, sprouting root systems or seeds has helped ease food insecurity.

Rwanda - Planting of fruit and fodder trees to boost livelihoods and stabilise terraced farmland. (Besseau et al. 2018).

Restoration can happen by taking deliberate steps to integrate a greater number and variety of tree species into gardens, farms, fields and forests, or by allowing natural regeneration of overgrazed, polluted or otherwise overused ecosystems (Besseau et al. 2018). Forest landscape restoration seeks to restore ecological integrity and improve productivity and economic value of degraded forest landscapes, which may comprise other land uses in addition to forests. Essentially, it is a process to improve the productivity and capacity of landscapes to meet the various and changing needs of society. The FLR restores important goods and services while improving the livelihoods of local people. It is also a tool for achieving diverse landscape goals through developing mosaics of complementary, productive land uses (Winterbottom 2014).

About 2 billion ha of forests have been deforested since 1990 and most deforested and degraded land offers opportunities for "mosaic restoration" – where forests and trees are combined with agriculture, waterways protected areas and settlements on a landscape scale. The Global Partnership has developed an integrated, flexible and effective approach to forest and landscape restoration applicable from coastal mangroves and mountain ranges to freshwater wetlands and intensively cultivated agrarian zones (Besseau et al. 2018). The members of the Partnership gain through support for capacity building, technical support for planning, implementation and monitoring, for example through the Bonn Challenge Barometer (Dave et al. 2017). Restoration commitments are increasingly aligned with national and sub-national policy objectives on climate, biodiversity and desertification.

In forests, restoration can mean improving the availability of forest products from timber to game animals, stabilizing drinking water supplies for burgeoning cities, and countering biodiversity loss. Tree based systems can also enhance food security and nutrition under a changing climate (Oeba and Abdourahamane 2019). In agriculture, restoration can entail adoption of agroforestry. Principles of forest and landscape restoration include engagement of stakeholders and support for participatory governance. A list is outlined in table 4.

The benefits of restoration include the following:

- Environmental and social benefits of clean water and food security.
- Conservation of biodiversity and climate change mitigation and adaptation.
- Indirect and direct economic benefits, e.g. jobs can be created in tree nurseries, on the land, farms and in timber industries.
- Mitigation of costs of repairing flood damage to infrastructure, dredging lakes and rivers to remove silt.
- Avoided filtering of drinking water.
- Engaging with and empowering stakeholders.
- Builds social capital and makes it easier to reach the compromises necessary to secure long-term support.
- Makes landscapes more hospitable to endangered species and more resilient under climate change.

Table 4: Principle of forest landscape restoration

Principle	Description
Focus on landscapes	FLR takes place within and across entire landscapes, not individual sites, representing mosaics of interacting land uses and management practices under various tenure and governance systems. It is at this scale that ecological, social and economic priorities can be balanced.
Engage all stakeholders and support participatory governance	FLR actively engages stakeholders at different scales, including vulnerable groups, in planning and decision-making regarding land use, restoration goals and strategies, implementation methods, benefit sharing, monitoring and review processes.
Restore multiple functions for multiple benefits	FLR interventions aim at restoring multiple ecological, social and economic functions across a landscape and to generate a range of ecosystem goods and services that benefit multiple stakeholder groups.
Maintain and enhance natural ecosystems within landscapes	FLR does not lead to the conversion or destruction of natural forests or other ecosystems. It enhances the conservation, recovery, and sustainable management of forests and other ecosystems.
Tailor to the local context using a variety of approaches	FLR uses a variety of approaches that are adapted to the local social, cultural, economic and ecological values, needs and landscape history. It draws on latest science and best practice, and traditional and indigenous knowledge, and applies information in the context of local capacities and existing or new governance structures.
Manage adaptively for long-term resilience	FLR enhances resilience of forested landscapes and their stakeholders over the medium and long-term. Restoration approaches should enhance species and genetic diversity and be adjusted over time to reflect changes in climate and other environmental conditions, knowledge, capacities, stakeholder needs and societal values. As restoration progresses, information from monitoring activities, research and stakeholder guidance should be integrated into management plans.

Source: IUCN 2021. https://www.iucn.org/theme/forests/our-work/forest-landscape-restoration

4.3.3. Adaptation actions in forest management

Adaptive forest management

The best management practice for forest ecosystems would be to leave them intact. This is not practical and feasible given the rapid increases in human populations and associated demand for forest products. Some sort of management is inevitable to prevent total disappearance of forests. The activities that can promote some improvements in forest management systems are mainly based on the control of deforestation, reforestation and afforestation (Thompson 2011, Basnet and Karki 2020). Adapting forest management to climate change involves anticipating and monitoring changes and taking actions to prevent the negative circumstances or advantages of potential benefits of those variations (Levina and Tirpak 2006, Williamson and Nelson 2017, Ofoegbu and Speranza 2021). Furthermore, the forest stock needs to be correctly measured, monitored and reported.

Adaptive forest management includes several silvicultural measures such as changing species composition by converting monocultures to mixed forests, manipulating forest structure (e.g., shifting from even-aged to uneven-aged or coppice to high forest), intensification of thinning, or reducing rotation age (Yousefpour et al. 2017, Cosofret and Bouriaud 2019). Thinning is a silvicultural operation that focuses on stimulating growth of large residual trees, improving drought resistance, and providing greater resilience to future climate-related stress (Kerhoulas et al. 2013). Reducing the rotation period of tree crops can decrease their exposure time to risk and also reduces the risk of wind throws by limiting tree height. These adaptive management techniques generally reduce uncertainty and allows better adapted species to be replanted (Cosofret and Bouriaud 2019).

In adaptive forest management, responsive adaptation adjustments or interventions are processes that create or enhance the following:

- resilience and improved livelihoods,
- resilience and improved productivity in ecosystems, and
- sustainable governance - e.g., regulatory, institutional, educational (Lim et al. 2004).

For example, after a cyclone has destroyed housing infrastructure, all new houses that are to be constructed will have new building standards to enable them to be much stronger. In forestry, post cyclone salvage harvesting by the forest industries can be done.

Nyika (2021) suggested a five-step implementation plan on sustainable ecosystem management based on adaptive management and holistic consideration of ecological resources.

Sustainable Forest Management

SFM involves the design and implementation of caring and utilising forests and other wooded lands to meet economic, socio-cultural and environmental objectives.

> Sustainable forest management can contribute to climate adaptation and reverse the impacts of climate change on land degradation (IPCC 2019).

There are different goals for forest management ranging from protection for ecosystem services, timber production, NTFPs, protection of genetic resources, tourism, aesthetics or cultural values. Some goals can coexist whilst others cannot, e.g. sustainable commercial timber production and biodiversity conservation cannot coexist whilst management for ecosystem and genetic resource preservation can coexist through biodiversity conservation and providing goods and environmental services.

The application of principles and practices of SFM gives a sound basis for addressing climate change challenges. There are seven thematic elements designed as non-legally binding instrument for SFM (FAO/ITTO/INAB 2003) (Table 5).

Table 5: Thematic areas for sustainable forest management

Thematic area	Description
Extent of forest resources	Monitor extent and characteristics of forest resources to understand and reduce unplanned deforestation, restore and rehabilitate degraded forest landscapes, evaluate carbon sequestration in forests, other wooded lands and trees outside forests, and assign forests for different purposes.
Forest biological diversity	Covers the diverse life forms, genetic diversity and species ecological roles. Biological diversity in forest ecosystems allows species to evolve and adapt to changing environmental conditions (including climate), to maintain the potential for tree breeding and improvement (to meet human needs for goods and services and changing end-use requirements) and to support their ecosystem functions.
Forest health and vitality	Forest health and vitality is affected by several factors, including insects/pests, diseases, fire (wildfires and planned fires), other biotic factors such as wildlife browsing, grazing and physical damage by animals, abiotic factors such as air pollution, wind, snow, ice, floods, landslides, tropical storms, drought and tsunami and invasive species. Climate change is expected to increase pest outbreaks in new locations and greater severity of native and introduced pest impacts.
Productive functions of forest resources	Role of forests and trees outside forests in providing wood and non-wood forest products. Sustainable supply of primary forest products, while at the same time ensuring that production and harvesting without compromising management options of future generations.
Protective functions of forest resources	Role of forests and trees outside forests in moderating soil, hydrological and aquatic systems, maintaining clean water (including healthy fish populations) and reducing the risks and impacts of floods, avalanches, erosion and drought. Ecosystem conservation efforts and associated benefits to agriculture and rural livelihoods.
Socio-economic functions of forest resources	Contributions of forest resources to the overall economy and hosting and protection of sites and landscapes of high cultural, spiritual or recreational value, including land tenure, traditional knowledge and indigenous and community management systems.
Legal, policy and institutional framework	Includes the legal, policy and institutional arrangements necessary for supporting the other six themes and should include participatory decision-making, governance and law enforcement, fair and equitable use of forest resources, education and scientific research, infrastructure arrangements to support the forest sector, transfer of technology, capacity-building, public information and communication, and monitoring and assessment of progress.

Source (FAO/ITTO/INAB 2003)..

The management of forests based on the concept of SFM is dynamic and evolving aiming at the maintenance and enhancement of the four pillars of sustainability (social, economic, cultural and environmental values) in all forest types, for the benefit of all generations. It involves performing all activities related to the economic, administrative, legal, technical, social and scientific activities in both natural and planted forests. Management activities include protection and maintenance of ecosystem functions, and of specific socially or economically valuable species or groups of species for improved productivity. In this regard, SFM entails the human interventions promoting sustainable use and protection of forest resources to maintain and enhance their multiple forest uses. SFM is also considered together with the conservation of biological diversity and climate action.

Climate change can affect forest ecosystems, communities and infrastructure, thus exacerbating the vulnerability of forest dependent communities. This emphasises the need for policy and action to increase resilience through the forests (FAO 2020b). However, SFM initiatives need to be reconciled with local forest management interests if sustainable forest outcomes are to be assured. The initiatives should emphasise local control and management of existing forest resources, the multiple roles of trees in farming systems and the importance of working through local institutions to achieve sustainable forest management (FAO 2016c). As atmospheric GHGs increase, forest carbon sequestration becomes an important mitigation measure which can increase adaptive capacity of communities. Productivity of managed forests is essential, to prevent clearing of more virgin forests. SFM in natural and planted forests can help in poverty alleviation, reducing deforestation, stopping biodiversity loss from forests and reducing land and resource degradation apart from reducing climate change risk (Sim et al. 2004, African Union Commission 2020)

Case studies – Sustainable Forest Management

1. Coastal zone management in Guinea. Adaptation is promoted through management of 200 beehives carried out via a community association, making the common resource a closed resource. They also used an efficient charcoal production kiln called the meule casamancaise, which was first experimented with in Casamance (south of Senegal). Furthermore, eight hectares were reforested in order to concentrate the wood logging for charcoal production in managed areas. The SFM plan defines the logging zones, regulates access to these areas and specifies the sustainable harvesting yield. The project also included use of improved cooking stoves, with an enhanced efficiency of 35 % (UNDP 2018). In these communities, human, social and financial capitals greatly affect the attainment of positive results related to planned interventions (Ceci et al. 2018)

2. In Malawi, a community-based natural resource management approach used in Mwanza, showed that income from NTFPs and related activities can build up household livelihood strategies by increasing incomes and food sources of local people, and can provide for general sustainable development. The intervention in turn, encouraged communities to conserve and manage their natural resources in a sustainable manner because of the inherent direct value of the NTFPs (Mauambeta 1999).

Activity 4.5 (15 Minutes) Brainstorming
What are other methods or interventions carried out in your country aimed at enhancing resilience of the forest ecosystem in responding to the challenges of climate change and climate variability.

Summary

There are several ways in which forests and trees can respond to climate change and variability. These can be different depending on the type of forest and geographic location. Temperature, precipitation and CO_2 are important factors for plant growth and development. Climate change alters optimum requirements for plant growth inducing stress. Generally, biological diversity in forest ecosystems stabilises ecosystem functioning. Genetic diversity controls inter-specific competitive relationships that constitute fundamental determinants of potential species responses to change, in conjunction with mechanisms of dispersal. Climate change is likely to affect population dynamics, timing of reproduction or migration, and growth of forest ecosystem components. Under a changing climate, forest species can either adapt to climate change or become extinct. A healthy forest ecosystem sustains its processes, function, structure, productivity, composition, and resilience over time and space. When climatic conditions go beyond physiological thresholds of species or if the climatic conditions trigger insect pest outbreaks, tree mortality can occur at various levels. Forest resilience can also be linked to resilience approach to sustainable development where capacities are built to tackle unexpected events and people interact with the biosphere (air, water and land) as one of its components rather than as external drivers of ecosystem dynamics. If a system is more vulnerable, its resilience decreases as vulnerability increases when faced with major disturbances such as those linked to climate change. Management approaches that can build resilience of forest ecosystems include rehabilitation of degraded forests, forest landscape restoration, fire management and creation/expansion and adaptive management of parks/reserves. Others are protected areas and biodiversity corridors, fire management, silvicultural manipulations, pest management, forest governance, nursery techniques and control of invasive species. Forest management actions need to be adjusted to build the resilience of forests and trees to the negative impacts of climate change and build and maintain resilient landscapes.

Further Reading

Mansourian S, Berrahmouni N. 2021. Review of forest and landscape restoration in Africa. Accra. FAO and AUDA-NEPAD. https://doi.org/10.4060/cb6111en. Available at: Review of forest and landscape restoration in Africa 2021 (reliefweb.int).

4.4 Role of forests and tree resources in adaptation of social systems to climate change

Forests provide important services at all scales, from local to global, reducing the vulnerability of society to climate change. The Millennium Ecosystem Assessment (2005) defined forest ecosystem services as those benefits obtained by people from the forest. In this session, learners are introduced to the role of forest and tree resources in climate change adaptation. It addresses broad categories on how forest and tree resources support social systems to respond to climate change and variability. It also presents challenges to adaptation.

Learning outcomes

By the end of this session, the learner should be able to:

- Describe the role of forest ecosystem services in climate change adaptation.
- Identify technological adaptation options that could help forests and people to adapt to climate change.
- Develop forest-based climate change adaptation interventions in social systems.

Activity 4.6 (Brainstorming) (15 Minutes)

Share your views on the role of forest ecosystem services in adaptation to climate change and variability by societies.

There are four types of services from forests that directly contribute to human well-being: **regulating services**, such as regulation of water, climate, or erosion; **provisioning services** (also called ecosystem goods), such as food and fuel; **cultural services**, such as recreational, spiritual, or religious services, and **supporting services,** primary production, habitat, nutrient cycling etc. (Table 6).

Table 6. Examples of ecosystem services and adaptation of people and sectors to climate change.

Region	Problem	Adaptive measure
Central Africa	Local livelihoods affected by climate events	Forest products, that are less sensitive than agriculture, used as safety nets Improved forest management
Central America	Increasing rainfall intensity and soil erosion. Sedimentation of hydroelectric dams.	Upstream soil conservation and forest protection
Southeast Asia	Vulnerability of coastal areas to storms, waves and sea level rise	Protecting mangroves and provision of goods. Enhanced mangrove management

(Source Locatelli et al. 2008, Sokona et al. 2021).

Forests support social systems to adapt to climate change. When forests are degraded the flows of forests ecosystem services become insecure, making communities and sectors more vulnerable to climate change and vulnerability and can also lead to higher costs of adaptation (Locatelli et al. 2008, Sokona et al. 2021).

Forest cover facilitates resilience of hydrological ecosystems services (e.g. conservation of base flow) to climate change mitigation and adaptation. It also increases rainwater infiltration, reduces surface run-off and controls soil loss, consequently reducing the negative impacts of floodwaters. Forests and trees can also be sources of natural water recharge mitigating stream flow reducion that can be threatened by drought. The role of forest and tree resources in climate change adaptation can be grouped into two categories:

- Technological adaptation (agroforestry systems and practices, urban forestry, use of renewable energy, manipulation of plant water relations, soil and water conservation and intensification of production systems).
- Social and economic adaptation (sustainable and diverse livelihoods, strengthening social systems, gender considerations and forest based indigenous coping and adaptation mechanisms).

The following subsections provide key highlights on each of these categories.

4.4.1 Technological adaptation

As indicated above, technological adaptation encompasses agroforestry systems and practices, urban forestry, use of renewable energy, plant water relations, soil and water conservation, and intensification of production systems. These are explained in the sections below.

Agroforestry systems

There are several ways of achieving sustainable agricultural goals through a combination of increased yields and ecosystem services, with crop production providing other ecosystem service (Chavan et al. 2014). Woody perennials are an integral component of cropping and livestock systems. Agroforestry is one of the intense land-use management systems combining trees and/or shrubs with crops and/or livestock. Agroforestry is increasingly recognised as an efficient approach to minimise risks of production under climate variability and change (Lin 2010a).

Climatic and weather-related stresses have an impact on all sectors, including small-holder farming communities. It is, therefore, important to select land use options that simultaneously enhance agroecosystem diversity and farm productivity. Most of the benefits from agroforestry are directly linked to climate change adaptation although they also contribute to climate change mitigation. Given these benefits, agroforestry is gradually being considered as one of the sustainable land use options for enhancing the ability of farmers to adapt to climate change in multi-functional landscapes (Schoeneberger et al*.* 2012, Mbow et al. 2014).

The growing of trees on farms through agroforestry has long been suggested to have potential for increasing resilience of smallholder farmers to climate change risks, mitigate environmental damage, and increase income (Kerr 2012, Schoeneberger et al*.* 2012, Hughes et al. 2020, Kassa 2021). Smallholder farmers, particularly those in Sub-Saharan Africa, who are more dependent on rain-fed agriculture and forestry, coupled with intricate interactions of winds, local heat and hydrological feedbacks, are faced with challenges of temporal and spatial rainfall events. Furthermore, soil resources and water storage are affected by a changing climate, adding more stress on the farming system. When water availability is limited, agriculture will compete with other uses of water, worsening the stress (Boko et al. 2007, Gowing et al. 2020).

Trees planted in cropping areas can maintain production under variable climate and shelter crops against extreme climate and weather events (Chavan et al. 2014). The deep roots of trees explore deeper soils for water and nutrients, which can be beneficial to crops during dry spells. Tree litter increases soil porosity, reduces runoff, and increases water infiltration and retention and reduces moisture-stress during drought episodes (Rao et al. 1998, Haas et al. 2020). Excess water is pumped out of the soil more rapidly in agroforestry plots due to their higher evapotranspiration rates.

Maize agroforestry is practised in Zambia (300 000 ha) and in Malawi (half a million farms) resulting in increased maize yields of up to 400 percent. The leguminous trees and shrubs (mainly *Faidherbia albida, Sesbania sesban* and *Gliricidia sepium*) add from 100 to 250 kg of nitrogen per ha to the soil in two to three years. The growing maize with leguminous trees and shrubs generates higher net returns than growing maize with subsidised mineral fertiliser. The system uses water more efficiently and is more resilient to drought. Furthermore, agroforestry provides fuelwood and fodder, improves water filtration and sequesters carbon (FAO 2016b).

Products of agroforestry help small-holder farmers to obtain multiple products, markets and farm income while soil and water quality are improved (Lin 2010a, Amare et al. 2019). Furthermore, soil erosion is reduced, non-point source pollution and flood damages are minimised. In this regard, goods, services and income are obtained, including enhancement of local climate conditions and reduction of anthropogenic impacts on natural forests. Integrating agroforestry practices in the farming system can improve aquatic and terrestrial habitats, enhancing biodiversity while sustaining the land resource base (FAO 2016a, Luke et al. 2019). Agroforestry can also be an option for increasing water use efficiency in agroecosystems as tree roots facilitate infiltration of precipitation to the aquifer while controlling the flow down the slope during drought periods. Tree roots can also influence soil moisture through hydraulic redistribution and thus, enable crops to access sufficient moisture even during drier periods of the year. Furthermore, agroforestry trees can reduce evapotranspiration losses in both crops and soil (Lin 2010b).

Agroforestry can be managed to provide more resilience to extreme events (e.g. drought, floods etc.) by facilitating flexible responses to rapid shifts in ecological conditions (Lin 2011, Amare et al. 2019). In order for a system to be called agroforestry it should have the characteristic 4 ”I”s i.e. being intentional, integrated, intensive and interactive (Box 4.1).

N-fixing trees improve drought-resilience in agriculture due to enhancements of soil nutrients and water infiltration, mainly in degraded lands and help in adaptation to climate change. In Malawi and Zambia, maize yields improved where conservation farming was practiced incorporating Faidherbia albida (the tree sheds leaves early in the rainy season sprouting at the end of the wet season, limiting competition from crops). In Malawi, farmers who integrated *F. albida* and *Gliricidia sepium* with crops, harvested modest yields during drought seasons, while farmers without the practices experienced total crop failure (Akinnifesi et al. 2010).

Agroforestry systems are defined as multifunctional systems that can provide a wide range of economic, sociocultural and environmental benefits. FAO (2015) showed three main types of agroforestry systems but there can be variants to these depending on the main objective on the farm:

- **Agrisilvicultural** systems are a combination of crops and trees, e.g. alley cropping, improved fallow, windbreaks or home gardens.
- **Silvopastoral systems** combine forestry and grazing of domestic animals on pastures, rangelands or on-farm.
- **Agrosylvopastoral** systems have the three components of trees, animals and crops, which can be integrated on the same piece of land. Examples of practices included as home gardens with fodder as well as scattered trees on croplands used for grazing after harvests.

Agroforestry systems can be classified based on structure of the components, functions of the components, agronomic adaptation and technological inputs to the system. The systems and practices include a variety of land management options such as diversification of crops, home gardens, long rotation systems for soil conservation, boundary plantings, hedgerow intercropping, perennial crops, live fences, riparian buffers, forest farming, improved fallows or mixed strata agroforestry (Akinnifesi et al. 2010, Sjöberg and Sativa 2019).

Box 4.1 The 4 "I"s of agroforestry (Gold et al. 2013).

Intentional
Agroforestry is neither a mixture of monocultures nor monoculture but is a combination of trees, crops, and/or livestock in an intentional design, established and/or managed to work simultaneously or sequentially to yield multiple products and benefits, instead of individual elements managed separately.

Integrated
Agroforestry components are functionally and structurally mixed into a single, integrated management unit designed to meet the objectives of the farmer. The integration may be horizontal or vertical, above or below ground, simultaneous or sequential. Integration of multiple crops helps to stabilise economic production with resource conservation and exploits the land's productive capacity.

Interactive
Agroforestry dynamically controls and exploits interactions amongst components to provide multiple products, while at the same time delivering other conservation and ecological values.

Intensive
Intensive management of agroforestry practices maintains their productive and protective functions, and generally involves cultural actions such as cultivation, irrigation, fertilisation, pruning and thinning.

Some agroforestry practices that have been practiced throughout the world include improved fallows, alley cropping, home gardens, windbreaks/shelterbelts, riparian buffers, silvopasture and Taungya. Figure 5 shows some of the practices. These practices will be discussed in detail in the following sections.

Figure 5. Agroforestry Practices: A. Alley Cropping, B. Windbreak, C. Riparian buffer, D. Silvopasture, E. Forest farming (Source Bentrup and MacFarland 2020).

Improved fallows. Declining soil fertility and high costs of inorganic fertilisers contribute to poor food production in sub-Saharan Africa, despite the availability of improved crop varieties. Improved fallows are an agroforestry practice where legume shrub/tree species are planted sequentially with crops. Trees/shrubs grow during the fallow phase which can vary from six months to three years or longer while enriching the soil. The longer the fallows, the better the soil improvement (Amadalo et al. 2003). A short duration improved fallow can have residual effect lasting one to two seasons, whilst fallow period of eight months can have residual effects that last more than one season, depending on initial soil degradation level. Over 20,000 farmers in Southern and Eastern Africa have adopted improved fallows using species such as *Sesbania sesban, Crotalaria grahamiana, Cajanus cajan, Tephrosia candida, T. vogelii Mucuna pruriens* and *Callopogonium mucunoides* and using two-year fallows and maize rotations. Partey et al. (2017) showed that the nutrient use efficiency and soil fertility were improved after using fallows, resulting in increased maize yields up to about 6 Mg/ha, which was as good as conventional maize yields under inorganic fertilisers in the same areas. In this regard, improved fallows can contribute to climate change mitigation and adaptation, food security and the sustainable conservation of natural resources (Prinz 1986, Oeba and Larwanou 2017). Furthermore, the multiple outputs of improved fallows can also increase fodder availability over the dry periods and possible biomass for charcoal production. These livelihood options may become important financial safety nets during off seasons or in the event of crop failures. **Alley Cropping** is a specific practice where trees or shrubs in single or multiple rows are grown alternatively with agricultural crops. The trees are commonly pruned to limit the shading of the agricultural crop. Alley cropping can also contribute to nutrient cycling and erosion control. In some cases, high-value species can be used in alley cropping practices to potentially provide fruits and timber in the long-term. Alley cropping systems modifies the crop microclimate by reducing extreme temperature and wind speeds, increase humidity around the plant surface and in so doing they reduce water loss. Crops protected by fast growing hedgerows have increased photosynthetic rates and water use efficiency (AGFOWARD 2017).

> Adopting agroforestry practices helped smallholder farmers in East and Southern Africa by providing a constant soil cover. The trees growing on farms provide enough biomass to both meet livestock needs and improved maize yields (FAO 2016b). The trees also provided fuel for rural households. For example, in Zambia, farmers were able to gather 15 tonnes of fuelwood per ha after the second year of fallow with Sesbania and 21 tonnes after the third year. In countries such as Burkina Faso and Niger, agroforestry has been shown to improve the yields of millet and sorghum (Garrity et al. 2010).

Tree/shrubs planted as hedgerows shelter crops and soils from extreme weather events. The diversification increases productivity of the land and protects the farmer in case of complete crop failure (Schoeneberger et al*.* 2012, FAO 2016b).

Riparian and Upland Forest Buffers. Riparian Buffer Strips are linear bands of stable vegetation neighboring aquatic ecosystems intentionally grown to preserve or improve water quality, reduce runoff of sediments and pollutants from both overland and shallow subsurface flow and they contribute to reducing vulnerability to floods (Climate ADAPT 2015). A general, multi-purpose, riparian buffer design consists of a strip of grass, shrubs, and trees between the normal bank-full water level and cropland.

