African Forest Forum

A platform for stakeholders in African forestry

Forests and Climate Change Adaptation

A COMPENDIUM FOR PROFESSIONAL TRAINING IN AFRICAN FORESTRY

09

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Front cover photos: Nigerian Zogele plant (*Moringa oleifera*) Moringa leaves, Moringa flower on tree. Credit: Red Confidential (left), Third level waterfall in the primeval forest on a hiking trail crossing the Bwindi Impenetrable Forest in Uganda. Credit: Irmelamela (middle), a giant Outeniqua yellow wood, *Podocarpus Falcatus,* 1000 years old in Tsitsikamma Forest National Park close to Storms River on Garden Route, in Eastern Cape, South Africa. Credit: Benny Marty.

Back cover photo: Quiver tree in Namibia, Africa. Credit: Galyna Andrushko
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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
AF	Adaptation Fund
AfDB	African Development Bank
AFOLU	Agriculture, Forestry and Other Land Uses
AFRI100	African Forest Landscape Restoration Initiative
AMAT	Adaptation Monitoring and Assessment Tool
APF	Adaptation Policy Framework
ASP	Assessing Scaling Potential
BR	Biennial Reports
BSPE	Business Sector Prioritisation and Engagement
BUR	Biennial Update Reports
C	Carbon
CBA	Cost Benefit Analysis
CBD	Convention on Biological Diversity
CBFM	Community Based Forest Management
CBNRM	Community Based Natural Resource Management
CCA	Climate Change Adaptation
CCD	Climate Compatible Development
CCS	Carbon Capture and Storage
CEA	Cost Effective Analysis
CGIAR	Consultative Group on International Agricultural Research
CIF	Climate Investment Fund
CO_2	Carbon dioxide
CoBA	Community Based Adaptation
COP	Conference of Parties
CRiSTAL	Community Based Risk Screening Tool Adaptation and Livelihoods
CTCN	Climate Technology Centre Network
CTF	Clean Technology Fund
CVCA	Climate Vulnerability and Capacity Analysis
DFID	United Kingdom Department for International Development
DNA	Deoxyribonucleic acid
DRR	Disaster Risk Reduction
EbA	Ecosystem Based Adaptation
EUW	Effective Use of Water
EWS	Early Warning Systems
FAO	Food and Agriculture Organisation of the United Nations
FIP	Forest Investment Programme

FLR	Forest and Landscape Restoration
FMNR	Farmer Managed Natural Regeneration
FONERWA	Rwanda Green Fund
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GFDRR	Global Facility for Disaster Reduction and Recovery
GGW	Great Green Wall
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLF	Global Landscape Forum
GS	Global Stocktake
Ha	hectare
ICI	International Climate Initiative
ICF	International Climate Fund
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LDC	Least Developed Countries
LDCF	Least Developed Countries Fund
MCA	Multi Criteria Analysis
MDBs	Multi-lateral Development Banks
M&E	Monitoring and Evaluation
MEA	Multilateral Environmental Agreements
MRV	Monitoring, Reporting and Verification
MSE	Medium Scale Enterprises
NAPs	National Adaptation Plans
NAPAs	National Adaptation Programme of Action
NC	National Communication
NDC	Nationally Determined Contributions
NGOs	Non-Governmental Organizations
NHMS	National Hydro Metrological System
NTFPs	Non-Timber Forest Products
OECD	Organisation for Economic Cooperation and Development
PARCC	Protected Areas Resilient to Climate Change
PES	Payment for Ecosystem Services
PPCR	Pilot Programme for Climate Resilience
PPP	Public Private Partnership
PSD	Participatory Scenario Development
PSI	Private Sector Initiative

REDD+	Reducing Emissions from Deforestation and forest Degradation
ROA	Real Option Analysis
ROS	Reactive Oxygen species
SCCF	Special Climate Change Fund
SDGs	Sustainable Development Goals
SFM	Sustainable Forest Management
SI	Sustainable Intensification
Sida	Swedish International Development Agency
SIDS	Small Island Developing States
SPA	Strategic Priority on Adaptation
SREP	Scaling up Renewable Energy Programme
SWOT	Srengths, Weaknesses, Opportunities and Threats
TAMD	Tracking Adaptation and Measuring Development
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Management
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Decelopment
VRA	Vulnerability Reduction Assessment
WFP	World Food Programme
WRI	World Resources Institute
WUE	Water Use Efficiency