Buffer Strips can therefore, act as dispersal corridors for climate-induced species range shifts and to provide microclimatic refugia from warming (Krosby et al. 2018). Buffer strips also provide habitat for aquatic species and may help increase recharge of groundwater. Vegetated and unfertilised buffer zones alongside watercourses improve micro-climatic conditions and are shields against overland flow from agricultural fields. Riparian areas with trees also provide direct shade for the water body, reducing the influx of solar radiation on it and thus avoiding the corresponding increase in water temperature (Climate ADAPT 2015).

The success of buffer strips is strongly dependent on characteristics such as buffer zone width, slope of the adjacent fields, soil type and variety, and density of vegetation. Other benefits are increased biodiversity and aesthetic value, increasing people's enjoyment of the environment and providing green recreation spaces. As a climate change adaptation, the key benefits are linked to the cooling of the water body, increased air humidity and temperature stabilisation and water retention (Climate ADAPT 2015, Rempel and Buckley 2018).

Windbreaks and shelterbelts are agroforestry practices where vegetative barriers are planted to reduce or eliminate impacts of excessive wind. They comprise one or more tree or shrub rows adjacent to buildings or in open field areas. Shelterbelts can be created by planting species that are adapted to the area or by protecting natural plant communities (Ibrahim and Gaya 2016). Shelterbelts can also be produced during the clearing of land and forestry operations by leaving tree spaces. If timber production is one of the objectives, they are called timber belts. Given the anticipated increased frequency of extreme weather events, changes in wind frequency and intensity are likely to affect landscapes. Shelterbelts have the potential to reduce wind related vulnerabilities and risks and to moderate microclimates (Chavan et al. 2014). Shelterbelts retained in pastures could moderate losses in forage quality and quantity over the dry season.

Silvopasture is the practice of intentionally integrating the management of forages, trees and livestock. It can be done by establishing trees in existing pasture or establishing a selection of forages to intensively manipulate the forest environment to provide grazing and timber. Trees/shrubs used in silvopasture should be marketable, high quality and fast growing, deep rooted and tolerant to site conditions. The ultimate benefits are those of diversification, tree and animal productivity, reduced animal stress, improved nutrient cycling and enhanced wildlife habitat (Gold et al. 2013, Beillouin et al. 2021). However, to get maximum benefits the areas may need water supplies and to be fenced off, creating an additional cost.

Forest farming is an intentional and environmentally sound farming practice for generating marketable NTFPs in woodlands or forests with suitable site conditions. NTFPs include medicinal, edible, floral and decorative and craft species. The agroforestry practice facilitates forest management diversification and provides intermediate and periodic income opportunities and is important in times of drought or crop failure. It can improve forest composition and forest health apart from diversified income opportunities (Gold et al. 2013, Moubarakatou 2017).

Taungya is an agroforestry system linked to forest management where land is cleared and planted initially to food crops. Seedlings of desirable species are then planted on the same land, leading to harvestable tree crops. It involves a special arrangement between a forest organisation and farmers to simultaneously grow tree crops and agricultural crops. Taungya has a high potential to reduce vulnerability due to short-term food production and long-term plantation establishment (Kalame etl al. 2011) and can reduce the conflicts associated with land hunger. Adegeye et al. (2010) found higher crop yields under taungya than non-taungya areas. The resilience of taungya systems is associated with economic and social factors that show the cultivation of crops as an adaptive strategy of land use for communities around planatation forests.

4.4.1.2 Urban forestry, green cities and their contribution to climate change

Urban green spaces include lands covered with natural or man-made vegetation located in built-up areas (Phan and Nakagoshi 2007, Hernandez et al. 2018) and are associated with sustainable urban development. Urban green spaces provide several ecosystem services - environmental, aesthetical, recreational and economic benefits to urban communities (Hernandez et al. 2018) (Figure 6). Urban forests, like other forests, can be instrumental in adapting and mitigating to climate change by sequestering atmospheric CO_2, reducing energy requirements for heating and cooling in buildings, although trees can increase or decrease winter heating usage depending on location (Pauleit et al. 2013).

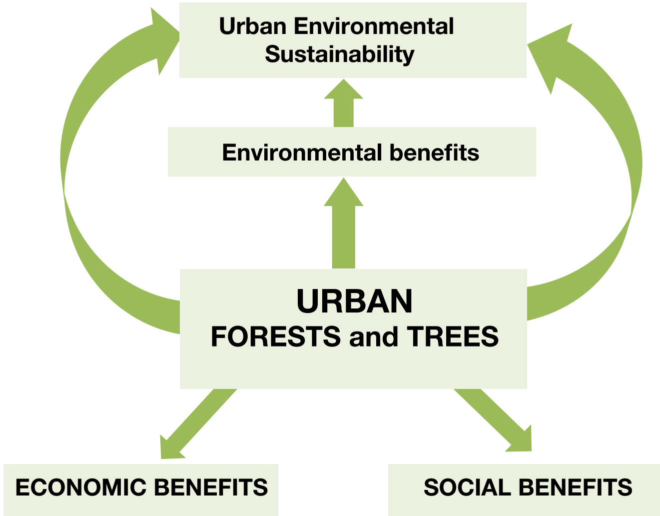

Figure 6. Relationship between urban forests and trees and sustainability.

Urban green spaces in developing countries are not as prevalent when compared to developed countries. Beyond the uses the focus has been shown to have good viability. Urban green spaces can also be important in biodiversity conservation, protection of water resources, microclimate amelioration, reducing urban air pollution load, mitigation of climate change related health issues, flooding control, provision of purified air, acting as heat absorber during the hot summer (temperature modification) and provision of food for urban dwellers (Lovell and Taylor 2013, Chen and You 2020, Xu et al. 2020, Holmgren and Sörqvist 2018, Priya and Senthil 2021). Urban forests and trees provide environmental, economic and social benefits (Frigeri et al. 2017). Examples are provided in the explanations below.

Environmental benefits include reduction of urban air pollution, reduction of urban heat island effects, ecosystem health, improved biodiversity, soil fertility improvement, soil conservation, environmental sustainability, reduction of noise and proving a barrier against natural disasters.

Economic benefits include employment opportunities for the urban poor, food and medicines, reduced health bill, tourist attraction and enhanced tourism, supply of fuel and energy.

Social benefits include aesthetic beauty, improved quality of life to urban dwellers, better public health, psychological development of urban children, poverty alleviation and social and recreational values. Urban forests and trees can also have positive impacts on physical and mental health by connecting with communities, providing opportunities for refreshment, reducing stress and areas for physical exercise. Urban forests and trees in cities provide urban inhabitants particularly the poor with recreation (Konijnendijk et al. 2013, Holmgren and Sörqvist 2018). For example, Uhuru park and Karura Forest in Nairobi, Kenya and Mukuvisi woodlands in Harare, Zimbabwe.

4.4.1.3 Use of renewable energy and energy efficiency

Renewable energy is a kind of energy that can return to nature unlike non-renewable energies. Examples of renewable energy include solar energy, wind energy, hydroelectric power, biomass energy, geothermal and tidal/wave energy. There are a variety of renewable energy technologies available, with technology-specific advantages and disadvantages (Shinn 2018). Renewable energies are important because they provide the following benefits: a clean energy source, have less environmental impact, resources are endless, resources reduce dependence on fossil fuels and provide energy security (Abdollahi et al. 2019). Some technologies can provide baseload power (e.g. hydro, geothermal and biomass) while others are more variable in nature requiring additional grid balancing services (such as solar and wind energy). Renewable energy sources are promoted at meaningful scale in many countries and are key to the replacement of fossil fuels. The use of renewable energy and the improvement in energy efficiency can lead to achievement of the 1.5°C ambitious Paris Agreement target of 2016. The fossil fuel capacity will need to be largely phased out by mid 21stcentury, with complete phasing out of coal power plants in the long term. In the interim, natural gas power plants can play a transitional role in replacing fossil fuels but will eventually need to be phased out in the long term because they are non-renewable (Climate Analytics 2019).

IRENA (2019) reported growth of renewable power capacity from 1,136 GW in 2009 to 2,351 GW in 2018 with African capacity only 2% of the global share. This is facilitated by the decrease in the cost of renewables such as solar Photovoltaic (PV) and wind energy (IRENA, 2019) and, in some countries, shortage of grid power supplies. More innovation is needed to improve efficiency and capacities of storage technologies, such as batteries and thermal storage for concentrated solar power (CSP). Limitations of renewable energy are linked to geographical location, weather conditions and annual and seasonal fluctuations. Another alternative source of renewable energy source is nuclear power, but it is hindered by rising costs, potential environmental pollution and limited provision of co-benefits compared to renewables (Climate Analytics 2019). Nuclear energy also faces considerable resistance from civil society, because of the probable hazards associated with the safety and the disposal of nuclear waste. Despite these challenges, some countries still consider nuclear energy to be a safe economic option (Abdollahi et al. 2019). Nuclear energy does not cause the many types of environmental problems associated with fossil fuels but once it leaks, the effects are extremely prolonged like in the case of the Chernobyl disaster in the 1980s.

The Agriculture, Forestry and Other Land Use (AFOLU) sector can also potentially contribute with negative emissions through increased storage of CO_2 in forests, soil, or other locations. Combining biomass energy (BE) with carbon capture and storage (CCS) can maximise the CO_2 absorbed by biomass during its lifetime, by ensuring that it is captured and stored after combustion for power or heat. Energy efficiency can help reduce emissions from fossil fuel and can additionally be reduced through energy efficiency measures and CCS.

> The Sustainable Participatory Energy Management Project (PROGEDE in French) in Senegal helped combat Senegal's rapidly growing demand for household fuels and the associated degradation of forests and the rural environment (World Bank 2016).

The world's forests remain the largest bioenergy source since time immemorial. Forests provide a reliable and affordable source of energy for many of the world's poorest people but there is need for proper management of techniques for the forests to ensure sustainability of the energy base (Bull 2018). Technologies such as improved cook stoves could reduce demand for wood. In 2014, traditional renewable energy (firewood and charcoal, agricultural residues and animal dung) in Africa represented over 85% of renewable energy consumption with 90% of sub-Saharan Africa relying on wood energy for cooking and heating (Otula et al. 2021). There is, however, a relationship between traditional biomass consumption and population growth, especially in poorer countries (World Bank and the IEA 2017). In Kenya, Uganda, Tanzania and Sudan, the expansion of access to electricity kept pace with population growth between 2010 and 2018 (World Bank 2020). Forest and woody biomass will likely remain the most effective replacement of fossil fuels, especially in many developing countries because forests are renewable and expandable, so they represent the greatest opportunity to sustainably expand the use of renewable energy and at the lowest cost. In this regard, the use of more renewable energy, including bioenergy, can be an effective tool in adapting to climate change (Bull 2018).

4.4.1.4 Intensification of agricultural production systems.

Sustainable intensification (SI) can provide productivity, socio-economic and environmental benefits to smallholder farmers and to society at large, including: high and stable production and profitability, higher farmer income and improved rural livelihoods, increased availability and consumption of the diverse range of foods necessary for a healthy diet, adaptation and reduced vulnerability to climate change and other shocks, enhanced ecosystem functioning and services, and reductions in agriculture's GHG emissions and carbon footprint (FAO 2011, Mutanga et al. 2018, Nassary et al. 2019, Tesfai et al. 2020). Sustainable agricultural intensification is required for increasing productivity of land, given the urgency to cut GHG emissions (Brandt et al. 2018, Kuyah et al. 2021). Intensification reduces and traps emissions whilst concurrently improving sustainable food security (Godfray and Garnett 2014, Kuyah et al. 2021)). In this regard, it becomes critical to adopt SI approaches where food production is increased in existing farmlands using activities of low environmental impact without compromising production of future food. This is because the growing food demand should be met using existing agricultural land without opening new land. This is achieved by increasing productivity per unit area. The SI approach is an important climate change adapting option, likely to lower emissions and reducing clearing of forests for agricultural expansion.

However, it is important to consider the fact that having a more efficient agricultural system could lead to higher profits and can motivate farmers to expand cropping land. In the short term, the extent of this direct recovery depends on the price elasticity and effectiveness of governance (Lambin and Meyfroidt 2011, Nyagumbo et al. 2018, Belton et al. 2020). Furthermore, protection of forested lands, grasslands and wetlands requires governance mechanisms for protecting areas with large carbon stocks, where communities obtain NTFPs. The protection of forests also facilitates soil and water conservation and can enhance crop production resulting in improved resilience to climate change and variability, thus building the coping mechanisms against adverse effects of climate change (Jhariya et al. 2019, López-Vicente and Wu 2019).

In text question (15 Minutes)

1. What is the link between sustainable intensification and forest conservation?
2. Give examples of forest based technological adaptations practices in your country.

Sustainable intensification is an adaptive measure because it affects farm incomes. Any activity that increases farm incomes allows farmers to increase their assets for use in times of stress or households are raised to a different development trajectory. In Africa, the sustainable agriculture intensification based on technologies that depend on investment inputs has been seriously hampered by poorly developed input and output markets (Dorward et al. 1998, Nagothu et al. 2018), and the technologies have performed poorly because of their inadequacy to fit within local smallholder systems (e.g. Giller et al. 2011). Furthermore, the potential benefits of agricultural intensification can have benefits such as land preservation, food security, reduction of GHG emissions, and reducing soil and general environmental degradation (Vanwalleghem et al. 2017). For example, Tittonell et al. (2013) and Chatrchyan et al. (2018) showed that when soil degradation occurs, African smallholder farmers will gain from the major components of intensification such as low fertiliser inputs and improved crop yields. In some cases, clearing of vegetation for cultivation, as practiced in most African savannahs triggers negative feedback loops or vicious cycles characterised by the disturbance of soil physical properties, increased erosion, accelerated decomposition rates and gradually decreasing soil carbon inputs in the form of crop residues caused by declining crop yields (Tittonell and Giller 2013, Zulu et al. 2021). Tilman et al. (2002) and Dakora et al. (2020) suggested that yield gaps can be reduced using agricultural intensification applying new technologies including soil fertility management to help poor countries to realise a more equitable food supply while contributing to decreased GHG emissions. SI also emphasises diversification and exploitation of complementarities between crops, across crop-livestock systems and in risk management (Campbell et al. 2014). Diversification is, therefore, a crucial component for building adaptive capacity.

4.4.2 Other important technological considerations

4.4.2.1 Plant water relations, including water efficiency and rainwater harvesting and usage

Water movement through plant tissues can occur through coexisting pathways: apoplastic, symplastic and transcellular. The apoplastic pathway has water fluxes around the cells whilst water moves across cells involving plasma membrane in the symplastic pathway. In the transcellular pathway water movement is also through vacuoles incorporating tonoplasts. The symplastic and transcellular pathways are the cell-to-cell pathways, under fine regulation, of transportation via plasma membranes (Barberon and Geldner 2014, Ai-hua et al. 2017). In the root cortex, the water movement is manly apoplastic, although the Casparian band, a deposit of suberin and/or lignin, restricts the radial water movement in the apoplast and cell-to-cell transport is carried out at the endodermis. Plants can modify the apoplastic and "cell-to-cell" pathway contributions depending on the environmental conditions and transpiration demand (Taiz and Zeiger 2010, Yang et al. 2018). Water potential affects several plant physiological processes (Figure 7

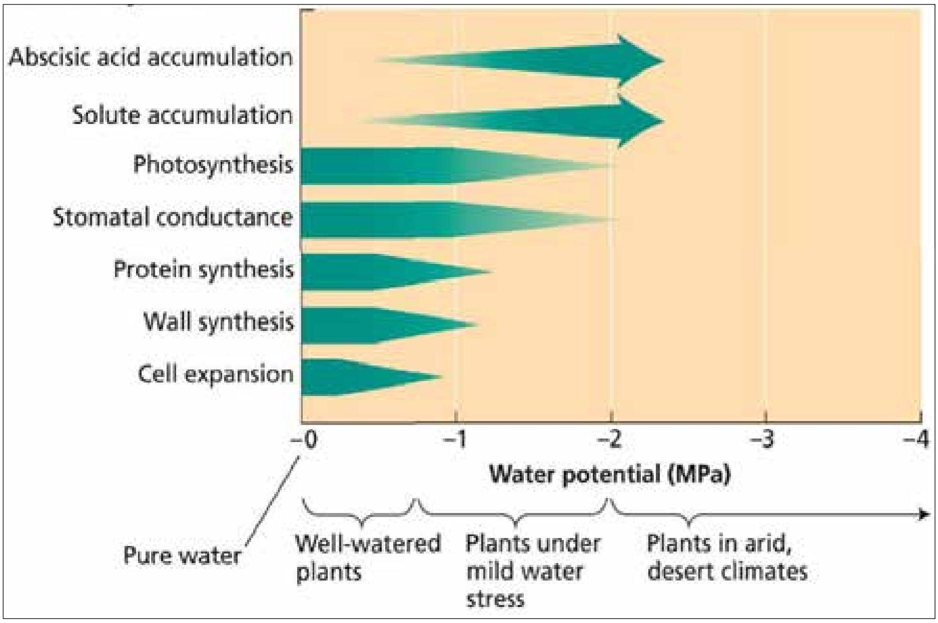

Figure 7. Effect of water potential on physiological changes due to dehydration (Taiz and Zeiger 2010).

Elevated CO_2 concentrations stimulate photosynthesis, modifying water and nutrient cycles leading to increased plant productivity (Soussana and Lüschert 2007, Hussein 2020). The growth of plants can be directly increased through improved photosynthesis, or indirectly via stimulated consumption of water by the plant. This affects root mass and whole-plant water transport, with the expense of water-use efficiency (WUE) and soil water content, reduced stomatal conductance and its effects on leaf water potential (Filipović 2020). WUE is often taken as an important factor of yield during stress and as an element of crop drought resistance. It has been used to show how rain-fed plant production can be increased based on water used per unit. Effective use of water (EUW) reflects highest soil moisture captured for transpiration and involves reduction of non-stomatal transpiration and negligible water loss through soil evaporation. Effective water use is the opposite acronym of WUE and high WUE is achieved at the expense of reduced EUW (Blum 2009, Ellesworth and White 2020), Capacity of root systems for water uptake depends on rooting volume (or rooting depth), activity and fine-root area (Wullschleger et al. 2002, Ries 2017). This is important in agroforestry systems.

In arid and semi-arid areas water is a crucial limiting factor causing the efficient use of water to be an important factor for increasing food and fibre production. The prolonged drought conditions in these areas advance the use of small-scale rainwater harvesting systems that have become formalised primarily through water conservation programmes and projects (Bowling and Cherkauer 2018, Owino et al. 2021). These include active rainwater harvesting systems capture, redirect and store precipitation for later use. The rainwater harvesting includes a combination technique including water storage in cellars or tanks, terracing, plastic-film cover, and micro-irrigation for increasing dryland-farming productivity (Mucheru-muna et al. 2017, Owino et al. 2020a). Rainwater harvesting systems have the potential to overcome water constraints by providing limited irrigation during the key stages of crop development. Water harvesting techniques help communities to solve problems of water shortage and to achieve food security (Owino et al. 2020b). Resilience to climate change depends on increasing availability of water to increase agricultural productivity (Sikka et al. 2018, Bedeke et al. 2019).

Increased degradation and deforestation of catchment areas expose forest ecosystems to loss of stored moisture even before it is released as runoff to rivers (Mango et al. 2011). The quality and quantity of water in streams for downstream users is affected by increased concentration of sedimentation and agrochemicals (Kimaro 2019).

In agricultural fields, several methods have been used to manage water use, including: mulching, contour farming where the ridge controls runoff overflow and the trench acts as a depression that collects runoff and transported sediments (Dunkelman et al. 2018) and water harvesting varying from small dams to small pits depending on locality (Dungumaro and Madulu 2003, Kathuli and Itabari 2015, Rockstrom and Falkenmark 2015, Reddy 2016). Agroforestry is another option for increasing water use efficiency in agroecosystems as tree roots facilitate infiltration of precipitation to the aquifer while controlling the flow down the slope during drought periods. The tree roots can also influence soil moisture through hydraulic redistribution and thus enable crops to access sufficient moisture even during the drier period of the year. Furthermore, agroforestry trees can reduce evapotranspiration losses in both crops and soil (Lin 2010b, Sheppard et al. 2020).

Further reading

Filipovic A. 2020. Water Plant and Soil Relation under Stress Situations. In: Ram Swaroop Meena RS, Datta R (eds) Soil moisture importance. IntechOpen.

4.4.2.2 Soil and water conservation technologies

Soil erosion is a result of non-anthropogenic and anthropogenic activities. Soil erosion together with forest degradation and land degradation are major problems affecting ecosystem productivity in developing countries where farmers and their animals are generally the main anthropogenic cause of soil erosion and silting of water bodies (Taiye et al. 2017, Davies and Boyd 2019, Pandey et al. 2019). Soil and water conservation are pillars in environmental conservation and food security, with failure leading to soil erosion (Delgado et al. 2019, Musinguzi et al. 2021). Although there are technologies used to manage non-anthropogenic causes of erosion, anthropogenic causes have been given little attention. Soil and water conservation measures are undertaken for the following reasons:

- maintain or to improve soil fertility,
- control water runoff and prevent soil loss through soil erosion,
- reduce soil compaction,
- conserve or drain water, and,
- gather runoff water.

Traditional soil and water conservation measures, such as bench terracing, water harvesting, water conveyance and application, and home gardens, have endured the test of time, and are easily available and socially acceptable (Everard et al. 2018). Traditional measures alone are, however, insufficient for conserving the critical soil and water resources and need to be complemented by modern practices to accomplish the goals of sustainability (Förch and Schütt 2004, Lai et al. 2021, Coulibaly 2021).

The use of Integrated Soil Fertility Management in agroforestry improved household food security soil fertility, increased maize yield and profitability, and reduced labour inputs (Ajayi et al. 2009, Coulibaly et al. 2017).

Physical measures, also called mechanical or technical measures, are structures constructed to conserve soil and water and include: stone/earth terraces, stone/earth bunds/walls, check dams, contour ditches, retention reservoirs, dams, grassed waterways and planting pits. In designing physical measures, the following principles should be considered (Tidemann 1996, Dimtsu 2018):

- Increase the time of run-off concentration to allow more water to infiltrate into the soil.
- Reducing amount and velocity of surface runoff by dividing a long slope into several short ones.
- Reducing velocity of surface runoff.
- Protection of the soil against damage caused by excessive runoff.

Biological measures are low-cost measures based on maintenance of vegetative cover to prevent splash erosion, reduce the speed of surface runoff, improve soil moisture conditions, facilitate soil particle accumulation, increase surface roughness to reduce runoff and increase infiltration, and stabilise the soil aggregates through organic matter and roots (Jiru and Wari 2019, Bezu and Tezera 2019). Examples include vegetation strips, vegetation cover in water ways, reforestation and protective bushlands. Reforestation is important where there is need to rehabilitate degraded lands or watersheds, with options for *in situ* or *ex situ* planting. Trees protect soil from erosion and conserve soil moisture and can provide communities with NTFPs.

Agronomic measures applied for soil and water management include strip cropping, intercropping, mulching, mixed cropping, contour ploughing, grazing management, agro-forestry, conservation farming, management of crop residue (including use of cover crops where viable) and crop rotations, improved management of irrigation systems, management of livestock grazing intensities, use of technologies, and precision conservation (Delgado et al. 2013, Misebo 2018, Ndambi et al. 2019).

Agroforestry was discussed in section 4.4.1.1. Conservation practices are important strategies for adapting to the impacts of climate change on soil and water resources. The measures can easily be used together with physical and/or vegetation measures. They, however, need more technical know-how than the other two. Implementation of the measures can be influenced by other socio-economic, political and institutional factors. To conserve soil and water in a changing climate, Delgado et al. (2013) and Ndambi et al. (2019) added that adaptation policies and strategies should include conservation practices that contribute to increased soil water-holding capacity, improved drainage, manure management and the development of new crop varieties and cropping systems that are more resistant to drought. Application of soil and water technologies in the agricultural sector will be discussed in chapter 5.2.1.2.

The use of Integrated Soil Fertility Management in agroforestry improved household food security soil fertility, increased maize yield and profitability, and reduced labour inputs (Ajayi et al. 2009, Coulibaly et al. 2017).

Activity 4. Revision (15 Minutes)

1. Give examples of ecosystem services under regulation and provisioning services.
2. Explain how agroforestry contributes to climate change adapatation.
3. Explain the importance of urban forests and trees in climate change adaptation.
4. Explain technological adaptation in the agricultural sector.
5. Explain technological adaptation in the energy and renewable resources sector.

Summary

In this session we learnt that there are four types of services from forests that directly contribute to human well-being: regulating, provisionings, cultural and supporting services. Adaptation to climate change can be either technological, social or economic. Technological adaptation is the application of technology to reduce the vulnerability, or increase the resilience, of natural or human systems to the impacts of climate change. Forest-based technological adaptation includes agroforestry, urban forestry, use of renewable energy, plant water relations, soil and water conservation and intensification of production systemsThese include agroforestry which can be in several forms depending on the objectives and has four pillars/characteristics which are referred to as the 4'I's. We also learnt of the importance of trees and forests in urban areas. Technological options in agriculture include intensification of agricultural systems and soil and water conservation measures. Soil and water conservation measures are undertaken to maintain or to improve soil fertility, control water runoff and prevent soil loss through soil erosion, reduce soil compaction, conserve or drain water and to gather runoff water. Soil and water consavation can be done using physical, agronomic, biological or traditional measures. Other options include manipulation of plant water relations including water use efficiency and rainwater harvesting and usage. Where plants can modify the apoplastic and "cell-to-cell" pathway contributions depending on the environmental conditions and transpiration demand. The use of renewable energy is important because it provides a clean energy source with less environmental impact. The resources are endless, and they reduce dependence on fossil resources and provide energy security.

Bibliography for further reading

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4.5 Social and economic adaptation

Socio-economic systems either amplify or moderate the impacts of climate change. Adaptation to climate change can vary depending on socioeconomic attributes such as education, occupation or income (López and Pardo 2018). Velichko et al. (2009) traced adaptation of human societies in Europe and found that the early stages of human prehistory coincided with key transformations linked to climate and landscape alterations and these affected the human well-being causing them to respond through societal adaptation. The responses unlocked opportunities for more progress in managing changing environmental conditions and assured them of their survival. They added that migratory adaptation became dominant at the Middle Paleolithic and at the commencement of Upper Paleolithic time when early humans were completely dependent on fluctuations of climate and environments. The trend shifted after the development and active use of protective measures (autochthonous adaptation) became prevalent and ensured human survival even in extreme conditions (Layton 2020). In this session we learn about social and economic adaptation, linked to forest based sustainable and diverse livelihoods.

Learning outcomes

i. By the end of this session, learners should be able to:
ii. Identify and implement forest-based sustainable livelihoods.
iii. Explain elements of social systems.
iv. Explain the meaning of gender and gender mainstreaming.
v. Explain some indigenous coping mechanisms.

Activity 4.7 (Brainstorming) (10 Minutes)

What is the contribution of forests and tree resources to socio-economic climate change adaptation in your country.

Climatic change is not one of the priorities in most developing countries because current priorities emphasise poverty reduction and economic growth. Measures of adapting, such as bearing and sharing the losses or changing use and location, are related to socio-economic status of individuals or the community (Asumadu-Sarkodie et al. 2020, Baarsch et al. 2020). The determinants of adaption, such as household head's age or gender, described in section 2.5.2 are linked to the socio-economic standing of vulnerable groups and determines how coping and adaptation can be achieved.

4.5.1 Forest-based sustainable and diverse livelihoods

Globally, more than 1.6 billion people depend on forests for subsistence, livelihoods, employment and income generation, and the wide range of forest-based goods and services create opportunities to address many of the most pressing sustainable development challenges (UNFF 2015). Forests and trees form the basis of life and are critically important for human and societal development (Arce 2019), providing both wood and non-wood or non-timber forest products and buffering communities during periods of scarcity and a source of nutrition for the poor (Agrawal 2013, Costa Carvalho and i Perez 2020).

A sustainable livelihood comprises the capabilities, assets and activities required for a means of living that can cope with and recover from stresses and shocks and maintain or enhance its capabilities, assets and activities both now and in the future, without undermining the natural resource base (Serrati 2017). Diversification is a process (if planned) where economic status of households could improve through, for example, growing new crop varieties, value crops, fruit trees, agroforestry, small enterprises, casual labour, etc. Diverse livelihoods demonstrate a person's reliance on several activities within a year. The activities could be land and/or non-land based, self-employment or labour and rural employment or out-migration (temporary). Lack of capital and skills restricts some families' capacity to retain or modify their traditional livelihoods (Cannon 2013, Owino et al. 2020b).

Several programmes have been initiated in Zambia to enhance resilience of ecosystems and communities to climate change through diversified ecosystem-based livelihoods. Initiatives such as Assisted Natural Regeneration, Agroforestry, Integrated Fire Management and Reducing deforestation and Degradation are reducing unsustainable utilisation of biomass for charcoal/firewood through promotion of energy and resource use efficiency (Anyango et al. 2018).

Diversification implies increased output from both industrial and service sectors while decreasing the share from primary production activities (e.g. traditional cultivation). Patterns of diversity differ with wealth status (World social report 2020).

When new economic activities offer greater returns than traditional activities, there is a 'pull' or a 'positive' diversification and households accumulate assets and have better lives. On the other hand, when new options deliver lower returns than usual activities, there are coping strategies for responding to the shock. This is referred to as a 'push' or negative diversification where households remain in the poverty cycle (Reardon et al. 2007, Chandra et al. 2020). Adaptation that supports sustainable livelihoods therefore entails the ability to:

- Engage in different actions to manage uncertainties and distribute the risk. For example, a family depending on own land, agri-labour migration etc.
- Cope with insufficiency - diverse activities may be undertaken to meet short-comings in the main activity or contingency. For example, failed harvest, loss of job or medical/funeral bills.
- Realise seasonality - some primary activities such as collecting fruits, nuts and mushrooms depend on seasons. Crafts are also seasonal. Off-season activities (though lower in returns) are more preferred than outmigration or unemployment.
- Compensate for failures in credit markets - other low return activities undertaken to fund the main activity/favoured activity in many rural areas. This is prevalent when access to credit is not in place or is on exorbitant terms. Such income is used as input for main activity, e.g. buying fertilisers, seeds etc.
- Gradually transform to new activities - change to new activity is incremental when returns are higher. It is an addition to existing activities rather than a substitute. Over time, if high returns are stable, it becomes a specialisation. Initially they are likely to be driven by necessity.

Complementarities can be built through household diversification activities that build on existing skills, experiences and information. For example, home-based part-time work complemented by part-time domestic tasks. The changes depend on previous conditions and experiences.

Throughout human history, forest products have been used for a variety of purposes including food, medicine, fibre, fodder, agricultural amenities and construction materials. They can play an important role in rural livelihood strategies and can contribute to sustained forested landscapes (Ros-Tonen and Wiersum 2005, Rai et al. 2019). The World Bank (2016) stated that rural households who live near forests get as much as 22 % of their income from timber and NTFPs, a contribution larger than wage labour, livestock or self-owned businesses. They added that about half of that income is non-cash and includes food, medicine, fuel, construction materials and fodder. Additional income could come from payment for ecosystem services. Forest based activities supporting the sustainable provision of these goods and services even under a changing climate include agroforestry and other tree planting activities, participatory forest management, fire management in natural environments, rehabilitation of degraded lands and environmental awareness/training.

For Kenyan communities near east Mau Forest, income from forests can be as much as 33% of total household income, with highest contributions from fuelwood (50%), food (27%), construction material (18%), fodder and thatching material (5%) (Langat et al. 2016).

4.5.2 Strengthening social systems and networks in the context of forest and tree resources

Social systems are patterned networks of relationships that form a coherent whole between individuals, groups and institutions. They represent formal **structures** with roles and status that can form in small or stable groups and are not directly observable entities but can systematically be defined domains of objects. Interactions between individuals are considered as social systems. Systems theory analyses how society adapts to its environment through modifications in organisation, with implications for their awareness of social order. Systems theory also shows the complexity of social evolution and stresses the limited likelihood of driving society. On the other hand, because society is vastly complex, social systems have a large range of adaptive opportunities for society (Marten 2001, Oeba et al, 2018, Cheruiyot 2019), including management of forest resources.

A social system is composed of persons or groups of persons who interact and mutually influence each other's behaviour.

In developing countries, local communities are severely affected by climate change, mainly those living in regions exposed to climatic hazards such as floods and droughts. These populations are usually poorer than the rest of the population within a country. Impacts of climate change can be subtle but significant, and their effects differ for different members of the same community. Some individuals or groups can perceive climate change as an opportunity whilst others experience losses, demonstrating community dynamics and complications about how they can adapt, including sharing of the costs of adaptation. Negative impacts are chance occurrences that come as surprises and their impacts can go beyond critical values of accustomed weather parameters. Negative impacts include effects imposed by climate risks such as cyclones, floods, droughts, strong winds, heat wave, subfreezing temperatures or forest/bush fire (Schneider et al. 2001, Brown and Sonwa 2018, Rao et al. 2019).

A resource system comprises three subsystems: biophysical, social and technological sub-systems, representing land, people and technology components of a resource system, respectively. The biophysical/ecosystem include soil, topography, climate, vegetation and other elements. The social system includes population, social, economic and political structures, etc., and the technological system includes tools, implements, cropping patterns, resource practices, dissemination methods, etc. (Firey 1960, Werdiningtyas et al. 2020).

In a social system, information and resources are important drivers supplying energy to the system. Energy of the system is the capacity for action or the power to implement change. System actions entail movement of energy or information within a system or between a system and its environment. In order to be useful, energy must be structured and shaped by available information. A system's energy is acquired from physical capacities of its members, shared sentiments, common values and social resources, such as loyalties and resources from its environment. The systems are either mechanistic or purposeful. Mechanistic is where the system does not determine its own goals, but behaviour is predictable as it reacts to predetermined stimuli (e.g., a computer or an airplane). A purposeful system determines its own goals and the ways to achieve them (e.g., an animal, household or nation). In this context, the purpose of the social system is to serve the purposes of its members while also serving the purposes of its environment (Gharajedaghi 2012, Gedi 2019, Luhmann 2020).

The five basic elements of a social system are:

- **Cohesion** describes the sense of common identity and interests which bring people together. Normally a product of shared history and culture and in some cases political and economic factors have a role. This means that a system has some form of organisation. Internal and external forces can disorganise a system. This is an element that persuades people to act collectively (Barrow and Murphree 2001, Hopper and Weyman 2019). The culture is the cement that integrates the parts into a cohesive whole. Nevertheless, since the parts have a lot to say about the organisation of the whole, consensus is essential to the alignment of multi-minded systems (Gharajedaghi 2012, Eräranta and Mladenović, 2021).
- **Boundaries/demarcations** can be real or imaginary and show a clear definition of what remains inside (endogenous) and what remains outside (exogenous). To understand a system, one should know the relationships between the endogenous components and how they independently and holistically relate to the exogenous environment. Cohesion sets the social boundaries and determines membership (Barrow and Murphree 2001, Wang and Li 2018).
- **Legitimacy** relates to both power and authority which can be internal or external. Internal authority is based on socio-economic and socio-cultural criteria. External authority can also assign legitimacy but may not be enough on its own (Barrow and Murphree 2001, Wang and Li 2018).
- **Resilience** describes whether a system changes or not. For example, in a steady state system, no changes in structure or function are expected within a given period. Boundaries of jurisdiction and social cohesion may change but resilience shows the organisational capacity to adapt in content and structure (Barrow and Murphree 2001, Amadi-Echendu et al. 2020).
- **Hierarchy** shows interrelatedness and interdependence in a system. For example, a human being is part of a household system, which is part of a community system, which is part of a district system, which is part of a nation, which in turn is part of the global (community of nations). To analyse any system in the hierarchy, cognisance of the influence of higher and lower-order systems must be taken (Harder and Kim 2018).

In each system, social network structures vary, with some managed through command and control or dominant and obedient relationships while others are more liberal. Other networks are distributive as in the rumour mill existing in most social systems. Collaborative social networks make everyone acceptable as a legitimate member by everyone else. Members are cohesive and natural, being the source of social capital or optimal group productivity. The systems are also a source of innovation, value creation and performance breakthroughs. In community conservation initiatives such as participatory forest/wildlife management, objectives shape the direction, content and process of community forest management activities (Barrow and Murphree 2001, Wang and Li 2018).

4.5.3 Gender and forest-based adaptations

Gender is a mixture of socially constructed norms and ideologies which determine the behaviour and actions of men and women. There is need to understand the gender relations and associated power dynamics in order to understand individuals' access to and distribution of resources, the ability to make decisions and the way women and men, boys and girls are affected by political processes and social development (World Bank 2012). Vulnerability to climate change impacts is intimately linked to poverty and economic marginalisation within developing countries and within particular groups of society, mainly the poor and other marginalised segments (women, the elderly, immigrants, indigenous groups, etc.), being structurally vulnerable (UNDP 2014).

Gender is one of the cross-cutting issues that must not be ignored in climate change adaptation since it is known that it affects women and men differently. In this regard, mainstreaming of gender is important for addressing concerns and experiences of women, men and youth in designing, implementing, monitoring and evaluating all policies and programmes so that women and men are treated fairly (UN 2002). Gender mainstreaming was adopted by UN's ECOSOC focusing on assessing how women and men are affected by any planned action, including policies, legislation, programmes at all levels, in all sectors. The UNFCCC (2014) developed a gender-sensitive approach for main-streaming climate change into development plans, based on good practice to address climate risk, climate-proof current plans, and ensure adaptive development. Figure 8 shows the gender based five step process for mainstreaming adaptation. Vincent and Colenbrander (2018) applied the steps in Zambia and concluded that the process was applicable in data-constrained environments where people have minimal training for assessing climate risk, facilitating adaptation and climate-resilient development.

In Tanzania, an increasing number of men are collecting NTFPs such as firewood and wild mushrooms due to climate-induced stresses in men's traditional livelihood activities (Balama et al. 2016).

Female-headed households in South Africa are slightly more likely than male-headed households (not statistically significant) to use NTFP collection as a coping strategy in response to shocks (Paumgarten and Shackleton 2016).

In Zambia, male-headed households are no more likely than female-headed households to use forests in response to crop failure (Kalaba et al. 2013).

In South Africa, the collection of non-timber forest products (NTFPs) plays a critical safety net role for marginalised populations after climate shocks, particularly women (Shacleton and Shackleto 2004).

In Zimbabwe, NTFP collection by women serves as an important source of fuel, food, and income in response to crop loss driven by climate change (Woittiez et al. 2013).

	1st Step Preparation	2nd Step Gender-sensitive climate risk assesment	3rd Step Climate risk Screening	4th Step Options to respond to Climate risk	5th Step Implementation, monitoring and evaluation
Purpose	To Ensure structures in place for effective climate change mainstreaming	To identify the nature of current and future climate risk	To determine climate risk to the development framework (in Zambia known as key issues and priorities) and to the implementation programe	To ensure that the davelopment framework (key issues and priorities) and implementation programme address climate risk , support adoption to climate change and enable climate resilient development	To ensure, through appropriate monitoring and evaluation, that implementation of the plan is supporting adaptation to climate change and enabling climate-resilient development

Figure 8. Five-step process for gender sensitive mainstreaming of climate change into development planning (UNFCCC 2014).

In Senegal, a project on Sustainable Participatory Energy Management introduced gender-equality goals, resulting in women being integrated into inter-village forest management committees and comprising 33-50% of the committees. Women also increasingly participated in training sessions on forest cutting and carbonisation techniques, activities that were formerly male dominated (World bank 2016).

Gender mainstreaming ensures proper responses to women's needs and aspirations. In West Africa, the involvement of women in forest management committees facilitated and supported women's leadership and equal participation in decision-making, strengthening their adaptive capacity (Aguilar et al. 2011). Forest management programmes that ignored or did not include women failed as the women sabotaged the programmes whilst those that included/benefited women had support in the form of labour, better conservation and endorsement (Agarwal 2009). In order to be successful, gender mainstreaming should include empowerment, paying particular attention to gender relations (Mwangi et al. 2011).

Activity 4.8 (Brainstorming) (10 Minutes)
Choose one development sector that is susceptible to climate change impacts. Analyse how men and women are affected.

4.5.4 Indigenous coping and adaptation mechanisms and strategies

Traditional, indigenous and local knowledge generally refer to knowledge systems embedded in the cultural traditions of regional, indigenous or local communities. Climate change impacts have affected livelihoods. However, some rural communities have developed their own coping and adapting strategies. The rural communities do not depend on modern scientific knowledge but have been managing their livelihoods, for example, by growing crops using their local knowledge of ecological conditions. The adaptive actions are a product of their knowledge, priorities and capacities which permitted them to plan and cope with local climate change and variability (CCV) (Mugambiwa 2018).

Communities have been using several strategies to cope and adapt depending on the type of livelihood. For example, communities in Tanzania have used practices such as tree planting, terracing, crop diversification and water harvesting using locally based water reservoirs and mixed cropping (Kahila 2018) to cope with CCV. In addition, they used strategies such as rainwater harvesting in ditches, check dams and they also engaged in alternative economic activities. Farmers in South Africa used kitchen garbage and manure to improve soil fertility whilst others changed to more drought-resistant livestock systems from cropping system. In another cases, cotton farmers in Zimbabwe irrigated their crops and diversified into more drought-resistant crop varieties or other crops. They also adjusted the timing of the planting period to coincide with the onset of the rains. Some use bottles for drip irrigation of local plants. Other smallholder farmers in drought prone areas of Zimbabwe switched from maize to traditional sorghum and millet resulting in improved food security (FAO 2017a, Mugambiwa 2018). Similarly, some early maturing, drought-resistant, high yield maize varieties have been introduced in Southern Africa (Fisher et al. 2015, Katengeza 2019).

In places outside Africa, farmers in Pakistan shifted to growing genetically modified cotton varieties and managed to avoid losses arising from pest attacks common in traditional cotton varieties. Furthermore, they planted wheat varieties that tolerated high heat stress as their response to increasing frequency of extreme maximum temperature events (Abid et al. 2016).

Indigenous knowledge (IK) has been emphasised as a source of resilience in both theory and practice, as it is built upon learning from past experiences of natural hazards (Hooli 2016). African communities have used IK to adapt to climate change and variablity (Osbahr et al. 2010), including droughts (Kihila 2018), floods (Hooli 2016), ocean warming (Belhabib et al. 2016) and drought (Ncube and Lagardien 2015).

Livestock farming has been considered to be most resilient to drought with some of the strategies dating as far back as times when farmers migrated with their animals to seek better pastures. Pastoralists in some areas sell their livestock early or destock without compromising the breeding herd. They also manipulate feeding strategies to sustain the herd (Esiobu and Onubuogu 2014). Farmers breed livestock for drought tolerance, change breeds, or switch to low input systems such as ostrich or game farming. Livestock farmers also conserve water through rainwater harvesting from mountain slopes, construct stock dams for water storage and use windmills to pump water from boreholes (Ncube and Lugardien 2015). Similarly, fishermen also adapted by changing fishing times, fishing in deep waters, scheduling times for fishing and engaging in alternative economic activities (Kihila 2018).

Furthermore, farmers in drought-prone areas protect trees on farms and in forests thereby managing biodiversity and reducing desertification. The domestication of indigenous trees is a strategy being adopted by many countries in Africa. However, low-income households residing close to forests, headed by risk averse older individuals who are less educated, depend more on forests to cope with climatic shocks than the others (Ludena and Yoon 2015).

African farmers are known to have practiced fallow systems of cultivation, which encouraged the development of forests. However, due to population growth, the length of fallow has been reduced to the extent that the practice no longer exists in many areas. Forests have been recognised by traditional institutions for managing communal forest reserves. In other areas, farmers have been using natural fallows to regenerate or restore soil fertility and others used leguminous plants for quick restoration of soil fertility (Tarawali and Ogunbile 1995). Furthermore, agroforestry was done to increase in the amount of organic matter in the soil, improve water retention and promote crop diversification thereby improving agricultural productivity and reducing the pressure exerted on forests (Ajani et al. 2013)

Activity Revision (10 minutes)

1. Distinguish between push and pull diversification.
2. What are the main elements of social systems and how do forests support social systems adaptation?
3. What negative consequences result when adaptation and mitigation planning and financing do not consider gender differences and women's specific needs and capacities?
4. What is the importance of indigenous coping mechanisms in climate change adaptation? Give examples.

Summary

In this section we learnt about social and economic adaptation. Sustainable and diverse livelihoods are key for supporting community livelihoods. A sustainable livelihood comprises the capabilities, assets and activities required for a means of living that is able to cope with and recover from stresses and shocks and maintain or enhance its capabilities, assets, and activities, both now and in the future, without undermining the natural resource base A resource system comprises three subsystems: biophysical, social and technological sub-systems, representing land, people and technology components of a resource system. Social systems include population, social, economic and political structures, etc., and technological systems include tools, implements, cropping patterns, resource practices and dissemination methods. In a social system, information and resources are important drivers supplying energy to the system. In each system, social network structures vary, with some of the networks managed through command and control or dominant and obedient relationships while others are more liberal. Social systems have five elements. We also learnt that gender is one of the cross-cutting issues that must not be ignored in climate change adaptation because climate change affects women and men differently. We also discussed a gender based five step process for mainstreaming adaptation which was applied an African country. The section concluded by showing that communities have been using several local knowledge and strategies to cope and adapt depending on the types of livelihood ventures.

4.6 Challenges to adaptation

Climate change is now adding new challenges related to the many uncertainties, the potential scope and severity of impacts, and the unprecedented speed and type of change that threatens to undermine fundamental ecosystem resilience. Deforestation and forest degradation have become major barriers to the implementation of SFM and conservation in most developing nations (Bamwesigye et al. 2020, Kline and Dale 2020). Furthermore, effective governance is important for efficient operations of institutions. In this section we will discuss the barriers and challenges in planning and implementation of climate change adaptation initiatives. These include, technological, social, financial or economic, institutional/political, informational or cognitive and biophysical challenges.

Learning outcomes
By the end of this chapter, the learner should be able to:
Identify categories of barriers and challenges to adaptation.

Activity 4.8 (Group work) (10 Minutes)
Categorise major barriers and challenges of Climate change adaptation?

In general, governance rests on the promotion of democratic and participatory principles as well as on ensuring access to information, knowledge and networks. Institutional strengthening and capacity building have been highlighted as priority needs in developing countries (Kumamoto and Mills 2012, Tchawe 2019). In assessment of river basin planning in Brazil, Engle and Lemos (2010) found that improving governance mechanisms enhanced adaptive capacity. Similarly, water trading schemes facilitated by government measures reduced the impact of a major drought on the economy in Australia (Mallawaarachchi and Foster 2009). The effectiveness of such approaches depends on both the commitment of government and capacity building among those affected.

Changes in one system on earth can affect others, and actions taken to limit or adapt to climate change may result in unintended consequences, both positive and negative. Climate change may happen so quickly, or be so severe, that adaptation becomes impossible because either there are no strategies to address the risks, or they become too expensive, or the consequences of the adaptation are considered unacceptable. In this case, climate change has reached a threshold or limit to adaptation. Limits may be ecological, physical, economic, technological or societal. Despite the benefits adaptation initiatives can provide, there are many challenges and barriers that could make individuals reluctant. Such factors complicate and impede the understanding, implementation and support for adaptive actions (Ransom 2017, Seo 2017).

Forest governance issues can be barriers to successful forest-based climate change action. Atyi (2017) identified five barriers related to forest governance:

- Poor enforcement of forest laws and regulations.
- Invasive political influence on forest policy and decision making.
- Lack of land-use planning.
- Lack of coordination between government ministries.
- A substantial but poorly monitored informal sector.

Moser and Ekstrom (2010) and Chenani et al. (2021) defined a barrier to adaptation as any type of challenge or constraint that can slow or halt progress on adaptation but that can be overcome with concerted effort. For example, people who have a low personal understanding of climate change will find it difficult to plan for its impacts or even to accept that others should plan to adapt. This may be because they feel that too little is known about climate science, or that the science isn't 'settled', or that there needs to be more certainty about the science before actions can take place or that the risks are small, and action can be delayed. Another example is lack of capacity within the organisation, including inadequate funds for adaptation, and an organisational culture that limits or prevents decision-making on adaptation can be a barrier. The political will or government support is also important but generally, these factors can be categorised as institutional, social, economic or technological.

4.6.1 Adaptation gaps and barriers

Adaptation barriers can be social, economic, institutional/governance, technological, informational or personal/cognitive. A summary of barriers to adaptation is given in box 4.2.

Box 4.2: Barriers to adaptation (Niang et al. 2014, Hallmeyer and Tonkonogy 2018)

- **Poor policy environment** - Policy environment has no conditions to support sector-specific investment (e.g., no specifications for businesses to execute disaster risk management actions).
- **Poor institutional environment** - Absence of legal and regulatory institutions or infra-structure to support investment (e.g., tenure rights, permits, rule of law, etc.).
- **Poor market environment** - Unsupportive market environment for general investments and different sectors (e.g., weak economy, weak historical track records, etc.).
- **Poor value chains and human capital** - The required capacities for initiating and establishing successful investment are lacking (e.g., no local sectoral expertise or sector-specific value chains).
- **Uncertain or unknown value-added** – Users not aware of the value or benefit of the technology or it is uncertain; climate risk is not considered by users in decision-making. High operational cost of technology.
- **Lack of technical capacity -** Prospective users of the technology don't have the technical capacity that is needed to implement or use the technology.
- **Lack of internal capacity** – Inadequate internal management and operational capacities of the adaptation product or service provider.
- **Cognitive barriers** - Include alternative explanations about extreme events and weather such as religion (God's will), the ancestors, and witchcraft, or seeing these changes as out of people's own control
- **Informational barriers** - Lack of information on climate change predictions and weather, agroforestry and/or afforestation, different crop varieties and adaptation strategies.

4.6.2 Policy challenges

In most African states, development of policies is done by central government agencies, with other actors insufficiently involved while local communities are mostly excluded (Hamilton and Lubell 2019, Alemaw and Sebusang 2019). Some of the weaknesses in policy and policy formulations are:

- In some cases, where practical implementation strategies are absent, there is political interference, and the different implementation levels (village, ward, district, provincial, national etc.), constrain adaptation efforts.

- Climate change is a global phenomenon that requires efforts of both developed and developing countries.
- Insufficient knowledge or resources by decision makers, means they are not able to formulate correct policies. Most adaptation measures require high levels of coordination between different governance levels (IPCC 2014).
- Cross-sectoral and inter-ministerial collaboration is not always clear on how the complex set of actors and their activities can be consolidated.
- Political and institutional inefficiencies, where prioritising climate change adaptation initiatives in Southern Africa is blocked by other issues such as mitigation, disaster and risk (Chevallier 2012, Nciizah et al. 2021).

4.6.3 Technical and technological challenges

One of the challenges is that of understanding the behaviour of ecosystems when adapting to a changing climate and how increasing ecosystem vulnerability might change based on existing ecological information. Although models indicate that climate change is expected to affect the distribution of ecosystems and species, there is need to understand the behaviour and how it affects the flow of ecosystem services. Maladaptation and short-term coping strategies create a challenge by creating additional pressures on ecosystems. For example, when NTFPs used as safety nets are collected from forests that are not sustainably managed (IUCN 2008, Apeaning 2019). To overcome some of these problems, planning challenges should be linked across sectors and scales. Technological and technical challenges affect planning and implementation of adaptation initiatives. Some of the challenges are discussed below.

- Poor seed quality and no inputs ascribed to a lack of quality controls by government and corrupt business practices by traders, poor market access and insecure tenure (Angaine et al. 2020, Owino et al. 2020c, Onyango et al. 2020).
- Technical knowledge or capacities are often lower in the developing world than in the developed world. For example, issues about trees and forest management options suitable under future climates and how negative climate change impacts can best be minimised. Most existing policies do not apply the landscape approach frameworks for implementing climate and development objectives (Aronson et al. 2019). Chambwera et al. (2014) and Steiner et al. (2020) showed that only a few of the suggested adaptation measures will be implemented because of technical and physical limits as well as differences in objectives.
- Implementation of NDCs and NAPAs suffer from lack of capacity to use the specific policy tools and actions for forestry projects.
- Inability to carefully consider and factor in the potential of trees to provide ecosystem services under changing climate.
- Challenges related to scientific methods and tools to assess useful trees in various socio-ecological perspectives and unavailability of data and information to all stakeholders.
- Adaptation actions can have direct and measurable outcomes, although impacts of climate change on vulnerability are usually not directly visible in the short term but can be evident only over a long period (many decades), where there will be different interpretations on characteristics of adaptation success (Ford et al. 2015).
- Disentangling the role played by adaptation is further complicated by the fact that baseline climatic and socioeconomic conditions that determine adaptation effectiveness also change, potentially rendering interventions ineffective (Ford et al. 2015).