Compendium Overview

The ability of a forest ecosystem to adjust to climate change to reduce its vulnerability and enhance its resilience to anticipated impacts of climate change is the main thrust of this module. Climate change impacts society and ecosystems in many ways. Adaptive responses occur in physical, ecological and human systems, and involve changes in social and environmental processes, perceptions of climate risk, practices and functions to reduce risk, and exploit new opportunities. This module emphasises the role of forests in climate change adaptation (CCA), and shows how forests and trees adapt to climate change. The module also introduces learners to the concept of adaptation to climate change, types of adaptation, assessment of forest and non-forest-based adaptation mechanisms, determinants of adaptation, monitoring and evaluation (M&E), impact (economic, social, biological) assessment of adaptation, as well as integration of CCA into development policies and plans. It is expected that at the end of this module, learners will be equipped with knowledge and skills to design and implement forest and non- forest-based CCA strategies.

The compendium is divided into four sections/parts where **Part I** deals with basic concepts of CCA and comprises Chapters 1-3. **Chapter 1** deals with concepts related to CCA including, climate change, climate variability, hazards, risks, uncertainty, resilience and adaptation. Vulnerability can be biophysical (soil quality, water availability, sunlight, Carbon dioxide (CO_2), temperature suitability, and in some cases, pollinator abundance) or social (social, political and economic environment). An overview of climate change and climate vulnerability in development sectors and the vulnerability of forests and social systems to climate change are also discussed. The relationship between forests and people and forest-based adaptation strategies are highlighted. **Chapter 2** highlights issues related to adaptation to the impacts of climate change as individuals, communities and nations strive to moderate and cope with the impacts of a changing climate and its variability. 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 climate change. 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). Characteristics that influence a system's capacity to adapt such as resilience, susceptibility, responsiveness and adaptability are also discussed.

Chapter 3 discusses assets and resources that influence a system's propensity to adapt. 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. 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 that is exposed to hazards 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, feedbacks and functions through risk management, it is resilient. Some tools for prioritising adaptation strategies include cost-benefit analysis (CBA), cost effective analysis

(CEA), multi-criteria analysis (MCA), assessing scaling potential, business prioritisation and engagement, participatory scenario development (PSD) and strengths, weaknesses, opportunities and threats (SWOT) analysis are given followed by financing mechanisms for adaptation actions. Financing of adaptation can be through the private sector, national governments, bilateral or multilateral sources. The chapter concludes with a discussion on mainstreaming CCA into development planning and the frameworks that can be used to develop adaptation projects.

Part II of the module highlights forest based CCA and begins with a discussion on mechanisms used by trees and forests to respond to climate change effects in **chapter 4**. Forest responses and resilience can be for individual trees or species or vegetation assemblages. This can also be in the form of intra and inter species genetic variation. The mechanisms and management activities that can be applied to increase adaptation of ecosystems and human societies who depend on the forests include forest restoration, land rehabilitation and forest management adaptation actions which include silviculture manipulations, fire management, nursery techniques, pest management, increasing Carbon (C) sequestration and improvements on forest governance. In **chapter 5**, we learn that forests have a role to play in sustaining humans and animals that depend on them. The chapter also discusses gender-based adaptation and indigenous coping and adaptation mechanisms. Adaptation can be in form of technological innovations such as soil and water conservation, agroforestry, urban forestry and re-greening, agricultural intensification and use of renewable energy. Socio economic adaptation includes forest-based adaptation initiatives such as use of non-timber forest products (NTFPs), strengthening social systems, gender considerations and use of indigenous coping and adaptation mechanisms. **Chapter 6** highlights national, regional and international adaptation strategies and highlights the importance of protecting current patterns of biodiversity. The chapter shows importance of National Adaptation Programme of Actions (NAPAs), National Adaptation Plans (NAPs) and National Determined Contributions (NDCs). There are challenges, barriers and gaps in the implementation of adaptation that can be linked to policy/institutional, technological/technical, financial/economic or social categories. The chapter concludes with some African adaptation initiatives.

Part III deals with non-forest-based CCA and begins by analysing how the development sectors are affected by climate change and their coping mechanisms in **Chapter 7**. The sectors include agricultural; coastal, marine and fisheries; health and sanitation; built environment and infrastructure; energy; water; transport and tourism sectors. Adaptation measures in each of the sectors include options that are technological, structural and physical, socioeconomic and policy options. **Chapter 8** discusses other sectoral adaptation measures including early warning systems (EWS), structural and physical options, ecosystem-based adaptation (EbA) and socio-economic options. **Chapter 9** deals with policy, institutions and regulatory issues associated with CCA. The chapter concludes with discussion on disaster management and some case studies.

Part IV is the last with two **Chapters 10 and 11**. **Chapter 10** focuses on monitoring, reporting and evaluation of adaptation practices. This concept and purpose of monitoring are covered including types of M&E systems that can either be programme, project or policy based. The chapter also covers parameters of M&E and includes M&E for vulnerability, resilience, adaptive capacity and associated indicators. The chapter closes with a discussion on methods, frameworks and tools for CCA, including reporting and feedback process. **Chapter 11** summarises some of the issues and looks at the future of CCA in African forestry.

Compendium Learning Outcomes

To equip learners with knowledge and skills to design and implement forest and non- forest-based CCA strategies.

Compendium objectives

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

i. Describe the concepts related to climate change and CCA;
ii. Describe different types of adaptation;
iii. Understand how climate change affects development sectors;
iv. Explain the vulnerability of people and forests to climate change;
v. Analyse determinants of adaptation to climate change in the context of forestry;
vi. Describe factors that affect adaptation;
vii. Describe assets and resources for CCA;
viii. Apply different tools for prioritising adaptation options;
ix. Apply/operationalise adaptation financing mechanisms;
x. Describe basic analytical tools for identifying mainstreaming opportunities and entry points;
xi. Identify appropriate examples to adopt in own situations;
xii. Analyse the M&E approaches to adaptation; and
xiii. Design and operationalise adaptation projects.

PART I:
CLIMATE CHANGE ADAPTATION CONCEPTS

Chapter 1: Overview Adaptation Concepts

1.1 Chapter overview

Forest ecosystems regulate climate systems through their ability to accumulate huge quantities of Carbon (C) in biomass, litter and soil. In this regard, the importance of forests has been highlighted in climate change mitigation and adaption. In order to understand the concepts of adaptation, it's important that you get acquainted with meaning of some key operational terms and concepts used in climate change adaptation (CCA). This chapter introduces learners to the concepts of change related to adaptation and vulnerability.

Learning outcomes

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

i. Define operational terms in adaptation to climate change;
ii. Define CCA; and
iii. Explain the purpose of vulnerability assessments.

Activity 1.1 Brainstorming (10 minutes)

Define some of the concepts related to CCA familiar to you.

1.2 Basic terminologies for climate change adaptation

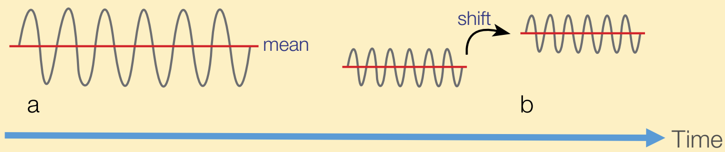
1.2.1 Climate change and variability

In order to understand the concepts of adaptation, it's important that you get acquainted with meaning of some key operational terms and concepts used in CCA.

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, typically decades or longer. Climate change may be due to natural internal processes or external forces such as modulations of the solar cycles, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2012). Change shows characteristics of the mean state. Apart from the changing climate manifested through extreme weather events, climate variability also affects different sectors.

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).

Activity 1.2 In text question
Which of the following represents climate change and climate variability?



1.2.2 Extreme events

According to McCarthy et al. (2001), **extreme climate** events or extreme weather events are events that are rare at a particular place and time of year. The characteristics of extreme weather may vary from one place to the other 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).