- Success of short-term adaptation actions may be maladaptive in the long term, worsening vulnerability due to alteration of behaviour, changing patterns of development, displacement of risks to other groups, and creation of path dependency, and these challenge maintenance of interventions (Barnett and O'Neill 2010, Fazey et al. 2010, Schirmer and Yabsley 2018).
- High variability of adaptation needs, risks and decisions about potential climate risk depending on economic/resource sectors and regions.
- Level and speed of adaptation in developing countries is affected by their technological progress.
- Limited understanding and development of reliable EWS in developing nations. Climate uncertainty, high levels of variability, lack of access to appropriate real-time and future climate information, and poor predictive capacity at a local scale are commonly cited barriers to adaptation from the individual to national level (Dinku et al. 2011, Okpara et al. 2017,).
- In Africa, monitoring networks are not sufficient and difficult to model because of the sparse coverage and short and fragmented digitised records available (Boko 2007).
- Inadequately resourced meteorological agencies with limited in-country expertise to interpret and use climate information for planning and decision making (Dinku et al. 2011, Myeni et al. 2019).

4.6.4 Financial and economic challenges

Finances drive the process of adaptation initiatives and the benefits obtained from such actions are important as motivation for sustainability. Savvidou et al. (2021) stated that about half of the adaptation finance in Africa is targeted to the sectors of agriculture and water supply and sanitation. They added that low adaptation finance disbursement ratio in Africa (at 46%) between 2014 and 2018, relates to barriers that impede the full implementation of adaptation projects such as: low grant to loan ratio; requirements for co-financing; rigid rules of climate funds; and inadequate programming capacity within many countries. The following are other challenges linked to financial and economic aspects of adaptation:

- Lack of finances to adequately prepare and to respond to climate change disasters due to inadequate economic capacity to adapt for most of the rural poor (Chaudhry 2021).
- Adoption of some adaptation strategies can be hampered by discouraging results, e.g. possible reduction in short-term crop yields.
- High costs of adaptation actions may require external inputs for poor communities (Potdar et al. 2019).
- Intangible advantages of taking specific actions (adapting or limiting emissions) are usually not clear to the laymen (Ajiboye et al. 2018).
- Lack of ready markets for ecosystem goods and services (Chaudhry 2021).
- Complicated and lengthy processes to get global environmental funds (Zhongming et al 2018).
- Uncertainty around investment returns.
- Inadequate consideration of climate risk in investment decisions.
- High upfront costs of technology.
- Discouragement resulting from possible short-term crop yield reductions can discourage adoption of some adaptation strategies.
- The costs and benefits of different courses of action (adapting or limiting emissions) are generally not well known and are difficult to quantify because many of the natural assets and ecosystem services that could be affected by climate change have no market value or are priced in a way that does not truly reflect social values (Zhongming et al 2018).

Further reading

Savvidou G, Atteridge A, Omari-Motsumi K, Trisos CH. 2021. Quantifying international public finance for climate change adaptation in Africa. Climate Policy 21(8):1020-1036. DOI: 10.1080/14693062.2021.1978053

4.6.5 Social challenges

The social challenges to climate change adaptation are linked to characteristics of communities that expose them to the impacts of a changing climate. Among these factors are poverty, lack of employment, heavy reliance on natural resources to support livelihoods, culture, population increase and religion (Nielsen and Reenberg 2010, Ramyar and Zarghami 2017). Poverty limits the means to cope with and adapt to climate change effects (Dungumaro and Hyden 2010, Adhikari and Baral 2018). Some of the social challenges are listed below:

- Farmers can become reluctant due to their own perceptions, views and beliefs about climate change. Social norms and cultural factors also have an influence on adaptation-decision making. Furthermore, ethics and distributional issues connect to vulnerability and adaptive capacity (IPCC 2014).
- Public understanding on climate change is disturbed by inadequate support for initiation, and implementation of adaptation measures.
- Behavioural challenges to adaptation include all behaviours causing irrational decisions made without using all available information and are not consistent with time (IPCC 2014).

Activity 4.9 Revision (10 minutes)

1. Give an outline of challenges linked to governance.
2. What are the activities that constitute technological and social challenges?

Summary

In this section we learnt that there are that challenges to climate change adaptation initiatives, including barriers and gaps in adaptation initiatives. The barriers can be social, economic, institutional/governance, technological, informational or personal/cognitive. Similarly, challenges can also be in the same categories and include insufficient policy support as one of the major challenges for adaptation in Africa. Technical and technological challenges affect planning and implementation of adaptation initiatives. Financial and economic resources drive the process of adaptation initiatives and the benefits obtained from such actions are important as motivation for sustainability. The social challenges to climate change adaptation are linked to social characteristics of communities that expose them to the impacts of a changing climate

4.7 Initiatives for adaptation in Africa

In the previous section we learnt about the barriers and challenges faced when planning and implementing climate change adaptation initiatives. In this section we dicsuss Nationally Determined Contributions (NDCs), Adaptation Benefit mechanisms and other African initiative. Adapatation initiatives are based on submissions submitted in the NDCs.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Explain initiatives for climate change adaptation in Africa.
ii. Explain the role of NDCs in adaptation.
iii. Explain Africa initiatives for adaptation, e.g. Adaptation Benefits mechanism

Activity 4.10 (Brainstorming) (10 Minutes)

Do you think African governments are doing enough for climate change adaptation?

4.7.1 Nationally Determined Contributions (NDCs) Adaptation

All Parties to the UNFCCC were expected to communicate their Intended Nationally Determined Contributions (INDCs) before COP 21 (2015), clearly displaying their transparency, understanding and clarity. These set out the steps that governments proposed to undertake to tackle climate change. The INDCs were expected to publicly outline each country's post-2020 climate activities following a new international agreement. The PA of 2015 (Article 4, paragraph 2) required every Party to formulate, communicate and sustain consecutive NDCs for reducing national emissions and adapting to climate change impacts. When countries adhere to the INDCs, global success of the ambitious 2015 agreement for a low-carbon, climate-resilient future is guaranteed.

The INDC is scaled into Nationally Determined Contribution (NDC) after a country formally joins the PA by submitting an instrument of ratification, acceptance, approval or accession. Parties should monitor their domestic mitigation and adaptation actions, aiming to achieve objectives of their contributions. Submission of NDCs to the UNFCCC secretariat is required every five years. Sequential NDCs should signify a progress linked to the preceding NDCs and reflecting maximum potential ambitions. The next new or updated NDCs were required by 2020 and every five years thereafter for all Parties, irrespective of their implementation stages. In this regard, beginning in 2023 and every subsequent five years. Governments are required to assess the implementation towards achievement of the purpose of the PA and its long-term objectives (Taibi and Konrad 2018).

The PA adopted at COP21 of UNFCCC encouraged Parties to design programmes that include implementing REDD+ and joint mitigation/adaptation activities, taking into consideration the non-carbon benefits. Forests are important for both mitigation and adaption options, as reflected by being included in most INDCs. About 190 Parties had communicated their INDC by April 2018, of which 48 were African nations. The adaptation components given in the INDCs showed some methodological uncertainties associated with the evaluation.

The INDCs identified several vulnerable sectors, including agriculture, energy, water resources, health, forestry, biodiversity, energy, settlements, tourism and infrastructure. A few parties (3) acknowledged wildlife as one of the vulnerable sectors. NDCs also identified main climate hazards starting with one with the greatest impact: floods, saltwater intrusion, erosion of coastal areas, acidification of oceans, desertification/land degradation, increased intensity of precipitation, vector-/water-borne diseases, changes in precipitation timing, decreases in precipitation, storms, rising sea levels, increasing temperatures and drought. Fobissie et al. (2019) analysed African adaptation options under AFOLU in NDCs and found that agricultural management (88%), was a more preferred adaptive option than wetland restoration/conservation (75%) and afforestation/reforestation (58%) among 52 African countries.

4.7.2 Adaptation benefits mechanisms

AfDB developed a new funding mechanism called the Adaptation Benefit Mechanism (ABM), which draws on earlier experience with market mechanisms and aims to provide an incentive for investment in activities that contribute to adaptation (Maikuti nd). The ABM was created in 2019, as a revolutionary mechanism to mobilise new and additional public and private sector finance and create a new asset of certified adaptation benefits (rewards for adaptation outcomes instead of GHG reductions), compliant to the Paris Agreement, NDCs and the SDGs. The ABM projects are expected to be broad in scope to cover all aspects of adaptation to climate change and resilience with support from the Climate Investment Fund (CIF) (African Development Bank 2019, Feukeng 2019).

Project outputs include any outcome that makes households, communities or economies less vulnerable to climate change and improve them economically as forests bring multiple adaptation benefits, increasing their chances of withstanding climate induced shocks (Phillips 2017). The pilot phase in Côte d'Ivoire, Rwanda and Uganda are being implemented by the World Agroforestry Centre (ICRAF), the Center for Governance and Human Security Studies (CGHSS) respectively. The projects covered obtain Adaptation Benefit Units (ABUs) that are measured according to the approved methodologies. The ABM is a non-market mechanism and ABUs cannot be transferred (AfDB 2019).

4.7.3 African Adaptation initiatives

Although environmental management problems have always been associated with varying levels of uncertainty, limited information and risk, we need to rethink and reform management and conservation approaches in the face of climate change. African adaptation initiatives have mainly targeted resilience building through poverty alleviation and environmental sustainability, together with social justice. Most of the adaptation activities focus on watershed and protected area management, afforestation/reforestation, soil and water conservation, agroforestry and alternative livelihoods. Adaptations reported from Africa are mostly from adaptation funds aiming at reducing vulnerability and building resilience. These are mainly driven by national governments, NGOs and international institutions, with minimal involvement of lower levels of government or collaboration across nations (Ford et al. 2015, Muthee et al. 2017, Vink and Schouten 2018). Box 4.3 shows some case studies of African adaptation initiatives in Africa.

Box 4.3 Case studies of adaptation in Africa

Case study 1. Solving Land degradation in Ethiopia

The International Fund for Agricultural Development (IFAD) supported a project addressing land degradation in Ethiopia using the Community-based Natural Resource Management approach. The project was implemented in the Lake Tana watershed located in the northwest of the country, focusing on fighting land degradation and promoting sustainable land management (SLM) in order to increase agricultural productivity, household incomes, food security and climate change resilience. The project assisted farmers and communities to preserve natural resources and regenerate degraded lands; manage livestock grazing pastures by establishing 'no-go areas' in the most degraded lands, where smallholders cut and carry grazing/browsing material to their livestock.
http://africasd.iisd.org/news/ifad-project-combats-land-degradation-in-ethiopia/

Case study 2. Livelihood resilience and ecosystem protection in Ethiopia (UNDP 2018)

Communities in Ethiopia manage grazing lands by enforcing restrictions on open livestock grazing in designated areas, causing the areas along hillsides to regenerate. Communities also embarked on integrated soil and water conservation activities to increase agricultural productivity and protect the resource base. About 3,049 ha of land in six micro watersheds were rehabilitated. Furthermore, about 892,000 different trees and grasses raised and planted. Among the species planted is *Jatropha*, an evergreen drought-resistant bio-fuel plant being used to reduce deforestation and to control soil erosion. In these areas, *Jatropha* contributed to reduction of charcoal use by 50%. *Jatropha* oils extracted create savings and generate income. The forage of some plants such as *Senegalia polyacantha*, *Cajanus cajan*, *Sesbania* and lablab were used as fodder together with gully rehabilitation using gabions and sacks. The end result of these activities was advantageous to the farmers through increased crop productivity due to better soil and water conservation. Rivers and springs increased their discharge as degraded lands became rehabilitated.

Case study 3. Zimbabwe fruit orchard land use system (UNDP 2018)

A community in Ward 7 of Chiredzi District in Zimbabwe with 624 members planted a five ha mango tree orchard integrated with cassava and vegetable production to adapt to climate change. A farming group was initiated after members contributed a once-off membership fee of US$5 and then received support for fencing off the area, rehabilitate the borehole, install a diesel-powered water pumping system and drip line for one acre. They planted high quality, certified vegetable seed and grafted mango and citrus fruit seedlings. Farmers received training in fruit and vegetable management, group leadership, entrepreneurship, cooperatives and market development. The farmers later proposed contribution of a monthly or quarterly membership fee of US$1 to improve the group's cash flow. The cost-benefit analysis for mango production was favourable with participants generating US$27,500 (corresponding to US$352 per household per year). Initial costs were $32,440 reducing to $260 per year thereafter. Harvesting of tomatoes and green vegetables improved participating farmers' livelihoods. The 2011-2012 cropping season was dry with most farmers not getting any harvest from the rain-fed crop. The diversification with fruit trees became a safety net for the households especially the most vulnerable.

Case study 4. Livelihood resilience and ecosystem protection, Rwanda

In Rwanda, an integrated ecosystems-based approach was promoted by combining environmental conservation with improvement of livelihood through income-generating activities. Tree nurseries were established, and local people were paid for planting trees in their project areas. The commitment of local cooperatives is central to success of the project's activities. The project is run through Rwanda Environmental Management Authority who have a memorandum of understanding with the Rwanda Agricultural Board (RAB). The RAB pays cooperatives for raising seedlings and planting trees using a cash-for-work scheme and a national network of savings banks. The cash-for-work scheme covers 10 project sites/cooperatives (with about 50 people each), receiving 1,000 Rwandese Francs (US$1.5) for every 80-100 seedlings planted, depending on the terrain. The tree nurseries show sustainability of the project by continuously providing tree seedlings and generating income ror the people who work in these nurseries. The project has raised up to five million seedlings, three million were planted in 386 ha in four districts of the Gishwati region. The numerous benefits are fulfilled through trees, such as grafted mangoes, avocado, *Grevillea robusta, Calliandra calothyrsus* and *Podocarpus* spp. in Gishwati ecosystems, will have a greater impact on farmers' well-being because they fulfil more than one basic human need. Trees also improve the local livelihoods through provision of fruits and fodder for livestock and improving soil fertility. The fruits improve the nutritional value of household meals, while the sale of excess fruits generates income, thereby helping to fight poverty. Fodder provided by the trees support livestock whilst indigenous tree species are planted for medicinal value and help conservation of biodiversity. Furthermore, with greater environmental benefits of controlling floods and reducing soil erosion. Trees protect riverbanks in the catchment and along the Nyamukongoro and Muhembe rivers. Trees are also planted on the hilly areas along contour lines to reduce the speed of storm water flow.

Activity Revision (10 minutes)

1. What is the difference between INDC and NDC?
2. Discuss the relevance of ABM to the African continent.
3. Explain some of the forest-based climate change adaptation initiatives in Africa.

Summary

In this section we learnt that Intended Nationally Determined Contributions (INDC) set out the steps that governments proposed to undertake to tackle climate change post 2020. The INDC is then scaled into Nationally Determined Contribution (NDC) after formally joining the Paris Agreement by submitting an instrument of ratification, acceptance, approval or accession. The African Development Bank developed Adaptation Benefits Mechanism whose project outputs include any outcome that makes households, communities or economies less vulnerable to climate change and improve them economically as forests bring multiple adaptation benefits, increasing their chances of withstanding climate induced shocks. African, adaptation initiatives have mainly targeted resilience building through poverty alleviation and environmental sustainability, together with social justice. Most of the adaptation activities focus on watershed management, protected area management, afforestation/reforestation, soil and water conservation, agroforestry and alternative livelihoods.

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Chapter 5. Non-Forest Based Climate Change Adaptation

5.1 Chapter overview

Understanding strategies used in adaptation to climate change in non-forest-based sectors is fundamental in providing a holistic approach to relate them to forestry. This will enhance our knowledge and understanding because the forestry sector is inexorably linked to the other sectors, such as water, health, agriculture, tourism, fisheries and coastal ecosystems. This chapter will introduce learners to adaptation strategies and related mechanisms from sectors outside forestry.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Describe non-forest climate change adaptation measures.
ii. Explain impacts of climate change in sectors outside forestry.
iii. Assess the methods of reducing the impacts of extreme weather events in agriculture.
iv. Assess methods of reducing the impacts of climate change on the transport and energy sectors.
v. Describe the link between forestry and other development sectors.
vi. Describe the disaster management cycle.

Activity 5.1 Brainstorming (10 minutes)

Which development sector do you think is most affected by climate change?

5.2 Sectors impacted by climate change outside forestry

Generally, all sectors are impacted by climate change, and they manage risks to reduce vulnerability using measures that can be technological, ecological or socioeconomic. Some of the adaptation techniques require technical support and backup. In this section we deal with the folloing sectors: agricultural, water, marine and coastal, energy, transport and tourism. Options to improve climate change adaptation such as the effective use of early warning systems are crosscutting for all sectors.

5.2.1 Agricultural sector

Agriculture is one of the key sectors sustaining human life and is also critical for adaptation to climate change and climate variability together with mitigation initiatives. The sector also addresses climate change and is important for food security. Climate change impacts on agriculture have both positive and negative consequences on food availability which includes production, distribution and exchange supply. Climate change can also affect access (this includes affordability, allocation and preference) (Gregory et al. 2005). Box 5.1 shows impacts of climate change on the agricultural sector.

Activity 5.2 Brainstorming (10 minutes)
How does climate change affect agricultural development?

Box 5.1 Summary of climate change impacts on agriculture (Prutsch et al. 2014, Mendelsohn and Massetti 2017, Hertel and de Lima 2020)

- Specific species may not grow in areas where they are currently growing.
- Growing seasons may be extended or shortened.
- Increased CO_2 fertilisation and possible yield increases, mainly in C3 plants.
- Alterations in crop life cycles (e.g., foliage, reproduction, maturity).
- Reduced total precipitation during the cropping season.
- Plants become more stressed when there are dry spells and heat waves.
- Decrease in soil water content in the second half of the summer.
- Evaporation is increased.
- More radical fluctuations in summer precipitation.
- Torrential rains and drought increase risk of soil erosion.
- Increase in disease pressure in both plants and animals resulting from new thermophilic pests and diseases.
- Multiplication of fungal toxins (mycotoxins).
- Acceleration of mineralisation processes in the soil and decline in soil fertility.
- A reduced amount of frost action because of decreased frost days.
- Late frosts create a danger to plant development.
- New livestock pathogens can emerge.
- Higher summer temperatures reduce food intake and productivity in animal husbandry.

What are the two most important variables for crop growth that are impacted by a changing

Smallholder farmers and agriculture are threatened by rainfall and temperature variability. Impacts of agriculture are more severe for those who depend on rain-fed activities. Several adaptive actions have, however, been implemented in different circumstances. Adaptation strategies vary depending on area and type of crop because different crops are affected differently by climatic events. Adaptation strategies in agri-culture include: changing planting strategies, crop rotation, minimum tillage, switching crops, rain water harvesting, drip irrigation, improving methods, planting drought-resistant crops, shifts from rain-fed to irrigated agriculture and small and drought-resistant livestock (Akinnagbe and Irohibe 2014, Myers et al. 2017). Box 5.2 shows examples of adaptation in cropping and livestock practices.

Another way of adapting agriculture to climate change is through agroforestry (combining trees and shrubs with crops and/or livestock), which is increasingly being recognised as an effective approach for minimising production risks under climate variability and change (Sheppard et al. 2020). Trees in agricultural fields can help maintain production under a variable climate and protect crops against climate extremes through microclimate amelioration (Chavan et al. 2014). We have discussed the importance of trees in agricultural systems. mainly in agroforestry systems where trees can also pump excess water out of the soil more rapidly due to their higher evapotranspiration rates (IPCC 2001). Furthermore, N-fixing trees make agriculture more drought-resilient due to improvements in soil nutrients and water infiltration, especially in degraded land. In Malawi and Zambia, maize production yields were greater in areas where conservation farming was practiced with *Faidherbia albida*, while in Malawi, farmers used *F. albida* and *Gliricidia* and crops and harvested modest yields during drought seasons, while farmers without the practices experienced total crop failure (FAO 2016a). In Niger, Farmer Managed Natural Regeneration (FMNR) programmes with *F. albida* improved their sorghum and millet yields, partly due to reduced wind speed and increased soil moisture. Droughts had fewer negative impacts on the FMNR areas than on other areas where the programme was absent (Bufflle et al. nd, Garrity and Bayala 2019).

5.2.1.1 Shifts from rain fed to irrigated agriculture

Water is critical for all sectors, especially agriculture. Most productive agriculture systems are threatened by climate change, population pressure and upstream flow variability, caused by land-use change and upstream water developments. In other cases, excessive use of groundwater worsens saline intrusion to coastal aquifers and along rivers. Changes in demand for agricultural products, global markets and the increasing understanding of possible impacts of climate change on agriculture and the water cycle affects the choice of investment in irrigation and water control (Faurès et al. 2007, Barellas 2018).

Irrigation and other means of agricultural water management are essential in building resilience to climate change and variability. In west Africa, FAO implemented a project funded by IFAD aimed at improving sustainability and adaptation of small-scale irrigation systems across key agro-ecological zones. The project is implemented in Côte d'Ivoire mainly by using inland valley bottoms and drip irrigation in vegetable production to increase food security, generate incomes, diversify diets and increase resilience to climate change. Furthermore, traditional irrigation (used in inland valley bottoms and swamps where water management interventions are done), full control irrigation sprinkler schemes, surface irrigation (pump irrigation and river diversion) are used (FAO 2019).

> Small-scale irrigation includes a range of technologies and practices for crop production, through capturing, storing and distributing water in small plots owned by individuals or farmer groups that can be part of a larger irrigation scheme.

In Mali, the small-Scale Irrigation Promotion Programme developed by the Government is helping farmers to cope with rainwater shortages. In Niger, agriculture is mainly based on small-scale family farms, combining rain -fed cropping with irrigation. In the Gambia, rice and vegetables are cultivated in the lowlands generally by women while men grow coarse grains and groundnuts in the uplands, with millet and groundnuts being the major crops. Use of canals and groundwater can improve the flexibility and dependability of water resource provision for both small- and large-scale farmers (FAO 2019).

5.2.1.2 Soil and water conservation technologies

Land degradation affects the productivity of ecosystems. To adapt the land resource to climate impacts, responses can give immediate results (short term) or in the long term. Examples of coping strategies with immediate impacts include the conservation of high-carbon ecosystems such as peatlands, wetlands, rangelands, mangroves and forests, whilst in the long term it provides multiple ecosystem services and functions, achieved through afforestation and reforestation as well as the restoration of high-carbon ecosystems, agroforestry, and reclamation of degraded soils. Therefore, reducing, avoiding and reversing desertification enhances soil fertility, increases biomass and carbon storage in soils, while sustaining agricultural productivity and food security (IPCC 2019).

For the water sector, farmers are coping with drought by using mulching, irrigation, water harvesting, weirs and drip irrigation. Integrated water resources management improves water availability and other natural resources. The capacity of existing water resource facilities may be improved (e.g. increasing dam height) through recharging of groundwater, infiltration and storage of rainwater, building new dams and reservoirs to increase water storage. Water harvesting and mulching conserve soil moisture in croplands. In developed countries, seawater and saline groundwater (brackish water) are desalinised and wastewater is recycled.

More efficient irrigation systems are required to improve lives of affected farmers. However, there is need for proper packaging of a product that will be attractive to small-holder irrigation. Small- and large-scale farmers in Indonesia, Peru and Zimbabwe have successfully and sufficiently used their water supplies through sprinkler irrigation and drip irrigation techniques, whilst fog harvesting has been used by small scale farmers in Nepal. Other farmers have used rainwater harvesting. For soil management, farmers in India, Nicaragua and Uganda have used integrated nutrient management systems to sustain productivity in cropping lands. In Ecuador and Philippines farmers used slow-forming terraces to manage their soils. Others, in Brazil and Kenya, adapted through conservation tillage (Clements et al. 2011, Obia et al. 2020)

Management Practices for Maintaining Soil Productivity

- *To improve soil structure and biological health, reduce erosion, and increase efficiency of water and fertiliser use:*
  mulching with natural materials and plastic, leaving crop residues, application of manure and biosolids, incorporation of cover crops in the rotation cycle, agroforestry, contouring of hedge rows, terracing and engineering structures, precision farming, conservation tillage and no tilling, controlled grazing, improving pasture species, controlled irrigation, land-use planning and land-tenure reform.

- *To improve soil nutrient budget:*
  Integrated nutrient management, biological N-fixation, judicious use of chemical fertilisers (National Research Council 2009)

5.2.1.3 Other adaptation in Agricultural systems

The agricultural sector is more threatened by variability in rainfall and temperature and has already implemented several practices and techniques to adapt to impacts of climate change. Some of the adaptive actions have, however, been applicable to different circumstances (FAO 2015). Strategies for adaptation in agriculture include planting drought-resistant crops, changing planting dates, improvement of agricultural methods, e.g. using conservation farming, shifting from rain-fed to irrigated agriculture, crop rotation and diversification, agroforestry, crop switching, rain water harvesting and drip irrigation. Practices such as agroforestry, mulching, manuring/compositing and water harvesting can improve soil nutrients, water availability, soil moisture and other conditions for growth (Yosef and Asmamaw 2015). Mandumbu et al. (2020) and Jepkemei et al. (2017) used tied ridges with better cotton varieties and water harvesting to cope with the impacts of a changing climate in Zimbabwe and Kenya, respectively. Furthermore, crop changes and/or diversification depends on rainfall and temperature trends, rainfall, anticipated seasonal shifts and potential hazard shocks. Crop diversification can include the following:

- Use of new staple food crop varieties (e.g. resistant to higher temperatures).
- Switching to new food crops.
- Changing from subsistence to market crops (food and/or non-food) to increase income).
- Moving more from (marketed) food crops to traded non-food crops (e.g. tobacco, cotton and biofuel).
- Switching from subsistence or marketed staple foods to traded non-staple food crops (e.g. sugar cane, coffee or fruits).

It is important to guard against maladaptation from some of the crop shifts (e.g. unsustainable extraction of ground water, use of more water or more energy). Issues to be guarded include the fact that farmers should have access to suitable seed sources for adaptation, other required inputs, technical knowledge and training, and water should be available (Antwi-Agyei and Nyantakyi-Frimpong 2021).

There are many activities that can be done to build adaptive capacity, but for the agricultural sector, it is important to build ecosystem services in agricultural systems. Resilience can be enhanced by building the capacity of institutions for collective action, disseminating knowledge and embarking on local adaptation planning (Bennett et al. 2014, Onyango 2017). Climate information services and information related to planting dates, pest and disease control, and water availability are crucial.