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 described as a disruption of the equilibrium in the natural event's system (Burton et al., 1993). In this compendium, the term hazard usually refers to climate-related physical events or trends or their physical impacts (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 geophysical hazard refers to natural land processes and events with potential to cause harm to human health, livelihoods, systems or natural resources (IPCC, 2014).

Risk 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, 2020a). Emergent risk is a risk arising from the interaction of phenomena in a complex system, for example, the risk caused when geographic shifts in human population in response to climate change led to increased vulnerability and exposure of populations in the receiving region (IPCC, 2014).

1.2.4 Uncertainty

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). 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 in 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; and

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

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).

The IPCC (2007a) 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

The term **vulnerability** is in most cases used to describe the potential (adverse) effects of climate change on ecosystems, infrastructure, economic sectors, social groups, communities and regions. Vulnerability in general has no universally accepted definition and there is no single "correct" or "best" conceptualisation that would suite all assessment contexts (i.e., each community has its own definitions) (EEA, 2015). Thus, it is necessary to specify clearly which terms are used in a specific context.

1.2.6 Vulnerability to climate change

This is the degree to which a system is susceptible to, and unable to cope with adverse effects of climate change, including climate variability and extreme and it 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 (IPCC, 2007b). The impact of climate change is determined by the 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).

The potential impact is therefore determined by exposure and sensitivity and that, overall vulnerability 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 also be defined 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). Biophysical vulnerability focuses on the nature, frequency and magnitude of the natural extreme event itself and its impacts upon a society's resources and is the exposure of human systems to natural extreme events and, as a consequence, to hazard (Burton et al., 1993). Biophysical resources include soil quality, water availability, sunlight, Carbon dioxide (CO_2), temperature suitability and in some cases 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). 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).

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).

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, access to health services and existing ecological conditions (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; OECD, 2009). In support of this, the UNFCCC (2019a) showed that the drivers of vulnerability include the status of a country (e.g. being a small island developing state or least developed 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 poor health sector.

Activity 1.3 (Brainstorming) (15 Minutes)
Discuss how climate change and climate variability affect vulnerability of forests, trees, people and other sectors of socio-economic development.

The African continent has been projected to be most vulnerable to the impacts of climate change due to factors linked to recurrent droughts, widespread poverty, inequitable land distribution and overdependence on rain-fed agriculture and natural resources (IPCC, 1998). This is also confirmed by IPCC (2007b) who showed that the main vulnerable sectors included agriculture, food supply, infrastructure, health and water resources.

1.2.7 Resilience

Resilience is defined in several ways but the meaning remains the same, that of a system's capability to recuperate after a disturbance. The United Nations Office for Disaster Risk Reduction (UNDRR, 2009) defined resilience as, "the ability of a system, community or society exposed to a hazard to resist, absorb, accommodate, adapt to, transform and recover from the effects of the 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 system that is more vulnerable, resilience decreases as vulnerability increases when faced with major disturbances such as those linked to climate change.

A resilience approach to sustainable development puts emphasis building on capacities to tackle unexpected events. The approach considers interaction of people 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. People also transform the biosphere in numerous ways through activities such as timber poaching, agriculture, settlements, road construction and cities. A resilience thinking approach attempts to explore best management options for these interrelating systems i.e. people and nature (social-ecological systems) to guarantee sustainability and resilient provision of necessary ecosystem services that sustain human existence (Simonsen et al., 2015).

1.2.8 Coping

Coping is an interim reaction to variability, whilst adaptation is an essential system to cause a new coping range to be accepted (Mertz et al., 2009). Acclimatisation is a form of adaptation which occurs all of a sudden through self-directed determinations (FAO, 2008).

There are several possible adaptation measures and 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 preventative, whilst others respond to changes that already occurred. Some adaptive actions can be initiated by the state, while others are by private groups or affected individuals. Some activities occur autonomously, while others are planned. Examples of adaptive 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). In this regard, to adapt means a system is able to maintain or strengthen resilience against existing disturbances (Adger et al., 2013). However, adaptation plans should assess all actions being considered against their potential for maladaptation.