Box 5.2 Examples of adaptation in the agricultural sector

Some early maturing, drought-resistant, high yield maize varieties have been introduced in Southern Africa. Other smallholder farmers in drought prone areas of Zimbabwe switched from maize to traditional sorghum and millet resulting in improved food security. In Tanzania, farmers' adaptive strategies include rainwater harvesting in ditches, construction of check dams and engaging in alternative income generating activities. On a much smaller scale, bottles are used for drip irrigation of local plants. In places outside Africa, e.g. in Pakistan, farmers changed from growing traditional cotton varieties and escaped losses arising from pest outbreaks common in traditional varieties.

Activities by livestock farmers in sub-Saharan Africa date back to times when farmers used to migrate with their animals to better grazing areas. They have been most resilient to drought and others react by timely marketing of their livestock and destocking without altering the breeding herd. They also manage livestock feeding regimes to preserve their herd. Farmers also breed livestock for drought resistance, varying breeds or altering the systems to another low input system such as ostrich or game farming. For improving water supplies, livestock farmers harvested rainwater, constructed stock dams for water storage and used windmills to pump borehole water. (Fisher et al. 2015; Abid et al. 2016; FAO 2017a; Katengeza et al. 2019)

Activity 5.3 Brainstorming (15 Minutes)
What are the relationships between forest-based and non-forest-based technological options .

5.2.2 Water Sector

We have learnt how climate change affects agriculture and associated adaptive actions. Water shortages affect the agricultural sector and consequently food availability. Water shortage is an induced problem attributed to climate change that affects a quarter of the African population. There is, therefore, need for wide-scale implementation of adaptation measures to increase resilience and adaptive capacity under a changing climate especially in northern and southern Africa. Increased wet season rainfall patterns together with more frequent high-intensity rainfall events, affecting productivity, causing substantial economic losses due to crop vulnerability, after droughts or floods (Jiménez Cisneros et al. 2014; Prutsch et al. 2014, Nyiwul 2021). In this section we discuss climate change impacts and adaptation in the water resources sector.

Climate change affects all types of water. The scarcity of water, especially freshwater, has become a global problem, with its intensity aggravated by climate change and human activities. Freshwater is the water from precipitation and can be divided into green and blue water resources. Green water is site-specific precipitation that does not run off and can be in the form of productive green water, i.e. transpiration from biomass production in terrestrial ecosystems, or non-productive green water, i.e. interception and soil evaporation. Blue water is surface and groundwater that is stored in aquifers, rivers, dams and lakes and can be extracted for human use (Rockström and Falkenmark 2000, Falkenmark and Rockström 2006).

Climate change affects the role of forests in water regulation and soil protection through reductions in rainy-season flows and increases in dry-season flows which are of little value when total annual rainfall is low and significant quantities of water are lost through evapotranspiration and are consumed by the forests (FAO 2017b).

Water resources are affected by the amount of rainfall and the rate of ground-water recharge. When there is excess or little rainfall in the wet season, other sectors are affected, including economic losses due to the vulnerability of crops/livestock to droughts or flooding. Increased evaporation and variability of precipitation can result in a decrease in soil moisture available to plants and eventually affecting tree growth, crop yields and hence food security. Water shortages can also affect the industrial sectors such as soft drinks and bottled water which are water dependent (Duva 2014, Rankoana 2020). Challenges in the water sector are associated with the following:

- Increase in the intensity of precipitation that affects crop/livestock production and habitats.
- Reduced groundwater recharge due to drought or other events.
- Increased temperatures and depleted groundwater recharge can increase pollutants.
- Reduced water levels in summer parallel with increasing water demand due to rising temperatures.
- Cyclones or other weather-related events cause changes in river water levels.
- Shift of flood risk to other seasons such as winter and spring.
- Increased regional flood risk for most rivers resulting from small-scale heavy rainfall events.
- Operational limitations for hydropower plants due to high or low water levels and increased sediment transport.
- Soil moisture available to plants decreases with increased evaporation and variability of summer precipitation.
- Reduction in water yield of near-surface springs in dry periods.
- Soil erosion.

In some countries, seawater and saline groundwater (brackish water) are desalinised while wastewater is recycled for human consumption. Water harvesting, mulching, trees/shrubs can be used to conserve soil moisture in croplands. Forests and tree resources have a role in the water sector by controlling water erosion and dust storms, reducing river sedimentation, protecting catchment areas, facilitating ground water recharge and mitigating small floods.

5.2.3 Coastal, marine and fisheries

The rising sea-levels threaten many low-lying coastal areas, affecting groundwater levels and leading to reduced availability of fresh water (Oppenheimer et al. 2019). Climate change may worsen these stresses. Ocean acidification also poses a problem for the fishing industry where shellfish, like clams and oysters, do not thrive in some more acidic environments. As sea levels rise, the fishing industry will be one of the most adversely affected (Doney et al. 2012, IPCC 2013, Dutta et al. 2020). In this section we discuss impacts of climate change on coastal, marine and fisheries and adaptation options.

Fisheries already face multiple stresses, including overfishing and water pollution. Salmon and trout, for instance, thrive in cold, free-flowing water. Habitat loss for both could be as high as 17% by 2030 and 34% by 2060 if emissions of heat-trapping pollutants are not reduced (O'Neal 2002). Furthermore, changes in temperature and seasons can affect the timing of reproduction and migration as they affect aquatic life cycles that are controlled by temperature and changing seasons. Some marine disease outbreaks have been linked with changing climate. Higher water temperatures and higher estuarine salinities have facilitated the spread of parasites and diseases of oyster and salmon, respectively. Warmer temperatures have caused disease outbreaks in corals, eelgrass and abalone (Dutta et al. 2020). Box 5.3 shows an example of adaptation in coastal areas of Guinea.

Communities living in coastal areas are adapting to climate change. For example, in Mauritius, villagers of Grand Sable, a small planters'community between the mountains and a lagoon, are creating new, climate-resilient approaches to safeguard their future through the planting of 20 000 mangroves, which serve as a natural coastal defence against rising water, flood and lagoon siltation. In Guinea, communities engaged in coastal protection focus on clearing silt and sedimentation from 4200 metres of the drainage channels in Kaback and building 13 000 metres of stone dykes (UNDP 2018).

Box 5.3. Case studies in coastal areas

Adaptation in coastal zones of Guinea (UNDP 2018)
The coastal management project focused on strengthening protection of vulnerable coastal communities and areas against harmful effects of climate change. About 94 000 people (56% women and 44 % men) in 35 districts of Guinea worked on integrated approaches for coastal protection measures and land restoration. Coastal protection activities included clearing silt and sedimentation along 4 200 metres of drainage channels in Kaback and building a 13 000 metres stone dykes in Kaback, Kakossa, Koba and Kito between 50 to 150 metres from the sea. About 880 ha of agricultural land which was abandoned due to saltwater invasion was restored. Furthermore, 1 356 ha of rice fields were protected against saltwater intrusion and flooding, and erosion of channels. This is expected to increase rice yields from 600 kg/ha to 2 500 kg/ha, thus improving food security. The protection dykes and the use of seeds that are tolerant to salt water and soil acidity has resulted in improved rice yields.

The project is also focusing on the protection of mangroves, focusing on five activities:

- A community association managing 200 beehives.
- Efficient charcoal production kiln used “the meule casamançaise”. About eight ha planted for extraction of charcoal wood in managed areas. An SFM plan will be used to define logging zones, regulate access and determine the sustainable harvesting yield.
- Improved cook stoves, with an enhanced efficiency of 35%.
- Cultivation of oysters to diversify income.
- Solar kits for salt production to replace the resource-intensive traditional method, which requires more than three tonnes of green biomass (mainly from mangrove forests) to produce one tonne of salt.

Adaptation in coastal areas of lake Turkana- Kenya
Sustainable management of the available forest cover coupled with protection of fish breeding grounds was beneficial to arid and semi-arid land communities around the western shores of lake Turkana. The communities were able to show attitude change and realise income from an area that was previously filled with negative attitude towards the invasive *Prosopis juliflora* (Owino et al. 2020d).

5.2.4 Health and sanitation

In this section we look at climate change and adaptation in the health and sanitation sector. Africa is vulnerable to several climate sensitive diseases including malaria, tuberculosis and diarrhoea (Guernier et al. 2004, Güil 2017). Under climate change, rising temperatures are changing the geographical distribution of disease vectors which are migrating to new areas and higher altitudes. For example, migration of the malaria mosquito to higher altitudes will expose large numbers of previously unexposed people to infection in the densely populated east African highlands (Boko et al. 2007, Bartlow et al. 2021). A summary of the impacts of climate change on health is given in Box 5.4.

Activity 5.4 Brainstorming (10 minutes)
Give examples of climate related health issues that are linked to forests.

Box 5.4 Impacts of climate change on human health (Prutsch et al. 2014, Ayanlade et al. 2020, Nhamo and Muchuru 2019, Coates et al. 2020)

- Human health is directly affected by heat waves and natural hazards.
- Adverse effects on performance and well-being, as well as an increase in heat-related illnesses and deaths (esp. cardiovascular and respiratory diseases) due to heat waves and an increase in minimum temperatures at night.
- Intensification of bioclimatic stress, especially in cities and towns through effects of urban heat islands.
- Expansion of distribution areas and establishment of new disease vectors (insects, ticks, rodents) and pathogens (e.g., lyme disease).
- Climate change can cause occurrence of allergenic plants and animals.
- Reductions in the quantity and quality of drinking water.
- Food-borne infections can increase due to growth of microorganisms in food facilitated by high temperatures.
- Increase in the formation of ground-level ozone, which can cause irritation of mucus membranes and respiratory reactions.
- Increased UV radiation increases the risk of skin tumours and cancer.

According to UNFCCC (2017), extreme temperatures can aggravate cardiovascular and respiratory disease and increase mortality. Future climate variability will also interact with other stresses and vulnerabilities such as HIV/AIDS and conflict and war (Harrus and Baneth 2005, Sharifi et al. 2021), resulting in increased susceptibility and risk to infectious diseases (e.g. cholera and diarrhoea) and malnutrition for adults and children (WHO 2004). Countries with intensive malaria grew by 1.3 % less per person per year between 1965 and 1990, and a 10 % reduction in malaria was associated with a 0.3 % increase in economic growth.

Forests are important as supplementary and alternative sources of food, through provision of NTFPs, especially in years of crop failure due to climate related disasters. A wide range of NTFPs provide a source of income that allows for the purchase of food for both dietary diversification and to supplement calorie intake in periods of shortage, indirectly contributing to food security. Such increased consumption and use of NTFPs in times of stress can be viewed as an effective autonomous coping mechanism for dealing with threats to food security and is likely to expand under predicted climate change (Msalilwa et al. 2013, Shackleton 2014). Furthermore, medicinal plants, important for communities around forested areas, are likely to be affected by climate change leading to extinction of some of species and with changes in chemical content, potentially affecting quality or even safety of medicinal products from forests (Applequist et al. 2020). This has implications on the health of communities.

5.2.5 Built environment and infrastructure

Besides social conflicts and pollution, increased occurrence and magnitude of weather disasters continue to pose problems in settlements, infrastructure and industry. Flooding events cause loss and damage to property, whilst droughts and other weather-induced catastrophes activate migrant movements. In this section we look at climate change and the built environment including infrastructure development.

In Africa, the population in urban areas is relatively low but is likely to rise and pose more problems. Climate change destroys built environment and infrastructure. A summary of the impacts is given in Box 5.5. Figure 9 shows an area affected by floods in Harare, Zimbabwe.

Box 5.5 Impacts of climate change on infrastructure development (Prutsch et al. 2014)

- Heat stress can increase, and indoor conditions become bad.
- Sealing/insulation measures can increase concentration of pollutants inside buildings.
- More energy demand for cooling in summer.
- Energy demand for heating can be decreased in winter.
- More frequent heavy rains and thawing of the permafrost can increase mass movements, e.g. mudslides.
- Building structures can be damaged due to increased fluctuations in temperature and distinct changes in water table levels.
- Wet snow can be a danger to buildings.
- Increased frequency of heavy rains can overload the capacities of buildings, residential rainwater and waste-water systems (sewer systems, gutters, sewage treatment plants, etc.) Buildings and infrastructure can also be damaged by storms.

Activity 5.5 Brainstorming (10 minutes)

How can we minimise the impacts of climate change in the built environment?

Figure 9. Residential areas affected by floods in Harrare, Zimbabwe, in 2020 rainy season.

Infrastructure adaptation can be categorised into two:

Structural adaptation measures: e.g., changing the composition of road surfaces so that they are not deformed in high temperatures, building seawalls or using permeable paving surfaces to reduce run-off during heavy rainfall. Ecosystem-based approaches using natural infrastructure to design adaptation measures are also key alternatives to be considered alongside structural adaptation measures. In Madagascar, building of cyclone proof schools (Pauw et al 2016).

Management (or non-structural) adaptation measures: e.g., changing the timing of maintenance to account for changing patterns of energy demand and supply, investment in early warning systems or purchasing insurance to address financial consequences of climate variability. These measures can also include enhanced monitoring of existing assets to reduce the risk of failure as climate (EUFIWACC 2016).

5.2.6 Energy resources sector

In this section we discuss climate change and the energy sector. Most African countries have substantial deposits of fossil fuel resources, but their extraction is becoming less appealing due to their contribution to GHG emissions. Depletion of the reserves may also cause a gradual shift to new technologies and renewable energy (African Climate Policy Centre (ACPC) 2013). Countries have opportunities to exploit their potential by investing in infrastructure and necessary technologies. In developing countries, biomass is a renewable energy which can be transformed into transportation fuels, heat and electricity. Biomass energy is sourced from organic matter (animal or plant origin) and through transformation of wastes. This renewable energy source is classified as either forestry biomass, energy crops or biomass from wastes and residues (Nyika et al. 2020).

The use of fossil fuels is also likely to be threatened by international fossil fuel regulations threatening oil, gas and coal industries (Caldecott et al. 2013). However, most countries in Africa‘s rural areas depend on biomass as the primary source of energy (Bildiricia and Özaksoy 2016) but they can maximise the use of solar energy. Box 5.6 shows some of the impacts of climate change on the energy sector.

Box 5.6 Impacts of climate change on the energy sector (Prutsch et al. 2014, Chersich and Wright 2019).

- High or low water levels disrupting hydropower plants.
- Power shortages can be experienced as more energy is demanded for cooling, with corresponding lower river water levels.
- Power plants affected by water shortages or by water that is too warm.
- Higher air temperatures reduce efficiency of electricity generation.
- Interruption of power supply networks after extreme weather events.
- Climate change events can affect biomass production.

Thermal conversion efficiencies for thermal power generation will also be affected by rising temperatures. Demand for heating energy can decrease or increase depending on whether temperatures have increased or decreased, with the extent varying with geographic, technological and socioeconomic conditions (van Ruijven et al. 2019).

Solar energy provides access to lighting for longer working and studying hours per day, impacting on education and increasing opportunities for better livelihoods especially in rural areas (Murphy and Corbyn 2013). In Africa, solar energy provides off-grid lighting to more than 6.5 million people in Tanzania and many more in other African Countries. Solar energy also provides opportunities for charging phones and listening to the radio, facilitating communication channels for early warning systems and climate communication to all (Brown 2020). Further-more, energy saving stoves reduce forest destruction. For example, in Kenya, energy saving stoves reduced the amount of deforestation by consuming less wood with savings of 12.7%-33.3% of wood fuel with less pollution (Manoa et al. 2017).

There is also room to minimise emissions by improving the efficiency of existing power plants. Volumes of thermal power generation will decrease in many regions of the world whilst water use for cooling will increase, causing a reduction in power generation, reduction in operation capacity, and some temporary power plant shutdowns. There is a strong relationship between water and energy (Rodriguez et al. 2013). The global use of renewable energy resources can supply the world's energy demand, protect the environment, and provide energy security although they can be affected by seasonal variations (e.g. water, wind or solar) (Kumar 2020). These three forms of biomass will be discussed in the transport section.

Further reading:

Rodriguez DJ, Delgado A, DeLaquil P, Sohns A. 2013. Thirsty energy. World Bank. Washington DC. Available at: www.worldbank.org/water.

Nyika J, Adediran AA, Olayanju A, Adesina OS, Edoziuno FO. 2020. The Potential of Biomass in Africa and the Debate on Its Carbon Neutrality, Biotechnological Applications of Biomass, Thalita Peixoto Basso, Thiago Olitta Basso and Luiz Carlos Basso, IntechOpen, DOI: 10.5772/intechopen.93615. At: https://www.intechopen.com/chapters/73230

5.2.7 Transport sector

The transport sector encompasses rail, road, air and marine transport and is an important enabler of most business activities as virtually all other sectors rely on its infrastructure. Climatic events such as high temperatures, heavy rains, storms, cyclones, hurricanes etc. and sea level rise may damage transport infrastructure (Chinowsky et al. 2015, Chakwizira 2019) (Figure 10). Lack of resilient and reliable transport infrastructure reduces and can hamper growth and investment opportunities and have a negative overall impact on human welfare and socio-economic status (Gachassin et al. 2010, Rweyendela and Mwegoha 2021). Climate change will take a heavy toll on the African road system - virtually all models show that weather extremes will put considerable pressure on Africa's road system.

Figure 10. Road destruction from cyclone Idai (2019) in Eastern Zimbabwe: (a) road damaged (b) softened road surface causing busses to sink (c) Bridge washed away.

Risks associated with climate change include the following:

- Extreme weather events can affect drivers causing delays and increasing costs of transportation.
- Higher temperatures can cause pavement to soften and expand, creating rutting and potholes, as well as warping of rail tracks.
- Floods arising from periodic torrential rainfall, affect maritime, rail, road and air networks.
- Drought and changes in water availability can affect transport costs.
- Ports can be damaged by storms, hurricanes, cyclones, sea level rise or other damaging events.
- Destruction of infrastructure including roads and bridges during storms.

Activity 5. 6 Brainstorming (10 minutes)
What is the extent of biofuel use in your country?

The damage and accelerated aging of roads caused by climate change will require increased maintenance and more frequent rehabilitation[1]. According to IPCC (2014), because of climate change it is predicted that floods or flash floods are going to be more frequent and/or intense in future. Floods and flash floods in informal urban settlements, low-lying areas and mountain environments, destroy roads. This will increase the cost of maintaining and repairing the road transport network. The direct impacts of flooding

1 https://www.worldbank.org/en/topic/transport/publication/enhancing-the-climate-resilience-of-africas-infrastructure-the-roads-and-bridges-sector

on transport infrastructure include washing away of roads or sediment transport and associated drainage blocking that impairs roads (Fig 11). This also involves indirect costs such as travel delays or costly detours. In rural areas there are usually few alternatives once a road is blocked. For example, in 2007 floods washed away bridges and roads in eastern Uganda and cut off communication (Mwangi 2007).

a b

Figure 11. (a) A section of Kabale-Katuma road in Uganda damaged by heavey rains, and (b) Flooded road in Kampala.

People were forced to take longer routes - in one case people moved 200 km instead of the usual 10 km. This was associated with higher transportation costs and loss of agriculture produce, among others. Floods are now more frequent and have been reported most recently in Kasese and Mbale Districts. It is generally accepted that unpaved roads and bridges are more vulnerable to precipitation extremes. This is of particular concern to low- and middle-income nations, such as Uganda, where most roads are not paved.

On the other hand, the transport sector presents challenges for GHG emission mitigation, due to inadequate data on transport policies and the complexity of the transport sector as a system. In many countries, transport is a significant and growing contributor of GHG emissions. An efficient, effective and climate-resilient transport sector is crucial to lower the overall cost of doing business and to increase competitiveness. The UNEP (2020a)'s Emissions Gap Report showed that improvements in shipping and aviation technology and operations can improve fuel efficiency and reduce emissions from the sector. To reduce emissions from the transport sector, solar and electric powering are being developed.

The use of biofuels has been advocated to ease the fossil fuel burden in most developing countries. Examples of biofuel use in Africa include bioethanol generation from sugarcane in Malawi and Zimbabwe, jatropha electrification in Mali, the use of sisal waste for biogas production in Tanzania and the production of ethanol from cassava in Benin (Smeets et al 2009, Watson 2009, Smeets et al 2020). Some African countries (Botswana, Burkina Faso, Cameroon, Gambia, Ghana, Zambia, Kenya, Liberia, Sierra Leone, South Africa, and Tanzania) developed, formalised and implemented policies on the use of bioenergy (COMPETE project 2009).

Activity 5.7 Group discussion (20 minutes)
Discuss the role of biofuels in responding to climate change in the transport and energy sectors.

5.2.8 Tourism

Tourism is affected by climate change in that holidays are planned to be during favourable weather condition. Heat, cold and rain affect tourist activities. There are different types of tourism, including adventure tourism, bicycle tours, beach tourism, cultural, eco-tourism, geo-tourism and industrial tourism. Climate change will be, or is already, affecting the behaviour of wildlife including animals and plants that often attract tourists to some sites. Drought has caused some deaths of elephants in some national parks in Southern Africa. Impacts of climate change on each form of tourism may differ. Box 5.7 shows some of the impacts of climate change on the tourism sector.

Activity 5. 8 Brainstorming (10 Minutes)
Identify forms of tourism in your country and how they are affected by climate change

Box 5.7 Impacts of climate change on tourism (Prutsch et al. 2014, Pandy and Rogerson 2018, Dube and Nhamo 2020)

- Reduced trends of snowfall in lower and middle elevations affects skiing.
- Reduction in snow-making opportunities at elevations.
- Reduced reliability of snow can affect the economic viability in ski areas.
- Shift in the start of the winter season to later in the year and shortening of the winter and longer of summers.
- Reduced precipitation in summer months affects vegetative tourist areas.
- Increased water temperatures promote swimming but can also decrease water quality.
- Landscape changes due to glacial retreat.
- Melting of the permafrost increases possibility of rockslides, rock falls and mudslides, signifying a possible danger for mountaineers and the strength of tourism infrastructure.
- Variations in the demand for and availability of energy and water for the tourism sector.

Activity 5.9 Revision (10 minutes)

1. Explain impacts of climate change on the following sectors:
   i. Agricultural sector
   ii. Energy sector
   iii. Water sector
   iv. Transport sector
   v. Coastal resources
   vi. Health
2. How do you minimise impacts in each of the sectors above using forest-based measures?

Summary
In this session, we have learnt about impacts of climate change in sectors outside forestry, including agriculture, water, energy, transport, marine and coastal resources (including fisheris), tourism and water resources, and their relationship with climate change and variability. We also learnt that forests and trees are important in all sectors and in water resources management from evaporation to ground water recharge and protecting water sources.

5.3 Sectoral adaptation measures

Adaptation options can be categorised by sector. IPCC (Noble et al. 2014) developed three categories based on the diversity of adaptation options for different sectors and stakeholders - structural/physical, social and institutional. These will be outlined below.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Identify suitable technological options for adaptation.

ii. Identify suitable socio-economic options for adaptation.

Activity 5.10 Brainstorming (15 Minutes)

What technological options for adaptation to climate change are used in your country/ region?

5.3.1 Structural and physical adaptation

This includes application of discrete technologies and the use of ecosystems and their services to serve adaptation needs and the delivering of specific services at national, regional, and local levels. Options encompasses actions related to engineering and built environments, technological options, ecosystem-based adaptation and services. IPCC (Noble et al. 2014) showed four categories of structural and physical options and these are discussed below.

- **Technological** options include new crop and animal varieties, genetic techniques, traditional technologies and methods, efficient irrigation, water saving technologies (including rainwater harvesting), conservation agriculture, food storage and preservation facilities, hazard mapping and monitoring technology, early warning systems, building insulation, mechanical and passive cooling, renewable energy technologies and second-generation biofuels. Some of these have been discussed under their relative sectors.

- **Engineered and built environment** include sea walls and coastal protection structures, flood levees and culverts, water storage and pump storage, sewage works, improved drainage, beach nourishment, flood and cyclone shelters, building codes, storm and waste-water management, transport and road infrastructure adaptation, floating houses, adjusting power plants and electricity grids. Building settlements in safe zones and improving building designs will be discussed in detail in the following sections.

- **Ecosystem-based** including wetland and floodplain conservation and restoration, increasing biological diversity, afforestation and reforestation, conservation and replanting mangrove forest, bushfire reduction and prescribed fires, green infrastructure (e.g., shade trees, green roofs), controlling overfishing, fisheries co-management, assisted migration or managed translocation, ecological corridors, *ex-situ* conservation and seed banks, community-based natural resource management (CBNRM) and adaptive land use management. Some ecosystem-based adaptation options will be discussed in detail in the following sections.

- **Services** include social safety nets and social protection, food banks and distribution of food surplus, municipal services including water and sanitation, vaccination programs, essential public health services (including reproductive health services), enhanced emergency medical services and international trade.

5.3.2 Technological options

Technology options reduce adverse impacts of climate change and range from more efficient irrigation and fertilisation methods, plant breeding for greater drought tolerance, and adjusting planting based on projected yields to the transfers of traditional technologies (Noble et al 2014). Some of these have been discussed under the agricultural sector. Technology Mechanism that was acknowledged under the UN-FCCC is meant to help in addressing technological needs. There are two components - the Technology Executive Committee and the Climate Technology Centre and Network (CTCN). These are expected to respond to needs of different countries for technology development and transfer at both the policy and the implementation level (UNFCCC 2014). The CTCN is the implementation arm of the mechanism, offering targeted interventions that help countries unlock transformational climate change action (CTCN 2019). When adopting technology, there is need to consider the technological requirements for overcoming the impact of climate change in different sectors. The CTCN services focus on technical assistance, knowledge sharing collaboration and networking.

> Technology is the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts) (IPCC 2007b).

In most African countries, technical assistance from CTCN in 2019 showed the need for supportive policy frameworks and included climate smart agriculture policies, energy efficiency regulatory frameworks, land restoration and management, and a strong overarching demand for capacity building. A total of 38 African countries received technical support from CTCN. One of the products of 2019 was new product standards for an ancient cooking tool that was expected to provide significant energy savings in Ethiopia (CTCN 2019).

> In 2017 Ghana, Kenya, Mauritius, and Namibia worked on transformational change towards sustainable cooling appliances. Tunisia is transitioning to energy-efficient lighting on a national scale. The CTCN also developed educational materials on the design and management of energy efficient lighting systems, regulations, and government policies in order to build the necessary capacity to implement Tunisia's ambitious National Energy-Efficient Lighting Transition Strategy. In Cote d'Ivoire, CTCN helped by strengthening the ability to make informed climate change decisions through building an environmental information system and an integrated data repository to facilitate sound planning and policy making for the future. In the same year, the CTCN also worked with communities in Lindi, Mtwara and Pwani in Tanzania to develop sustainable charcoal and wood fuel value chains, including charcoal and cook stove production for use in both rural and urban areas (CTCN 2017).

IPCC (2007) also defined technology transfer as the exchange of knowledge, hardware and associated software, money and goods among stakeholders that leads to the spreading of technology for adaptation or mitigation, including diffusion of technologies and technological cooperation across and within countries.

Activity 5.11 In text question
Identify and describe at least three case studies in your country or region on the application of various non-forest-based technological options applied in different sectors of development.

Early warning systems

Early warning system (EWS) are one of the climate change adaptation actions integrating communication systems to assist community preparedness to dangerous climate-linked events. The EWS improves the vigilance for climate-related hazards by both individuals and decision-makers and improves their willingness to optimise positive weather conditions. These can be complemented by hazard mapping and monitoring technologies. The EWS for natural risks require comprehensive scientific and technical foundation, with a strong emphasis on communities exposed to the threats, using a systems approach to incorporate all relevant issues associated with that risk, either emanating from the natural disasters or social susceptibilities, or from long- or short-term practices (Luther et al. 2017, Schlef et al. 2018).

However, proper messages and reliable institutions are important pre-requisites for effective EWSs. The elements of EWSs follow a logical sequence having direct mutual linkages and interactions with each other. There are four interacting elements for effective and complete EWS, including information about the risk, provision for monitoring and warning services, communication and dissemination protocols, and capacity to respond (UN Office for Disaster Risk Reduction (UNISDR) 2016).

EWSs can address climate impacts on human health, for instance those related to drought and heat waves. Heat waves emanating from climate warming causes death and injury, risking human health. Given these consequences, timely notification using EWSs to vulnerable people can be an adaptive option for reducing human health disasters. The correct use of an early warning system may result in significant reduction of damages resulting from extreme climate change events. A wide range of systems ranging from traditional passive announcements (e.g. broadcasting statements), to active communication with vulnerable individuals, e.g. message alerts to target groups using mobile phones can be used. The correct use of an early warning system results in significant reduction of damages resulting from a climate change event. Promotion of the development and operationalisation of people-centred, multi-hazard EWS has been prioritised at the global level (UNISDR 2015). Examples of EWS applied globally are shown in box Box 5.8.

Box 5. 8 Examples of EWS

- UNDP's programme on "Strengthening Climate Information and Early Warning Systems (SCI-EWS) for climate resilient development and adaptation to climate change" is implemented in Africa, Asia and the Pacific. The model integrates components of risk knowledge, monitoring and prediction, dissemination of information and response to warning systems, and is used at sub-regional and regional levels to guarantee readiness and rapid responses to natural disasters. In Uganda, SCIEWS was implemented by equiping obsolete and deficient meteorological stations with 43 modernised systems. This has reduced disaster risk impacts through more effective ways of generating and disseminating information. The information is essential for strengthening climate change resilience and food security with 64 % of Uganda`s population depending on subsistence agriculture.
- UNEP's Climate Risk and Early Warning Systems (CREWS), is an initiative that was launched at UN CCC in Paris in 2015 to increase the capacity of Multi-Hazard Early Warning Systems. The initiative operates in areas most susceptible to tropical cyclones and floods in 19 countries of Africa and the Pacific. Progress of the different initiatives is reported by CREWS (2019).
- The Gambia has an integrated project for advancing national planning, raising awareness and increasing knowledge sharing, building capacity and creating national rapid response and early recovery mechanisms through their Disaster Risk Reduction (DRR) and Climate Change Adaptation programme (UNDP-UNEP 2015).

- The technique of framework analysis in conjunction with the conceptual framework of protection motivation theory to interpret flood perceptions and mitigation actions of flood victims and public officials in Ouagadougou, Burkina Faso, showed that, despite the experience of a devastating flood in 2009 and clear understandings of flood causes, mitigation actions in Ouagadougou after the 2009 flood varied widely. This occurred due to adverse perceptions that mitigation actions are costly and that personal ability and responsibility to effect change is limited. These adverse perceptions offset neutral or positive perceptions that mitigation measures, if correctly implemented, are effective, and that the risk of flooding is high.
- The Climate Information for Resilient Development in Africa (CIRDA) created a model to deliver effective weather and climate services in sub-Saharan Africa. This was funded by GEF and implemented by UNDP. The end product is a toolkit for communicating early warning systems.
- Outside Africa, climate change stimulated early rehabilitation and advanced improvement of EWSs. In Europe, they have had considerable experience with early warning systems, especially concerning flood and flash-flood risk, but also heat waves. For example, the availability of several global collaborative weather prediction systems through the "THORPEX Interactive Grand Global Ensemble" (TIGGE) archive that offers prospects of new dimensions in early flood forecasting and warning. The data has been used as meteorological input for the European Flood Alert System (EFAS) and was applied in a flood event in Romania in October 2007. It was possible to raise awareness for the flooding event eight days before the event and the other forecasts provided greater understanding of a range of potential flood conditions (Bougeault et al. 2010).

Activity 5.12 Brainstorming (10 Minutes)

1. Identify some of the activities facilitating early warning systems in your country?
2. What are the challenges associated with effectiveness of early warning systems in your country

Several technological and social barriers prevent effective implementation of EWS. According to UNDP (2016) and Mazambani and Mutambara (2018), there are eleven major challenges that affect effectiveness of early warning systems in Africa:

Absence of reliable data. Most National Hydro-Metrological Systems (NHMS) in sub-Saharan Africa provide incomplete information though it is improving with time. Reliability is affected by issues of limited capacity of staff, limited resources and defective monitoring systems.

Lack of credibility. Although information generated by NHMS has improved because of improved investments in climate observation and communication services, the information generated by most NHMS in sub-Saharan Africa is still very limited. Most NHMS do not give reliable information.

Lack of protocols. The packaging, diffusion and preventative response actions of most African nations are limited to a few who can gather weather and climate data, to produce some innovative communication protocols.

Limited sophistication in packaging. Weather information should be packaged to give early alerts and action-oriented climate information, e.g. Public Service Announcements (PSAs) and crop reports, including how people should react when there is bad weather. Other packages could be tailored for private sectors. The creation of interesting packages gives NHMS opportunity to overcome credibility problems and create new effective relationships with consumers of their products.

Limited relationships with traditional media and other actors. Early warning messages generated by NHMS are often passed onto other actors, such as extension agencies, the media, government partners and private companies for dissemination and action. There is a great opportunity for success when these actors (potential brand ambassadors and messengers) are effectively engaged.

Lack of distribution systems. It is necessary to find appropriate ways of disseminating the information to farmers, including those living in remote areas. Information that is well packaged and good is likely to be more trusted as users are enlightened on what to do in the event of bad weather.

Limited business-development capacity and necessary frameworks. Skills required to develop business proposals and information systems, or the development of favourable legal and policy frameworks, are different from traditional skills of just gathering, examining and sharing/dissemination of information. To develop business skills, NHMS should manage credibility snags, create income streams and connect with new groups of potential partners, that are currently not existing in some countries.

Cultural challenges. One of the biggest problems associated with use and/or understanding of early warnings is linked to cultural beliefs, gender, age, language, education and literacy levels. There should be ways of reaching the diverse groups who speak numerous languages, have peculiar cultural beliefs about weather information and are usually illiterate.

Political challenges. Most NHMS lack credibility which has resulted in limited political support for NHMS budgets or institutions. There is potential to break the status quo by reconnecting in the political space and creating clear communication strategies where relevant actors at the policy and public level are actively involved. In most cases, politicians do not recognise climate adaptation as politically urgent enough to be elevated on the policy agenda.

Economic challenges. In poor nations, circumstances may lead to diversion of funds intended for weather and climate services to other services. Communication systems used in developed countries are not very suitable for the unique social, cultural, political and economic settings of the African continent.

Climatic challenges. The changing climate and associated weather patterns and conditions such as droughts, heat, cold, floods, heavy rains, lightning, and other extreme weather events present new challenges for NHMS and their advancement.

Activity 5.13 In text question (10 minutes)
Identify the challenges associated with early warning systems in your country.

5.3.1.2 Engineered and built environment

Engineered and built environment options include building of sea walls and coastal protection structures, flood levees and culverts, water and pump storage, sewage works, improved drainage, beach nourishment, flood and cyclone shelters, building codes, storm and wastewater management, transport and road infrastructure adaptation, floating houses, adjusting power plants and electricity grids. Some of these adaptations options were discussed under respective sectors.

5.3.1.2.1 Building settlements in safe zones

Most engineering options are expert driven, capital-intensive, large-scale and highly complex (Sovacool 2011, Vincent and Mambo. 2017). Many are extensions and improvements of existing practices, plans and structures. Newer projects are now considering a risk of climate change in initial designs, including management of storm and wastewater flow (both inland and coastal), flood levees, seawalls, upgrading existing infrastructures to improve wind resistance, beach nourishment and flooding resilience (Ranger and Garbett-Shiels 2012, Vincent and Mambo 2017). For example, during the engineering design of the Qinghai-Tibet Railway, various measures were proposed to ensure the stability of the railway embankment in permafrost regions in vulnerable areas (Wu et al. 2008).

In coastal areas, sea walls and coastal protection structures can be built. Flood levees and culverts, water and pump storage, sewage works, improved drainage, beach nourishment, flood and cyclone shelters, building codes, storm and waste water management, transport and road infrastructure adaptation, floating houses and adjusting power plants and electricity grids are some of adaptation actions that can be taken to reduce vulnerability (IPCC 2014).

5.3.1.2.2. Better building designs

Adaptation may mean building designs that consider predictions of increased risk and intensity of extreme events. Adapting to climate change to minimise exposure and improve resilience in built areas requires the adoption of climate compatible infrastructure. Technological options to improve building designs include use of building insulation and mechanical and passive cooling. In this regard, buildings should be energy-efficient to reduce emissions from buildings. Ward and Wilson (2019) suggested several adaptation options for building for the climate impacts and these are summarised in Table 7.

Table 7. Adapting buildings to climate change impacts.

Climate impact	Adaptive actions
Warming temperatures	• Design cooling-load-avoidance measures into buildings. • Design natural ventilation into buildings. • Model energy performance with higher cooling design temperatures. • Reduce urban heat islands by tree planting, installation of green roofs on buildings, roofing with reflective membranes or coatings, and installation of light-coloured pavement and walkway surfaces.
Drought and water shortages	• Avoid new developments in the driest regions. • Specify water-efficient fixtures and appliances. • Plumb buildings for graywater separation and water-conserving fixtures. • Rainwater can be collected and stored for outdoor irrigation, toilet flushing, and, with proper filtration and treatment, potable uses. • Plant native, climatically appropriate trees and other vegetation.
More intense storms, flooding, and rising sea levels	• Avoid building in flood zones. • Design buildings to survive extreme winds. • Expand storm water management capacity and rely on natural systems. • Raise buildings off the ground and elevate mechanical and electrical equipment in flood prone areas. • Plan for rising sea levels in coastal areas. • Install components that protect buildings from flooding or allow flooding with minimal damage. • Specifications for materials that can survive flood and hurricane damage.
Wildfire	• Specify Class A roofing. • Eliminate gutters or design and maintain them to minimise fire risk. • Avoid vented roofs or protect vents from ember entry. • Installation of high-performance, tempered windows. • Manage vegetation around homes.
Power interruptions	• Provide dual-mode operability with high-rise buildings • Provide site-generated electricity from renewable energy, e.g. solar-thermal energy. • Provide solar water heating. • Plan and zone communities to maintain functionality without power.

There is need for proactive adaptation to avoid the dangerous impacts of climate change. For example, buildings in coastal areas should focus on re-enforcement of structural and non-structural protection or even to move away (relocation). Other activities can include the construction of cyclone resistant houses.

Activity 5.14 Brainstorming (10 Minutes)
How can forests facilitate structural and physical adaptation options?

5.3.2 Ecosystem based adaptation approach

Ecosystem based adaptation (EbA) entails the use of biodiversity and ecosystem services to help people to adapt to adverse effects of climate change. This is an important physical adaptation option which will be discussed as a separate section. The options under EbA include: ecological restoration, including wetland and floodplain conservation and restoration; increasing biological diversity; afforestation and reforestation; conservation and replanting mangrove forest; bushfire reduction and prescribed fire ; green infrastructure (e.g., shade trees, green roofs); controlling overfishing; fisheries co-management; assisted migration or managed translocation; ecological corridors; *ex situ* conservation and seed banks; community-based natural resource management (CBNRM); and, adaptive land use management. Some of these have been discussed under the respective sectors.

While some institutions developed their own working definitions of EbA, most are like the definition adopted by the Convention on Biological Biodiversity (CBD) (2009) stating that EbA is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. This definition of EbA has four major elements:

- Adapting to the adverse impacts of climate change as the main goal.
- EbA should be the overall strategy.
- Using biodiversity and ecosystem services as an approach or sub-strategy.
- Assisting people (the target).

Bertram et al. (2017) showed that EbA elements outlined in CBD (2009) can further be broken down into five criteria that can be used for effective EbA:

- Reduce social and environmental vulnerability to climate change.
- Generate social benefits and support the most vulnerable.
- Restore, maintain or improve ecosystems and biodiversity.
- Be mainstreamed into policies at multiple levels.
- Support equitable governance and enhance capacities.

In this regard, EbA strives to help people adapt to climate change through enhancing and safeguarding ecosystems and ecosystem services important for human survival. It also increases resilience of people. The difference between EbA and conservation is that the former makes people more resilient whilst the later aims at conservation of populations or ecosystems in a changing climate.

EbA can encompass activities focusing on ecological restoration, wetland and floodplain conservation and restoration, conservation of biodiversity, conservation and replanting of mangrove forest, afforestation and reforestation, wildfire management and prescribed burning, control overfishing, green infrastructure (e.g., shade trees, green roofs), fisheries co-management, ecological corridors, assisted migration or managed translocation, *ex situ* conservation and seed banks, adaptive land use management and community-based natural resource management (CBNRM).

In South Africa, they promote the use of EbA using biodiversity and ecosystem services to help people adapt and build resilience to adverse effects of climate change. EbA encourages the use of ecological infrastructure as a complement or substitute for built infrastructure. Ecological infrastructure includes healthy mountain catchments, rivers, wetlands, coastal dunes, and nodes and corridors of natural habitat, which together form a network of interconnected structural elements in the landscape (DEA and SANBI 2016).

In some drought-prone areas, farmers embark on biodiversity management and reducing desertification through protection of trees on farms and in forests. Indigenous trees are being planted because of their drought tolerance. People who depend on forest resources for their survival are usually those of low-income households, living close to the forest, are headed by the elderly, are less educated or illiterate and are more risk averse (Kihila 2018).

Integrated water resources management

Integrated Water Resources Management (IWRM) is a practice that supports development of water management, incorporating land related resources so as to equitably increase social and economic benefits with no compromise to the sustainability of vital ecosystem processes. The success of IWRM depends on proper selection, adjustment and application of the correct mix of tools for a given situation to ensure water security. The principles for IWRM are based on agreements made at the International Conference on Water and the Environment (1992) in Dublin and are referred to as the Dublin Principles:

- Fresh water is finite and vulnerable, yet necessary for sustaining life, development and environments.
- Participatory approaches should include users, planners and policymakers at all levels to develop water management options.
- Women play a significant role in providing, managing and safeguarding of water resources.
- Water should be acknowledged as an economic good because of its economic values in all competing uses.

In this regard, IWRM is grounded on the fair, efficient and sustainable management and use of water, recognising that water is crucial in ecosystems as a natural resource, a social and economic good. The quantity and quality of water determine the nature of its utilisation. The general framework for IWRM includes economic and social equity (Figure 11) emphasizing the use of an integrated approach. The integration clearly shows how water resources management is linked to the "3Es" of sustainable development: economic efficiency, equity and environmentally/ecologically sustainable.

Figure 11. General Framework for IWRM (source: https://www.gwp.org)

The IWRM approach is based on three pillars (GWP 2020):

- An enabling environment of suitable policies, strategies and legislation for sustainable water resources development and management.
- Appropriate institutional framework for policy implementation.
- Development of managerial instruments necessary for the institutions to work.

International collaboration on water issues is managed through the Global Water Partnership Organisation (GWPO), comprising the global secretariat, a Steering Committee, and a Technical Committee.

Options under **services** include the building of social safety nets and social protection, food banks and distribution of food surplus, municipal services (including water and sanitation), vaccination programs and essential public health services.

5.3.3 Socio-economic options

Social adapatation includes educational, informational and behavioural options. Social adaptation options are categorised by IPCC (2012) into educational, informational, behavioural and economic options.

Educational adaptation options include activities targeting raising of awareness on climate change and adaptation, integration of climate change into education curriculum, gender equity in education and extension services. The sharing of local and traditional knowledge, including their integration into adaptation planning. The use of participatory action research and social learning, community surveys, knowledge-sharing and learning platforms. Involvement in international conferences and research networks and communication through media.

Informational options include hazard and vulnerability mapping, early warning and response systems, including health early warning systems, systematic monitoring and remote sensing. It also includes provision of climate services including improved forecasts, downscaling climate scenarios, longitudinal data sets and integrating indigenous climate observations. Community-based adaptation plans should include community-driven slum upgrading and participatory scenario development.

Behavioural options include accommodation, household preparation and evacuation planning, retreat and migration (has own implications for human health and human security). Other option are soil and water conservation, livelihood diversification, changing livestock and aquaculture practices, crop-switching; changing cropping practices, patterns, and planting dates, silvicultural options in forestry and reliance on social networks (IPCC 2012, Thibaut et al. 2017, Morissette 2020). Some of these options have already been discussed in detail.

Economic options include financial incentives including taxes and subsidies, insurance, including index-based weather insurance schemes, catastrophe bonds, revolving funds, payments for ecosystem services, water tariffs, savings groups, microfinance, disaster contingency funds and cash transfers. Selected social and economic options will be discussed in the coming sections (IPCC 2012, Akamani 2021).

Activity 5.15 (Brainstorming) (10 Minutes)
Share your views on connection between forest and socio-economic adaptation options.

5.3.3.1 Livelihoods diversification

All forms of livelihoods, whether subsistence farming, fishing, full-time labour employment or seasonal work, are threatened when climate change causes losses in sectors such as agriculture and fisheries production. Lack of asset diversification and access to formal financial markets can increase susceptibility among people living in poverty (World social report 2020).

Livelihood diversification is one of the long-term approaches to adaptation planning that is most applicable at the community and household levels with a goal of creating an environment that enables people to shift to additional sources of income while maintaining a certain level of living quality. Economic diversification aligns best with regional and national policy-making processes. Strong ownership of planning and strategy, inclusion of women, and inclusiveness of NAPs can assist economic growth and increase the income of vulnerable people (UNCC secretariat 2019a).

Engagement in off-farm activities largely depends on patterns of assets held by individuals or households, and their capacity to increase livelihood opportunities and reduce vulnerability. Off-farm activities are heterogeneous and complex, varying in space and time. Engagement in such activities is normally a response to external factors (such as market, policy or an extreme weather event) which often take place rapidly.

The factors can either be *distress-driven* (activities are not always 'good' for people, environment or development, e.g. deforesting to make charcoal, begging or sex work) or *opportunity-driven* (chosen preferentially over existing activities including farming) involve earning income and/or investments that shift the dependence of the person or household away from a relying on farming. The activities, however, differ in several cases between men and women and by age of the individual (Ellis 2000, Kuhl et al. 2020). In some communities, household members migrate, and the resulting remittances improve adaptive capacities as a form of cash injection. Venturing into agroforestry and tree planting activities can help small holder farmers to diversify their income and livelihood, while conserving natural resources, enhancing ecosystem services, and adapting to and mitigating the effects of climate change (FAO 2016b).

5.3.3.2 Improved access to market

Adaptive capacity can be enhanced through improved access to markets, and this can include the upgrading of rural markets and/or ensuring that women also get some space. Other infrastructure includes roads for access to market, appropriate climate resilient sheds, sanitation, water supply and drainage facilities. Women benefit most from improved access to markets because lack of it obstructs them from opportunities associated with nonfarm activities (Assan et al. 2018, Arakelyan 2017). Furthermore, Belay et al. (2017) and Gessesse and Zerihun, (2017) showed that access to input and output markets can have positive and significant effect on farmers' input intensity and crop diversification.

5.3.3.3 Use of indigenous knowledge and practices

Changes in climate affect rural livelihoods, prompting them to develop different means for coping and adapting to climate change effects (Musarandega et al. 2018, Baffour-Ata et al. 2021). Different traditional adaptive and coping strategies, such as rotation of crops and early planting, have been implemented to adapt and cope with changing climate. Smallholder farmers are not well exposed to modern scientific techniques but have been cultivating crops based on existing local knowledge and ecological conditions. Their adaptation approaches are a product of their priorities, capacities and knowledge shaping how they plan and cope with climate change issues.

Unique methods are used by communities who depend on natural resources to ensure their survival in the face of climate change. For example, in Tanzania, some communities used techniques such as tree planting, terracing, mixed cropping, diversification and water harvesting in locally based water reservoirs (Kihila 2018). In South Africa, DRC and Uganda, farmers improved soil fertility by applying manure and kitchen garbage in the fields whilst others switched to more drought resistant livestock systems from cropping systems (Adediran et al. 2003, Upenji 2020, Mfitumukiza et al. 2017). Cotton farmers in Zimbabwe used irrigation and diversified to more drought-resistant crops to cope with climate change (Mdungela et al. 2017, Fagariba et al. 2018). They also adjusted the periods of planting to match with the beginning of the rainy season. In other parts of Africa, farmers adopted conservation farming methods such as minimum tillage to improve soil quality, trap moisture and minimise soil erosion, subsequently decreasing dependency on rainfall while increasing crop yields.

There is growing recognition of the importance of traditional water and land-management practices in groundwater recharge, and the generation of other ecosystem services due to enhanced water availability (Everard et al. 2018).

5.3.3.4 Social and safety networks

Social safety nets are instruments for extending support to those adversely affected by extreme weather events. The interactions are shaped by the government, communities, organised groups, or families who are key components of strategies to minimise expected losses from climate change. Managing risk may also include enhancing social safety nets and providing agricultural insurance (Campbell et al. 2014, Hathie et al. 2017). Services that contribute to social safety nets and social protection, include food banks and distribution of food surplus, reliable municipal services such as water and sanitation, vaccination programs, availability of essential public health services (including reproductive health services), emergency medical services and international trade.

Sources of safety nets can either be private (transfers from family, community members, and institutions) or public (support expected from the government). The most important safety net for communities in developing countries are forest resources that have often been the major victim of distress-driven actions. Firewood, mushrooms, indigenous fruits, medicines, timber, edible insects and fibre are often harvested unsustainably during times of crisis (Shackelton 2014, Tieminie et al. 2021). In most cases outsiders also exploit these resources at the expense of local communities with communities allowed access to less economically valuable resources (NTFPs) whilst outsiders exploit the most valuable ones (Bergen 2001, Nelson 2010, Hutauruk et al. 2018).

5.3.3.5 Migrations including internally displaced people

The IPCC (1990) gave a warning that one of the greatest impacts of climate change could be linked to human migration as millions of people become displaced by shoreline erosion, coastal flooding and severe drought. Climate change impacts driving human migration can either be drivers related to *climate processes* (e.g. water scarcity, sea-level rise, desertification and salinisation of agricultural land) or *climate events* (e.g. droughts, floods, storms and glacial lake outburst floods). These are compounded by other non-climate drivers, such as government policies, weak community resilience to natural disaster and population growth (Brown 2008, Martin et al. 2020).

However, it is difficult to directly attribute human mobility to climate change because people move for a wide variety of reasons, and even where hazards contribute to this decision, effects of socioeconomic, cultural, political and environmental processes can either enable or constrain the ability of people to cope resulting in their movement (Stapleton et al. 2017). The impact of climate change depends on the number of people affected and the speed with which people react. Temporary migration is an adaptive response to climate stress where people move temporarily and return after the climate event. However, the ability to migrate is a function of mobility, financial and social resources, with the most vulnerable people not likely to migrate (Wilkinson et al. 2016). When the situation becomes too serious, people are forced to migrate. Forced migration hampers development efforts by adding pressure on urban infrastructure and services, undermining economic growth, increasing the risk of conflict and worsening health, educational and social indicators among the migrants (Brown 2008, Martin et al. 2020).

National adaptation strategies usually do not consider large-scale migration as evidenced by the absence of homes or shelters for climate migrants. When migration is planned and used as a voluntary coping mechanism, it can serve as a social safety net for loss of income, for example through sending remittances, and could potentially serve to alleviate pressure on already degraded lands (Laczko and Aghazarm 2009, Faozanudin and Islam 2021).

However, migration is usually considered as a failure to adapt. To reduce the risk of creating migration refugees, countries should adequately be prepared, with effective early warning systems and widespread climate change education. If adaptation is carefully planned together with disaster management processes and plans, there is potential for reducing vulnerability and ensuring individuals, communities and countries have the necessary skills to cope with and respond to climate-related hazards; determination of flows, conditions and impacts of human mobility; and supporting migrant and displaced workers and communities (Crawford-Brown 2017, Stapleton et al. 2017).

Activity 5.16 Revision (10 minutes)

1. Identify technological options for climate change adaptation in the following sectors:
   i. Agriculture
   ii. Health
   iii. Transport.
   iv. Fisheries
2. What are the adaptation actions in the energy, tourim and water sectors?

Summary

In this section we learnt that there are several adaptation measures that can be used to adapt to climate change impacts. These include technological options such as early warning systems and modification of building designs. The other category of measuresis the socio-economic options which include livelihood diversification, use of indigenous knowledge, improved market access, building of social safety nets and managing migration.

5.4 Disaster risks management

A disaster is a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts (Lavell et al 2012, Pereira et al. 2019). In this session we learn about aims and objectives of disaster management, types of disaters, hazard management, disaster management cycle and the link between disaster management, climate change and sustainable development.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Discuss the aims and objectives of disaster risk management.
ii. Categorise types of disasters.
iii. Explain the disaster management cycle.
iv. Explain approaches to hazard management.

Activity 5.17 Brainstorming (10 Minutes)

What are some of the climate change disasters common in your country?
Share your views on the nexus between forests and disaster risk management in the context of coping with impacts of climate change and climate variability.

5.4.1 Aims and objectives of disaster management

Climate-related risk is the result of interaction of physically defined hazards with the properties of the exposed system i.e., its sensitivity or (social) vulnerability. Risk can also be considered as the combination of an event, its likelihood, and its consequences – i.e., risk equals the probability of climate hazard multiplied by a given system's vulnerability. A risk management framework provides a way of systematically analysing risks and possible interventions to reduce threats. Risk management includes the plans, actions or policies implemented to reduce the likelihood and/or consequences of risks or to respond to consequences and is a fundamental concept in adaptation (IPCC 2007a, Amuzu et al. 2017). Disaster risk reduction (DRR) is a systematic approach to identify, assess and reduce the risks. It aims at reducing socio-economic vulnerabilities to disaster as well as dealing with the environmental and other hazards that trigger the disasters.

Disaster management is the complete set of policies, procedures and practices that are undertaken before a disaster occurs, when it occurs and after it occurs (Warfield 2008).

The Sendai Framework for Disaster Risk Reduction 2015–2030 highlighted that disasters worsened by climate change are increasing in frequency and intensity, thus significantly impeding progress towards achievement of sustainable development. The activities are based on management of current and future risks, with the building of resilience as the main target to be achieved by 2030 (UNISDR 2015). In this regard, countries are expected to pursue four priorities of action:

- understanding disaster risk,
- strengthening disaster risk governance to manage risk,
- investing in disaster reduction for resilience, and,
- enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction.

Uncertainty was defined in chapter 1 as a state of having limited knowledge where it is impossible to precisely describe existing state or future outcomes. It applies to predictions of future events, to physical measurements already made, or to the unknown.

A risk framework represents a good strategy for dealing with uncertainties. Risk is the potential for something given that an outcome is uncertain, for lives, livelihoods, ecosystems, health, economic, social and cultural assets, services, and infrastructure. In climate change, major risks lie in the failure to adapt to changes in the environment, leading to instability and insecurity of economic systems to threaten adequate levels of societal welfare (ECONADAPT toolkit).

Risks categories used to guide decision-making are:
- acceptable risks,
- bearable risks, and
- intolerable risks (exceeding a socially negotiated norm).

Approaches to disaster risk management are based on four distinct public policies or components (Cardona et al. 2012, Botzen et al. 2019):

- Risk identification (involving individual perception, evaluation of risk, and social inter-pretation).
- Risk reduction (involving prevention and mitigation of hazard or vulnerability).
- Risk transfer (related to financial protection and in public investment).
- Disaster management (across phases of preparedness, warnings, response, rehabilitation, and reconstruction after disasters).

5.4.2 Types of disasters and disaster management

Disasters can either be natural, technical/human induced or emerging complex (Table 8).

Table 8. Types of disasters. Source: Khan (2008).

Natural Disasters	Technological/Human Induced	Complex Emergies
• Earthquakes • Extreme Heat • Floods • Drought • Tropical cyclones • Landslides • Tornadoes • Tsunamis • Volcanoes • Wildfires • Winter weather • Infectious disease outbreaks • Insect outbreaks	• Radiation disasters from nuclear blasts, nuclear reactor accidents, or accidental spills of radioactive material • Release of hazardous chemicals accidentally • Bioterrorism • Oil spills • Destruction or bombing of nuclear reactors • Pollution	• War • Conflict • Displaced populations • Food insecurity • Epidemics

Natural disasters are also categorised by the Centre for Research on the Epidemiology of Disasters (CRED) (2009) as:
- Biological (e.g., insect/animal outbreaks and disease epidemics and).
- Climatological (e.g., drought, extreme temperatures and wildfires).

- Geophysical (e.g., earthquakes, tsunamis, landslides, and volcanic activity).
- Hydrological (e.g., floods and avalanches).
- Meteorological (e.g., storms/wave surges and cyclones).

In managing climate change risks, it is important to understand linkages between adaptation to climate change, disaster risk reduction and development (Figure 12). Proper planning can build resilience and enables systems to recover from hazardous events, to improve or to adapt (Usman et al. 2013). Management of disasters follows a cycle that links disaster risk with climate and development (IPCC 2012, Carby 2018).

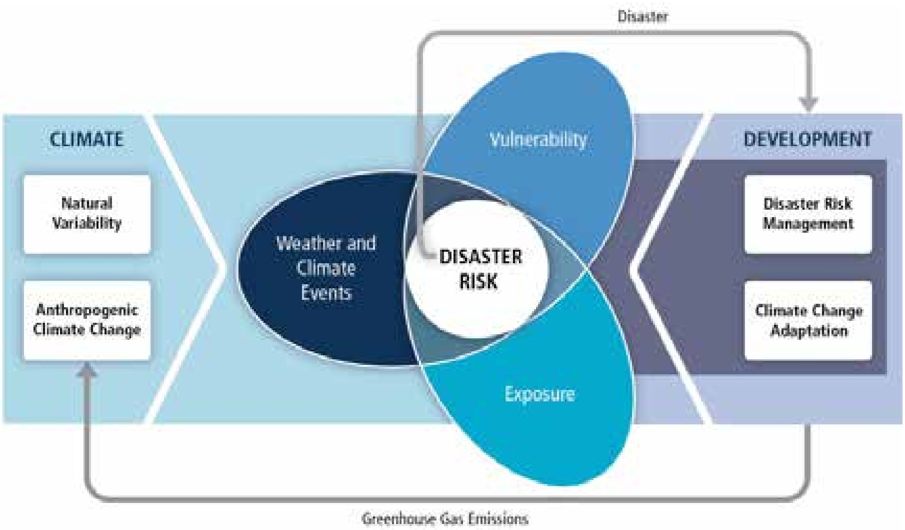

Figure 12. Linkages between climate, disaster risk and development (IPCC 2012).

Disasters can be managed through four types of activities: hazard management and vulnerability reduction, economic diversification, political interventions and public awareness (Department of Regional Development and Environment Executive Secretariat for Economic and Social Affairs Organisation of American States 1991).

Hazard management and vulnerability reduction is a process where several activities are undertaken to reduce loss of life and destruction of property. Natural hazard management depends on the nature of the hazard, area and people involved. The process can be divided into:

- Pre-event measures includes actions aimed at mitigating natural hazards through collection and analysis of data (natural hazard, vulnerability and risk assessments), vulnerability reduction and preparedness for natural disasters (prediction, emergency preparedness, training and education).
- Actions during and immediately following an event – includes rescue and relief measures.
- Post-disaster measures include rehabilitation and reconstruction.

Economic diversification is a component of economic resilience that is also a key component of sustainable development because of its ability to reduce poverty while generating long term employment. Diversification into different sectors, e.g. tourism, agriculture and energy, can allow people to respond to emerging climate changes and developing resilient systems that are reasonably flexible (UNDP 2021).

Strengthening climate resilience of agricultural livelihoods in Agro-Ecological Regions I and II in Zambia
The project supports the Government of Zambia to strengthen the capacity of farmers to plan for climate risks that threaten to derail development gains, promote climate resilient agricultural production and diversification practices to improve food security and income generation, improve access to markets, and foster the commercialisation of climate-resilient agricultural commodities (UNDP).

Political intervention - political concerns before, during and after a natural disaster can define those who are at most risk, who is able to intervene, what actions can be taken, and who can benefit from the actions. Politics has a role to play on the impact of a natural disaster and the delivery of subsequent humanitarian assistance including policy formulation on disaster and inclusion of budget allocation for preparation and response. Hapeman (2012) showed that social, economic and political factors significantly amplified the devastating impact of a natural disaster in Bangladesh.

Public awareness - together with public education to reduce disasters in order to turn available human knowledge into specific local action for reducing disaster risks. Priority (iii) of the Sendai Framework emphasises the need for knowledge, innovation and education to build a culture of safety and resilience at all levels. It mobilises people through clear messages, supported with detailed information. People will know the specific actions they can take to reduce their risks; they are also convinced that these actions will be effective and they believe in their own ability to carry out the tasks.

5.4.3 Disaster Management cycle

The disaster management cycle follows steps from mitigation to recovery (Figure 13). These steps overlap with the length of each step determined by the severity of the disaster (Khan 2008).

Mitigation is a process where immediate assistance is given to maintain life, improve health or support the morale of people affected by disaster. The assistance can be in the form of limited aid such as blankets and food after displacement by floods However, efforts and actions depend on the integration of suitable measures in national and regional development plans.

Preparedness shows readiness to disaster events and can be in the form of strategic reserves of food, water, equipment, medicines and other essentials preserved for use after occurrence of a national or local catastrophy. Preparedness measures are affected by design and implementation of preparedness plans, warning systems, emergency training/exercises, emergency communications systems, evacuation plans and training, emergency personnel/ contact lists, mutual aid agreements, resource inventories and public information/education. As with mitigations efforts, preparedness actions also depend on the integration of suitable measures in national and regional development plans.

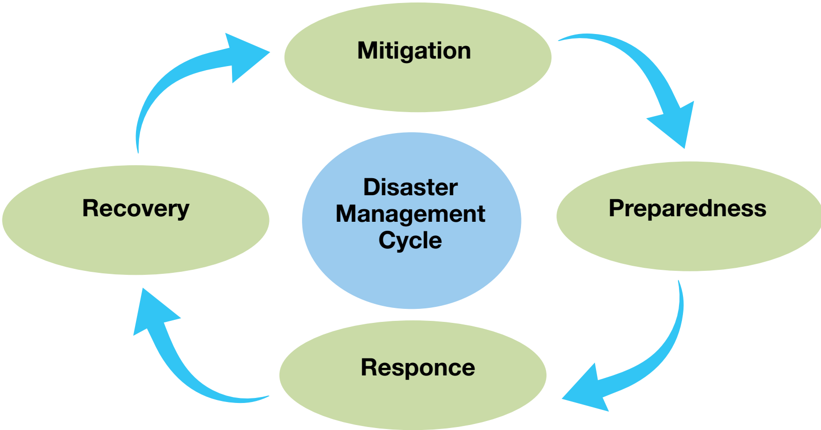

Figure 13. Disaster management cycle (After Warfield 2008).

Response encompasses immediate assistance that is given after a disaster to maintain life, improve health and support the confidence of the affected people. Such assistance ranges from provision of transport, temporary shelter, food, and semi-permanent settlements in camps and other locations. It also may involve initial repairs to damaged infrastructure (Lavell et al. 2012). The focus in the response phase is to satisfy the basic needs of the people until a permanent and sustainable solution is in place.

Recovery is a phase when the affected population can undertake an increasing number of activities to restore their lives and the infrastructure that supports them. Recovery activities continue until all systems return to normal or are improved. Measures of recovery can be both short and long term, including restoration of critical life-support systems to their minimum operating standards and provisions for temporary housing, public information, health and safety education, reconstruction, counselling programs and economic impact studies.

Activity 5. 18 In text question (5 minutes)
Which part of the disaster management cycle do you think is most important? Support your answer.

5.5 Case studies on non-forest sector climate change adaptation strategies

FAO-Sida funded project in eastern Africa (Ethiopia, Kenya and Tanzania)

The project on 'Strengthening capacity for climate change adaptation in land and water management' targeted climate change adaptation interventions to strengthen communities and individuals. It used different institutional training mechanisms starting with government to NGOs. The expected outcomes were to improve productivity, food security and livelihoods as well as building communities' and farmers' resilience to increasing weather variability and climate change. The activities included capacity building in soil health, diversifying livelihoods, water conservation and strengthening local institutions. The most appropriate technologies and approaches for each project, were determined by local factors, such as: biophysical factors, socio-economic factors and land ownership.

Feed the Future initiative addressing hunger and food security in Sub Sahara Africa

USAID is promoting the Feed the future initiative by the US government. The programme supports multi-stakeholder research projects in sustainable intensification under "Africa Research in Sustainable Intensification for the Next Generation' (Africa RISING). The programme aims at sustainably intensifying typical African farming systems using three types of projects in three regions of Africa:

- Crop-livestock systems in the highlands of Ethiopia.
- Cereal-based agriculture systems in the West African Guinea-Savannah comprising some districts in Northern Ghana and the Sikasso Region in Southern Mali.
- Maize-legume-livestock integrated farming in East and Southern Africa comprising a few districts in Malawi, Tanzania and the Zambian eastern province.

Adapting to Climate Change through goat rams and guinea fowls in Namibia
Floods have been occurring more frequently making it difficult to rely on cropping in Namibia. Furthermore, if the crops grow, they are usually consumed by birds that come as a result of the floods. Given this scenario, UNDP assisted farmers to adapt to climate change through the distribution of improved livestock and seeds. Goats were given to help farmers adapt to drier and hotter conditions in sub-Saharan Africa's most arid region. Boer goats were crossed with local goats to create a breed with higher rate of reproduction, is more valuable and more resistant to drought. Furthermore, guinea fowls were bred by the group and women living with AIDS, replacing chickens, and the results are favourable because the guinea fowls have greater reproduction and are more resistant to warming temperatures.

Activity 5.19 Revision (10 minutes)
1. Explain the meaning of disaster risk management.
2. Categorise types of disasters.
3. Explain the disaster management cycle.
4. Explain approaches to hazard management.

Summary

This chapter covered non-forest-based adaptation and included sectors of agriculture, fisheries, health and sanitation, built environment, energy, transport, water and tourism. Sectoral adaptation initiatives were also highlighted. All sectors are adapting to climate change through technological interventions such as early warning systems, integrated water resource management, soil and water conservation, building settlements in safe zones, better building designs and ecosystem-based approaches. In other cases, socio-economic adaptation is done through livelihood diversification, improved access to markets, use of indigenous knowledge and practices, social networks and migration. At national, regional or international levels, climate change mainstreaming occurs at all levels. At national levels, countries prepare national adaptation plans for implementation at sectoral levels. Government coordinate with other development agencies to promote adaptation at all levels with supportive legal frameworks. Finally, the chapter discusses disaster management types and cycle. The chapter concludes by giving some case studies on non-forest adaptation.

Suggested further reading

Noble IR, Huq S, Anokhin YA, Carmin J, Goudou D, Lansigan FP, Osman-Elasha B, Villamizar A, 2014. Adaptation needs and options. In Field CB, BarrosVR, Dokken DJ, et al. (eds.): Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of IPCC. Cambridge University Press, Cambridge and New York, pp. 833-868. Available at: 14 — Adaptation Needs and Options (ipcc.ch)

Chapter 6. Monitoring, Reporting and Evaluation of Adaptation Practices

6.1 Chapter overview

Effective monitoring, reporting and evaluation of adaptation practices and projects are important for climate change adaptation. This chapter is expected to enhance awareness of learners about these aspects.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Describe concepts of monitoring and evaluation in the context of climate change adaptation in forestry.
ii. Identify appropriate methods for monitoring and evaluation of climate change adaptation in forestry projects.
iii. Describe different methods used for monitoring and evaluation of non-forest-based adaptation options/projects to climate change and climate variability.
iv. Assess different types of adaptation measures to climate change in forestry projects.
v. Write reports detailing outcomes of monitoring and evaluation for adaptation practices.

Activity 6.1 Brainstorming (10 Mins)

What is the importance of monitoring and evaluation of any project?

6.2 Concepts and purpose of monitoring and evaluation

Monitoring and evaluation (M&E) is a process of regular and systematic collection, analysis, and reporting of information about a project's inputs, activities, outputs, outcomes and impact (Simon and Mwenda 2021). It is a stage in the project cycle used to assess progress and changes in order to adjust where progress deviates from objectives (Dinshaw et al. 2014, Simon and Mwenda 2021). At the national policy level, adaptation M&E is normally carried out for accountability and knowledge generation (OECD 2015). In this regard, the process, progress and effectiveness of investment projects and programs can be assessed. Before we continue, we define some basic terms in M & E:

Inputs. The human and financial resources, physical equipment, clinical guidelines, and operational policies that are the core ingredients of programs and enable programs to be delivered (Frankel and Gage 2007).

Outputs. The results of activities achieved at the program level, in two forms: the number of activities performed and measures of service utilisation. Outputs are what are produced as a direct result of inputs. They are the tangible, immediate, and intended products or consequences of an activity (Frankel and Gage 2007, USAID 2018).

Outcomes. The changes measured at the population level in the program's target population, some or all of which may be the result of a given program or intervention. Outcomes refer to specific knowledge, behaviour, or practices on the part of the intended audience that are clearly related to the program, can reasonably be expected to change over the short-to-intermediate term, and that contribute to a program's desired long-term goals (Frankel and Gage 2007).

Impact. The anticipated end results or long-term effects of a program (Frankel and Gage 2007).

Indicators. Quantitative or qualitative measures of program performance that are used to demonstrate change and that detail the extent to which program results are being or have been achieved. Indicators can be measured at each level: input, process, output, outcome and impact. Indicators measure characteristics or conditions of people, institutions, systems or processes that may change over time (Frankel and Gage 2007, USAID 2018).

Performance target. The specific, planned level of result to be achieved within an explicit timeframe with a given level of resources (USAID 2015).

Results framework. A logical summary that explains how a project's strategic objective (SO) is to be achieved, including those results that are necessary and sufficient, as well as their causal relationships and underlying assumption (Frankel and Gage 2007).

Theory of change. A process that describes how a particular intervention will bring about results. The process identifies a long-term goal and provides a backward mapping of the conditions necessary to meet that goal (Brown 2016). The result is a narrative description, usually accompanied by a graphic or visual depiction, of how and why a purpose or result is expected to be achieved in a particular context (USAID 2018).

Logic model. A program design, management and evaluation tool that describes the main elements of a program and how these elements work together to reach a particular goal. The basic elements in describing the implementation of a program and its effects are inputs, activities or processes, outputs, outcomes and impacts. A logic model graphically presents the logical progression and relationship of these elements. A logic model visually depicts the theory of change, illustrating the connection between activities and expected outcome (Frankel and Gage 2007, USAID 2018).

M&E is critical for ensuring the long-term success of climate change adaptation initiatives, plans and actions. It plays a vital role in three aspects of climate adaptation (CoastAdapt 2018):

- Tracking the performance of activities undertaken during the development of an adaptation plan (e.g. stakeholder engagement activities).
- Tracking pre-identified risk thresholds/trigger levels which identify when new adaptation actions should be undertaken.
- Determining whether planned outputs and outcomes from adaptation actions have been achieved.

Monitoring can be defined as the systematic, continuous critical assessment of actions in order to measure their evolution and adjust them according to circumstances and project's objectives. Data collected can be quatitative and/or qualitative. It is a basic and universal management tool for identifying project/programme strengths and weaknesses and reviewing progress (UNDP 2009). Results of monitoring help all concerned actors in making appropriate and timely decisions that help to improve the project. In other words, monitoring can be a systematic and continuous assessment of progress over time. It includes continuous measurement of activities relative to objectives or relevance of the project/programme. The logical framework, the activity schedule, implementation schedules, and project budget provide the basis for monitoring a project. The Global Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) (2013) showed that results of monitoring are used to:

- Document progress and results of a project.
- Provide required information for management to timely make decisions and take remedial action (when needed).
- Stimulate the accountability of all stakeholders in a project (to beneficiaries, donors, etc.), i.e. the monitoring process/activities shows whether programme implementation is on track and whether the planned activities are taking place as scheduled.
- Check whether the intended impact is on track to be achieved.

Evaluation shows the extent of achievement of objectives and their relevance, together with efficiency, effectiveness, impact and sustainability. It includes assessment of the design of the project and its implementation. Evaluation results improve quality and standards. Most development initiatives have increased their focus on evaluation. A definition of evaluation given by the OECD (2002) and Robbins (2019)) is "the systematic and objective assessment using research methods of an ongoing or completed project, program, or policy, its design, implementation and results. The aim is to determine the relevance and fulfilment of objectives, development efficiency, effectiveness, impact and sustainability". Evaluation findings are primarily used for:

- Giving conclusions - summary evaluations show a program's overall effectiveness, e.g., audit, renewal, quality control, accreditation.
- Enabling programme improvements using formative evaluation, e.g., showing programme strengths/weaknesses and progress.
- Generating knowledge through the conceptual use of the findings, e.g., generalisation, theory building.

In this regard, evaluation is a separate analysis that draws upon all these components, but also involves additional independent data collection and analysis. It is concerned with valuing and is conducted across the three stages: *ex-ante* evaluation, on-going evaluation and terminal evaluation. Evaluation can also be input-output based evaluations/outcome, impact or results evaluation, process-based evaluation, behavioural change evaluation, or economic evaluation.

> Monitoring data is one of the most important sources of information for evaluation

Evaluation is based on criteria that guide the appraisal of any project, programme or policy The criteria include:

Relevance. Value of the intervention relative to primary stakeholders' needs, national priorities, national and international partners' policies etc. Includes relevance in relation to the goals and objectives.

Mission Statement. Global standards can be used to serve as references in evaluating the processes through which results are achieved and the results themselves.

Efficiency. Assessing if the project or programme achieved its objectives using the most economical resources.

Effectiveness. Assessing if the activity achieved satisfactory results compared to stated objectives.

Impact. Assessing the results of the intervention - intended and unintended, positive and negative, including the economic, social and environmental effects on individuals, communities and institutions.

Sustainability. Determining if activities and their impact are likely to continue when external support is removed, and will the intervention be more widely replicated or adapted?

Evaluation differs from monitoring in terms of focus, timing and level of detail (Table 9).

Table 9: Some of the differences between monitoring and evaluation

Monitoring	**Evaluation**
A **continuous** process	A **specific** activity or moment
To provide information to day-to-day decision making (adjustments).	To provide recommendations to strategic decision-making processes.
It is carried out by the project team (to adapt and improve the impacts) and the donors (to follow the progress).	It is carried out by an evaluation team (internal or external to the project team) for the project team and the donors (lessons learned).
It focuses on input, activities and output.	It focuses on outcomes, impacts and overall goal.
Monitoring checks whether the project did what it said it would do	Evaluation checks whether what the project did had the impact that it intended.

Source: Adhikari 2017

Activity 6.2 Brainstorming (10 Mins)
What are the important criteria for monitoring and evaluation of climate change adaptation initiatives?

The process of M&E must be incorporated at all stages of an adaptation project from planning to post implementation. Within the main steps of the adaptive management cycle, M&E processes are included at the project cycle stages of:

- Identifying risks and project objectives
- Assessing risks
- Identifying actors and mapping of roles of each in the adaptation project.

Other components of M&E were given by Turner et al. (2014) and STAT (2017):

- **Indicators:** pointers of progress toward the proposed results can reveal the status of an activity, project or program. Indicators can be either performance, process, output or outcome indicators.
- **Reporting:** goes together with monitoring, often at monthly, quarterly or annual intervals. Performance reports prepared at intervals in the project/programme life help to track project progress and give updates on resources required to achieve project objectives. Performance reviews (e.g., stakeholder meetings, rapid appraisals) are done to improve capacity for effecting improvements. Such reporting can also reveal issues like increase of invasive spp. or drying of wetlands.
- **Data and Information management systems** through collection and sharing reliable and robust data for use in making informed decisions. Includes infrastructure (e.g. computers) and processes.

> Indicator is a measurable characteristic or variable which helps to describe a situation that exists and to track changes or trends – i.e. progress – over a period of time.

A results framework is often depicted as a theory of change (ToC), logic model, or log frame to identify results that should be achieved by an intervention, including the logical cause-and-effect relationship between the intervention's inputs, activities and these results. A ToC frame-work is increasingly favoured for climate change adaptation M&E initiatives. The designing and implementation of an adaptation strategy represents an opportunity for considering how the project progress and performance will be monitored, evaluated and reported.

Several tools are used to support effective monitoring and evaluation, including; Logical Framework, Indicator Tracking Matrix; an M&E Plan; Activity Tracking Matrix: and, budget and expenditure tracking. Table 10 shows evaluation criteria and how it is related to project logic using some forestry related examples for each component/element.

Table 10. Evaluation criteria and how its related to project logic.

GOAL/ INTENDED

IMPACT

Improved community resilience

OBJECTIVE/ INTENDED OUTCOME
Diversified farm production

OUTPUTS

Trees planted
Soil conservation
Trained farmers

INPUTS

Equipment
Personnel
Funds

EFFICIENCY

# of agroforestry plots, planned workshops

Quality of outputs
Costs per unit area

compared with Standard

EFFECTIVE-NESS

Fruit trees

Woodlots

Crop yields

Understanding of conservation

IMPACT

Intended

Improved forest/tree cover

Energy security
Increased soil fertility

Unintended
Conflicts-livestock grazing agroforestry plants

RELEVANCE

Whether people still regard Trees/shrubs important compared with crops with no trees

SUSTAINABILITY

People's resources, motivation, and ability to maintain the trees and improved soil fertility and food security in the future

Source: Modified after UNICEF 2003.

6.3 Types of monitoring and evaluation of climate change adaptation practices

Monitoring, reporting and evaluation of adaptation practices and projects is important for climate change adaptation initiatives in order to learn from the process and adapt. This chapter enhances awareness and knowledge of learners about monitoring, evaluation and reporting of adaptation, projects, practices, policies and strategies. In this section we learn about types of M&E which are basically divided into community-based and programme, project and policy M&E systems (Spearman and McGray 2011). There are several adaptation monitoring and evaluation frameworks.

Learning outcomes

By the end of this chapter, the learner should be able to:

i. Describe concepts of monitoring and evaluation in the context of climate change adaptation in forestry.
ii. Identify appropriate methods for monitoring and evaluation of climate change adaptation in forestry projects.

Activity 6.3 (Brainstorming) (15 Minutes)

Identify a forest-based adaptation project in your country or region and discuss the methods used for monitoring and evaluation.

6.3.1 Community based M&E systems

Community based M&E methodologies are normally bottom-up tactics that encompass local vulnerabilities and immediate community priorities. They incorporate local realities and relevant findings while improving local capacities (Estralla and Gaventa 1998, Bynoe 2021). Community based initiatives involve the use of participatory M&E frameworks where all stakeholders are engaged in most if not all steps of the process. Participatory M&E (PM&E) is a process where partnerships are developed by primary actors in a program for collaboration in its design and systematic implementation, including developing tools, setting objectives and indicators, and sharing experiences and knowledge. PM&E improves stakeholder trust, empowerment, ownership, inclusion, willingness for continuous learning and effective implementation of actions in adaptation projects (O'Connell et al. 2016).

The Global Fund (2020) defined community-based monitoring as a mechanism used by service users or local communities to gather, analyse and use information on an ongoing basis to improve access, quality and the impact of services, and to hold service providers and decision makers accountable.

PM&E methods are variable and include Participatory Monitoring, Evaluation, Reflection and Learning for Community-based Adaptation (PMERL) that uses participatory rural appraisal tools for stakeholders to analyse their own situations and develop mutual views on specific actions. Participatory approaches stimulate dialogue and allow the appreciation of the goals and assist stakeholders to reflect on the factors that influence adaptation and its value for different actions (Krause et al. 2015).

Another EU initiative is the Global Climate Change Alliance (GCCA), whose focus is to support dialogue and cooperation on climate change with developing countries that are most vulnerable to climate change. For example, in Uganda, the GCCA programme established a M&E baseline through an extensive participatory process, and this helped to correctly identify specific vulnerabilities at district level, sequentially permitting accurate measurement of changes attributed to programme actions. In establishing the baseline, communities were able to map climate vulnerability and select the most appropriate communities as the focus for the intervention (Lamhauge et al. 2011, IIED 2014, Richardson 2018).

The UNDP piloted the use of Vulnerability Reduction Assessment (VRA) tool in Guatamela demonstrating that it can be used as an indicator system suitable for community-based adaptation (CBA) projects (Wang et al. 2018). The VRA assessment is built on four questions that capture context-specific problems identified during community level meetings (3-4) in the course of the CBA project. Basic VRA indicators focus on vulnerability, livelihoods or welfare caused by i) existing climate variability and change; ii) developing climate change risks; iii) magnitude of barriers to adaptation; and, iv) ability and willingness of the community to sustain the project (Droesch et al. 2008, Lucky et al. 2021).

6.3.2 Program, project and policy based

Some projects do not consider M&E frameworks adaptation exclusively but that it is rather integrated within the development process. Another example of these initiatives is an approach by GEF that prescribed a series of outcomes and indicators compared against a baseline for each objective.

WRI´s National Adaptive Capacity (NAC) framework is another approach that gives an understanding of institutional aspects of national adaptive capacity. Furthermore, a consolidated monitoring, reporting and evaluation (MRE) system was also developed in Europe to work at the national level (EEA 2015). The MRE showed the importance of participation of a wide range of stakeholders, where indicators were mainly created using iterative and interactive processes involving experts and other stakeholders.

Another M&E framework aiming at linking the top down and bottom-up approaches is the Tracking Adaptation and Measuring Development (TAMD) which follows two tracks (Figure 14). Track 1 assesses institutional climate risk management while track 2 measures adaptation and development performance across scales (Brooks and Fisher 2014). The TAMD framework was used in Kenya and the results showed that the framework was suitable for both *ex ante* and *ex post* evaluation processes because of its capacity for exploring links between climate risk management at the subnational level and development performances at the local levels (Karani et al. 2015).

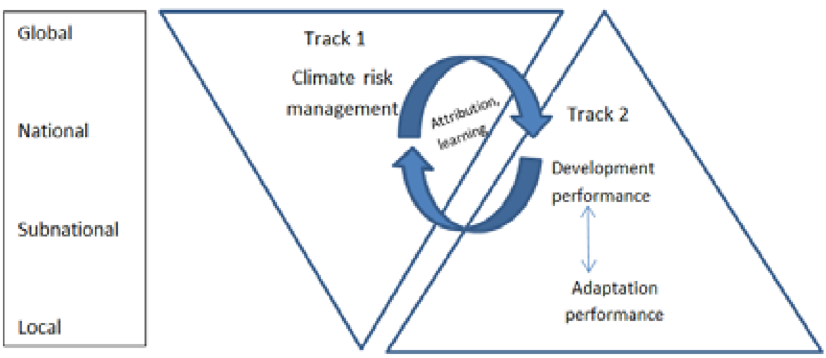

Figure 14. The relationship between track 1 and track 2 in TAMD (Brooks and Fisher 2014).

Kenya's National Climate Change Action Plan (NCCAP) covers both mitigation and adaptation. A complementary National Performance and Benefits Measurement Framework (NPBMF) has been proposed. The objective of the framework is to track both mitigation and adaptation actions and the synergies between the two. It is informed by a methodology developed by IIED called Tracking Adaptation and Measuring Development (TAMD). The indicator-based system uses outcome and process-based monitoring, reporting and verification (MRV) of actions under the indicators measured at the national and county levels. Agriculture and livestock are both sectors for which prioritised adaptation actions to be monitored are proposed (OECD 2015).

6.4 Monitoring and evaluation parameters

There are several monitoring and evaluation parameters in use. In this section, vulnerability, resilience, adaptive capacity and indicators will be explained.

6.4.1 Monitoring and evaluation of vulnerability

The IPCC (2007) defined vulnerability to climate change and showed that the measures of vulnerability typically include exposure to climate change, sensitivity to its effects, and the capacity to adapt to cope with the impacts and these were adequately explained in chapter 1. Adaptive capacity includes modifications of both behaviour, resources and technologies (Adger et al. 2007, Engle 2011, Vittal et al. 2020). The climate change vulnerability impact monitor identifies 22 climate impacts and 12 impacts linked to carbon economy (daraint.org.). The Vulnerability Sourcebook provides an M&E approach based on repeated vulnerability assessments at defined intervals. The outcomes of the repeated assessments are compared with the initial (baseline) vulnerability assessment to detect changes in overall vulnerability (Fritzsche et al. 2014, Vestby 2018).

6.4.2 M &E of resilience

Building resilience entails making individuals, communities and systems more prepared to withstand both natural and man-made catastrophic events and are able to bounce back more quickly and emerge stronger from these stresses and shocks without compromising their long-term prospects (Rockefeller Foundation 2015, UK DFID 2011). M&E of resilience is part of the many global monitoring tools in programmes such as the Pilot Program for Climate Resilience (PPCR), the Global Facility for Disaster Reduction and Recovery (GFDRR) and the Tracking Adaptation and Measuring Development (TAMD). In each of these, analysis of M&E systems and their various components is done to provide guidance and ideas for climate and disaster resilience. These include efforts done through the GEF Climate-Eval Community of Practice, OECD Studies on Climate Change Adaptation M&E, and SEA Change Community of Practice (CoP) (Williams 2016).

According to Williams (2016), development of climate and disaster resilience M&E should always consider the following:

- Wicked problems require creative, adaptive solutions - climate change is complex.
- Climate and disaster resilience M&E poses several methodological challenges - baselines, indicators, realistic and stable targets for outcomes and impact, realistic long-term impact – whether in indicator form or in general, accounting for maladaptation and suitable evaluation methodologies.
- The field of climate and disaster resilience M&E is young and learning (quickly) from experience. Stakeholder engagement is critical and plan to learn from experience and adapt accordingly.

6.4.3 M&E for adaptive capacity

M&E adaptive capacity can be done at local or national levels. For example, the CIF Project Cycle includes M&E of adaptive capacity using Adaptive Capacity Assessments (ACA) which identify the links between climate and development and promotes inclusion of climate adaptation activities in development programs. The assessment can be done before the project selection, during the design stage, at mid-term, or at the end of an initiative to identify results and further opportunities for improvement. It helps determine the capacity of human systems and find ways of addressing weaknesses in development initiatives. Villanueva (2011) and Recha (2017) stated that indicators of adaptive capacity represent factors that do not determine current vulnerability but that enable a society to pursue future adaptive options. The approach has been used in Uganda, Mozambique, Ethiopia, Kenya, Ghana and Sierra Leone.

6.4.4 Indicators

Indicators show aspect of adaptation that should be monitored and evaluated. There is need for clear information about the needs and key questions that must be answered by the M&E system as crucial for indicator selection. Adaptation indicators could reflect the following aspects (Schwan n.d, Vallejo 2017):

Climate parameters. Information on climatic conditions being observed, e.g. rainfall, temperature, extreme events. Climate indicators include global surface temperature, CO2 concentration, land ice and sea level.

Climate impacts. Information about the impacts being observed relative to climate change and variability on socioecological systems such as people displaced due to floods.

Adaptation action (implementation). Information to help track the implementation of adaptation strategies, e.g. people who received training, number of awareness raising workshops organised, % of building codes updated, etc.

Adaptation results (outcome). Information to help monitor and evaluate the outcomes of adaptation strategies – e.g. area planted or restored, % increase in crop yield per ha during dry season, % of household income used to treat water-borne diseases.

Social adaptation. Indicators for adaptive capacity designed based on detrminants of adaptive capacity (Smit et al. 2001), namely economic resources, technology, infrastructure (information, skills and management), institutions and networks and equity. Indicators can include the proportion of earnings from NTFPs, value of irrigation equipment, proportion of area under no- or zero-tillage, etc.

Activity 6.4 Brain Storming
Consider the forest-based adaptation project in your country or region. Define relevant indicators that can be used for monitoring the projects to achieve the intended outcome.

6.5 Methodologies in monitoring, evaluation and reporting

6.5.1 Methods and frameworks for M& E

6.5.1.1 Green Climate Fund (GCF) adaptation performance indicators

GCF adaptation performance indicators are linked to the accomplishment of improved resilience and livelihoods of communities and people, increased resilience of infrastructure and built environment to climate change threats, increased resilience of health, food and water security, and improved resilience of ecosystems and environmental services. The results framework of GCF outlines essentials of a paradigm shift regarding low-emissions and climate resilient, nationally driven development pathways in each country, and consolidated across funding actions for climate-resilient sustainable development (GCF 2014). Furthermore, the indicators include assessing the results of GCF investments in developing economic, social and environmental co-benefits and gender-sensitivity (Box 6.1) (Favolle et al. 2017).

Box 6.1 The GCF indicators (Fayolle et al. 2017)

- Percentage reduction in the number of people affected by climate related disasters, including the differences between vulnerable groups (women, elderly, etc.) and the population as a whole.
- Percentage of households adopting several livelihood strategies/coping mechanisms.
- Number of households that are food secure.
- Percentage of households with access to adequate water (quality and quantity for household use) throughout the year.
- Climate-induced disease incidence in areas where adaptation health measures have been introduced (percentage of population).
- Total area (ha) of agricultural land becoming more resilient to climate change by changing agricultural practices (e.g. planting times, new and resilient native varieties, efficient irrigation systems).
- Value of infrastructure made more resilient to rapid-onset events (e.g. floods, storm surges, heatwaves) and slow-onset processes (e.g. sea level rise).
- Number of innovative infrastructure projects or physical assets supported or constructed to resist climate change and variability.
- Area (ha) of habitat or kilometres of coastline rehabilitated, restored or protected.
- Area and number of forests, pastoral systems, agroforestry projects or ecosystem-based adaptation systems established or enhanced.
- Degree of integration/mainstreaming of climate change in national and sector planning and coordination in information sharing and project implementation.
- Availability of climate data collected, analysed and applied to decision-making of climate-sensitive sectors.
- Perception of men, women, vulnerable populations and emergency response agencies of the timeliness, content and reach of early warning systems.
- Degree to which vulnerable households, communities, businesses and public sector apply improved tools, strategies, instruments and actions to respond to climate change and variability.
- Percentage of target population aware of the potential impacts of climate change and range of possible responses.
- Number of indirect and direct recipients, disaggregated by sex and income levels.

6.5.1.2 Glbal stock take (NDC adaptation)

The Global Stocktake (GS) is a major component of the Paris Agreement's 'ratchet up' mechanism for maintaining the 1.5°C limit together with other Paris Agreement goals. It is a process for taking stock of collective progress toward achieving the goals of the Paris agreement at five-year intervals. It is prepared based on equity and the best science available. The GSs is expected to inform Parties so that they can progressively update and improve their pledges for climate action to keep the 1.5°C limit. The initial GS expected in 2023 is anticipated to enable Parties to revise their NDCs by 2025 (Fayson 2018). The process has three phases:

- Gathering of inputs - including data from latest IPCC reports, UNFCCC, UNEP and national communications.
- Considering the inputs through a technical process.
- Sharing the key findings at political level using a high-level event.

In planning the modalities for the stocktake (length, timing, phases, workflows and outputs), Parties should ensure that the process evolves and grows stronger over time by maximizing opportunities emerging from societal, economic and technological changes, lessons learned and integrating the new information and best practices (Nothrop et al. 2018).

6.5.1.3 GEF Monitoring and Evaluation (M&E) framework

The GEF's Results-Based Management (RBM) Action Plan aims to refine its focal area results frameworks, strengthen corporate-level results reporting, and improve the ability to make key management decisions based on the best available information on results (GEF 2016). In May 2014, the LDCF/SCCF Council adopted a revised RBM Framework for the Least Developed Countries Fund and the Special Climate Change Fund (LDCF/SCCF) (GEF 2014). The revised Framework and indicators form the basis for portfolio-level monitoring and reporting of the expected and actual results of LDCF/SCCF-financed climate change adaptation projects.

The monitoring and evaluation framework developed by OECD is mostly relevant for use by policy-makers and M&E practitioners. This was based on an evaluation of several M&E approaches. They discovered challenges related to monitoring and evaluation that are also relevant for adaptation and these included: i) assessment of attribution, ii) establishment of baselines and targets, and, iii) how to deal with long time horizons (Dinshaw et al. 2011).

6.5.1.4 Climate Vulnerability and Capacity Analysis (CVCA) framework

The CVCA methodology provides a starting point for engaging stakeholders, assessing current vulnerability and understanding future climate risks. Results provide a good basis for designing, implementing and evaluating adaptation strategies through a participatory learning and planning process and can be incorporated into the monitoring and evaluation system of a project, to track changes in vulnerability resulting from project interventions and changing climate conditions. The CVCA methodology gives an understanding of implications of climate change for the lives and livelihoods of the people and prioritises local knowledge on climate risks and adaptation strategies in the data gathering and analysis process. Vulnerability to climate change can vary within countries, communities and even households and CVCA focuses on communities but also examines enabling environment. The main objectives of the CVCA are to:

- ***Analyse vulnerability to climate change and adaptive capacity at the community level.*** The CVCA gathers, organises and analyses information on communities, households and individuals' vulnerability and adaptive capacities. It offers tools and guidance for participatory research, analysis and learning. Furthermore, the roles of local and national institutions and policies in facilitating adaptation are considered.

- ***Combine community knowledge and scientific data to yield greater understanding about local impacts of climate change.*** One of the challenges of working at the local level on climate change adaptation is the lack of scaled-down information on impacts. This is coupled with inadequate data and information on weather and climate predictions. The process of gathering and analysing information with communities serves to build local knowledge on climate issues and appropriate strategies to adapt. The participatory exercises and associated discussions provide opportunities to link community knowledge to available scientific information on climate change. This will help local stakeholders to understand the implications of climate change for their livelihoods, so that they are better able to analyse risks and plan for adaptation (Dazé et al. 2009.

Characteristics of CVCA:

- The CVCA emphasises the understanding of how climate change will affect the lives and livelihoods of target populations through examination of hazards, vulnerability to climate change and adaptive capacity in order to build future resilience. Tools such as Participatory Learning for Action (PLA) are used with a climate view.
- The CVCA attempts to combine good practices from analyses done for development initiatives, which tend to focus on conditions of poverty and vulnerability. This is done within the context of disaster risk reduction (DRR), focusing on hazards. It examines both hazards and conditions and analyse the interactions between the two. Hazards refer both to shocks, such as droughts or floods (rapid onset), and to stresses, such as changing rainfall patterns (slow onset).
- CVCA emphasises multi-stakeholder evaluation, collaborative learning and dialogue. Although the primary purpose of the CVCA is to analyse information, the procedure is intended to stabilise the research agenda with a process of learning and dialogue amongst local participants. This gives better understanding about local resources to support adaptation among communities.

Further reading
Care International 2009. Climate Vulnerability and Capacity Analysis (CVCA) framework Available at: care_cvcahandbook_0.pdf (managingforimpact.org)

6.5.1.5 Climate ADAPT

Climate change adaptation M&E frameworks should follow the ADAPT principles, i.e. ones that are Adaptive, Dynamic, Active, Participatory and Thorough (Villanueva 2011):

- **Adaptive learning and management** recognise experience-based learning and needs to deal with uncertainty.
- **Dynamic baselines** recognise changing conditions of adaptive capacity and vulnerability and provides real-time feedback.
- **Active understanding** recognises differing values and interests.
- **Participatory** recognises adaptation as a context-specific process and the need for triangulation of information and decision-making.
- **Thorough (avoiding maladaptation)**, evaluating trade-offs and recognising multiple stressors and processes across scales.

6.5.2 Tools of monitoring

6.5.2.1 CRiSTAL tool

Community-based Risk Screening Tool – Adaptation and Livelihoods (CRiSTAL) is a project planning and management tool designed to helps users to integrate risk reduction and climate change adaptation in community activities. The use of CRiSTAL follows a sequence of logically linked analytical steps where most of the information is collected from stakeholder consultations, although secondary scientific data on climate change also contributes to the analytical framework to improve understanding of (IISD 2011):

- How project area or local livelihoods are affected by climate-related hazards.
- How communities cope with impacts of climate-related hazards.
- Which livelihood resources are most affected by climate hazards and which ones are most important for coping.
- How project activities affect access to or availability of these critical livelihood resources.
- Adjustments that can be made to a project to increase access to or availability of these critical livelihood resources.

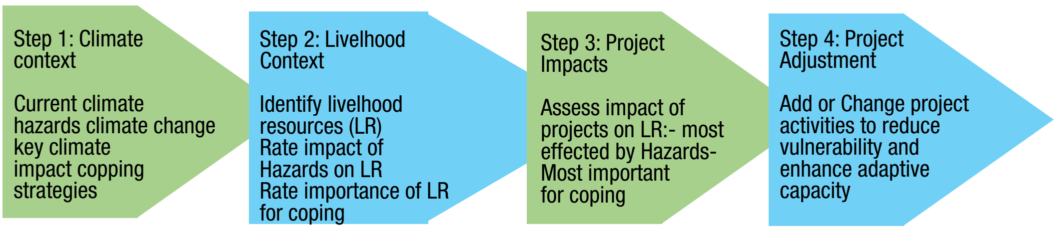

Figure 15. The CRiSTAL process (IISD 2011).

The process follows a logical 4 step process (Figure 15) and can help users to analyse the data on an excel sheet. Steps 1 and 2 give climate and livelihood information whilst steps 3 and 4 give information useful for planning and managing adaptation.

6.5.2.2 Adaptation Monitoring and Assessment Tool (AMAT)

Climate change adaptation monitoring and assessment (AMAT) tool is designed to enable the GEF to measure outputs and outcomes from the LDCF/SCCF projects and summarise them to produce an international progress report (GEF 2014). It is intended to eventually assist GEF to track and examine common indicators over time, thereby assessing progress and identifying measurable accomplishments. The tool is intended only for monitoring information explicitly aligned with the agency's logical framework for global aggregation and reporting (ibid). The AMAT presents the ways in which the Secretariat can operationalise the reviewed results framework and related aspects of the Programming Strategy as a basis for enhanced results-based management (RBM) of climate change adaptation under the LDCF and the SCCF.

In AMAT climate change adaptation objectives, outcomes and indicators can be easily classified and grouped. AMAT focusses on differences between support for adaptation M&E, and support designed for a specific programme or portfolio, representing a more top-down approach to M&E, guided by a flexible pre-defined list of indicators (Bours et al. 2014).

On the other hand, AMAT cannot be used as a complete toolkit because it ignores issues or concepts and does not justify, challenge or explain the agency's overall results-based management framework.

Instead, the tool is just a set of instructions to be followed by all programmes that are funded through GEF for reporting purposes, making application in other contexts very limited (Bours et al. 2014). The tool has a strong focus on tracking progress against specified indicators, rather than a more distinct investigation of what worked (or not), how, and why. The focus of AMAT is on checking if the following objectives have been met:

Objective 1: Reduce vulnerability to the adverse impacts of climate change, including variability, at local, national, regional and global level (20 indicators).

Objective 2: Increase adaptive capacity to respond to the impacts of climate change, including variability, at local, national, regional and global level (6 Indicators).

Objective 3: Promote transfer and adoption of adaptation technology (3 indicators).

6.5.2.3 AdaptME toolkit

AdaptME toolkit is a practical tool for providing practitioners with critical information and guidance for devising a climate change adaptation M&E framework that suits their programme, context, and purposes. AdaptME focusses on asking the right questions approach, which helps users to carefully employ the main concepts to their own priorities. The emphasis is mainly on using M&E as a learning tool (Pringle 2011, Bours et al 2014).

There are 17 core questions that are considered in the AdaptME process (Source: Pringle 2011):

Purpose:
- Why am I doing the evaluation?
- How can synergies be maximised, or conflicting purposes be managed?
- What are the learning objectives for the evaluation?

Subject:
- What is being monitored or evaluated?
- Does the intervention involve building adaptive capacity, adaptation actions or both?

Logic and assumptions:
- What is the Theory of Change underpinning the intervention?
- What assumptions have been made and are these valid?
- How have unexpected/unintended impacts and outcomes been considered?

Challenges and limitations:
- Which 'Tricky Issues' are relevant to the evaluation and how can these be managed?
- What limitations influence the M&E approach?
- What trade-offs have been made, are these justified?

Measuring progress:
- Are existing data sources used efficiently?
- Do indicators relate clearly to your purposes and objectives?
- Has qualitative data been used to complement metrics?

Engaging and communication:
- Who needs to be engaged in the evaluation process, when and how?
- Whose voice will be heard?
- How should I communicate the findings?

Activity 6.5 Brainstorming (10 minutes)
Explain the interlinkages and dependencies between planning, Monitoring and Evaluation

6.6 Reporting and feedback processes

6.6.1 Utilisation of M&E feedback (national communications, biennial reports)

M& E reports can be made for internal or external audiences. Internal audiences use the reports to support project or programme management while external reports are for stakeholders outside the project or programme teams. External reports are designed to demonstrate accountability, raise funds, promote wider learning and provide evidence for policy influencing work and many other different purposes (INTRAC 2018). For climate change adaptation reporting, several reporting mechanisms are provided under the UNFCCC, and these include adaptation communications, national adaptation plans (NAPs), national communications (NCs), nationally determined contributions (NDCs), and biennial transparency reports (BTRs).

National Communications (NCs) are the reports submitted by Parties to the UNFCCC presenting their actions for implementing the Convention. Guidelines for reporting are provided by the COP and are constantly reviewed and amended. NCs by developing countries must include information on actions for mitigating GHG emissions, GHG inventories, and attempts made to facilitate acceptable adaptation to climate change. Within three years after entering the Convention, developing country Parties are expected to submit their first NCs followed by one every four years thereafter (UNFCCC.int).

Communication can be done through Biennial Reports (BRs) or biennial update report (BURs). The BRs show progress made by Annex I Parties in achieving their emission reduction targets and support given to non-Annex I Parties in terms of technological, financial or capacity- building. Developing country Parties submit BURs to give updates of the information supplied in their NCs, especially, mitigation actions, national GHG inventories, challenges and gaps, plus the additional support that is required and that which has been received. The initial BURs were submitted by Parties in December 2014 and are expected after every two years thereafter. LDCs and Small Island Developing States (SIDS) can submit their BURs when convenient. Information on domestic climate-related finance is also supplied through limited sources, including national communications, BURs from the UNFCCC, Climate Public Expenditure and Institutional Reviews (CPEIRs), NDCs and other independent studies (UNFCCC.int, UNDP-UNEP-GEF nd).

6.6.2 Reporting of monitoring and evaluation outcomes

Reporting represents a means for gathering evidence of adaptation action and keeping track of adaptation planning processes and reporting on progress that has been made of its implementation and the effectiveness of actions. This reporting of processes and outputs of national adaptation M&E systems for components of NDCs, could potentially be used as a resource to inform Parties' communication of progress on adaptation under the UNFCCC (Vallejo 2017). The reports use country-specific data and are given as part of diverse M&E systems. For example, some African countries developed their national adaptation M&E systems and submitted their reports to UNFCCC. These include Kenya, Mozambique, Morocco and South Africa (Box 6.2).

The Adaptation Communication Drafting Assistance Tool (AdComm-DAT) developed by GIZ is one of the tools designed to facilitate adaptation reporting and can be used by countries. The tool reduces the reporting burden by presenting a structure that builds on the guidance provided in decision 9/CMA.1[2], focusing on nine elements (UNFCCC 2019).

Some reports from non- Annex I countries can be accessed at: [National Reports from non-Annex I Parties | UNFCCC]

2 FCCC/PA/CMA/2018/3/Add.1 (unfccc.int)

Box 6.2 Some examples of monitoring frameworks in Africa

Kenya - Proposed National Performance and Benefits Measurement Framework (NPBMF) which combined 73 top-down indicators assessing institutional (adaptive) capacity and 72 bottom-up indicators that measured vulnerability, at national level (Republic of Kenya 2012).

Morocco - National system building on sub-national efforts; Regional Environmental Information System (SIRE) in pilot regions focusing on changes in vulnerability in key sectors (water, agriculture, tourism and biodiversity/forests), the status of implementing interventions, and impacts/lessons learnt from those measures, all based on readily available data (Vallejo 2017).

Mozambique - National Climate Change Monitoring and Evaluation Framework (SNMAMC) having a set of 63 indicators for monitoring changes in climate vulnerability across eight sectors to inform allocations in the national budget and international climate finance (Republic of Mozambique National Council for Sustainable Development 2014).

South Africa - The National Climate Change Response M&E system made of building blocks focusing on i) climate information (observations and projections), ii) monitoring climate risks, impacts and vulnerability, iii) adaptation response measures (including governance and effectiveness aspects). The system defined ten generic desired adaptation outcomes against which progress can be measured, and they categorised their existing adaptation projects. The subsequent reports aim to assess the effectiveness of these projects and their contribution to the Desired Adaptation Outcomes (DEA 2016).

Activity 6. 6 Revision (15 Minutes)

1. Distinguish between the following:
   i. Monitoring and evaluation.
   ii. Output and outcome.
2. Explain the main components of evaluation.
3. What are the parameters considered in M&E of adaptation initiatives?
4. Identify and describe any two methods of M&E adaptation initiatives.

Summary

In this section we looked at issues of monitoring, evaluation and reporting of adaptation practices. Monitoring is an ongoing process whilst evaluation takes place at defined intervals and uses data from monitoring. M&E approaches can be community based or project/programme based. Parameters considered in adaptation initiatives include vulnerability, resilience and adaptive capacity. Several methods are used for M&E, and these include the GCF adaptation performance indicators, Global stocktake, GEF M&E and CVCA framework. Tools for M&E include AMAT and CRiSTal. We highlighted issues of reporting and feedback of M&E results. We learnt that reporting provides accountability, promotes wider learning, raise funds and provides evidence for policy formulation and many other different purposes. Finally, the chapter concluded by giving examples of some of the monitoring systems in African countries and showed that the countries can use the Adaptation Communication Drafting Assistance Tool (AdComm-DAT) to build the structure of adaptation reports.

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