1.2.9 Adaptation

Adaptation refers to the process of adjusting to actual and expected changes in climate, or its effects on social and ecological systems and encompasses the different activities tailored to fit specifics of target groups, sectors and places (OECD, 2009). Adaptation is focused on extreme weather events represented by weather events occurring only rarely in particular places and in a particular season, and deviating strongly from the usual seasonal weather patterns in the particular location. When the extreme weather events add up over a longer time period, under certain circumstances they can be called extreme climate events. A weather event categorised as extreme in one region may be very normal in another (IPCC, 2012). CCA 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).

> 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).

There is a wide range of possible adaptation measures. Whilst adaptation is a 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). 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 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, 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). An adaptation plan needs to assess each action being considered against its potential for maladaptation.

1.2.10 Maladaptation

Maladaptation 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 CCA 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 outlined by Magnan (2014, 2016) 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 can produce good results in the short term but fail in the longer term causing a risk that may accompany many low-regrets actions;
- Adaptation addressing one sector but failing to account for negative effects in other sectors or values of other people; and
- Retaining traditional responses that are no longer appropriate.

The IPCC (2007b) 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 also 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 1.4 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
We have learnt that climate change is a state of the climate that can be identified by changes in the mean and/or the variability of its properties that persists for an extended period, typically decades or longer. Climate variability is the spatial and temporal variations of the climate around average state at all spatial and temporal scales beyond that of individual weather events. Extreme climate events or extreme weather events are rare at a particular place and time of year. The socio ecological systems need to adapt to the extreme events caused by changing climate by coping and strengthening their resilience. Hazards reflect potential occurrence of a natural (physical event or phenomenon) or human-induced physical events or trends or physical impacts that may cause loss of life, injury, or other health impacts, damage and loss to property or infrastructure, impacting on livelihoods and environmental resources. Uncertainty refers to what we cannot know for certain in terms of outcomes, effects or impacts of a particular climate event and the probabilities cannot be calculated. The potential exposure to hazard is referred to as risk. Other terms discussed include extreme events, resilience, coping, adaptation and maladaptation. We concluded by learning that maladaptation occurs when effects of activities to reduce vulnerability to climate variability and change, results in worse situations that before, directly or indirectly and/or significantly whilst undermining abilities or opportunities for current and future adaptation.

Further reading:

African Forest Forum 2019a. Basic Science of Climate Change: A Compendium for Short Courses in African Forestry 03. Available at: https://afforum.org/publication/basic-science-of-climate-change-a-compendium-for-short-courses-in-african-forestry/.

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M. (Eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA. 582 pp. https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_Full_Report-1.pdf.

1.3 Overview of climate change and climate variability impacts on development sectors

Most of Africa depends on primary sectors such as agriculture and fisheries for food, fiber and income, making vulnerability to climate change evident in these climate-sensitive sectors as impacted by rising sea levels, increasing temperatures, floods and increasingly variable rainfall (CDKN, 2014). Climate change is regarded as one of the key challenges to sustainable development since it negatively impacts some key development sectors such as: agriculture, forestry, health, energy, transport and infrastructure, tourism and insurance. This section gives an overview of climate change impacts on development sectors, policies and strategies. The African Ministerial Conference on the Environment/United Nations Environment Programme (AMCEN/UNEP, 2002), predicted that rainfall in Africa could decrease by 5% in 2050 and can become more variable year by year and coupled with other changes including drought, increased CO_2 and changes in radiation which directly affect the productivity of agriculture, fisheries and forest ecosystems as vegetative growth, animal production and their development depend on optimum climatic variables. Water is an important ingredient for life on earth and droughts cause death in all ecosystems. On the other hand, flooding can result in salt water intrusion and increased contamination of drinking water, contributing to a range of health problems, including water borne diseases, diarrhea, intestinal worms and trachoma (Muoghalu, 2014). The rising sea levels are a result of the thermal expansion of the oceans, making oceanic temperatures to rise (Conway, 2009) and impacting on fisheries, aquaculture and coastal farming activities. Increased temperatures are expected to cause increased open water and soil-plant evaporation leading to increased potential evapotranspiration, decreased runoff and reduced soil water. In the agricultural sector, changes in rainfall patterns, temperature, CO_2, insect pests, animal and plant pathogens and weeds associated with global warming affect quantity and quality of food produced (Pimentel, 1993; Muoghalu, 2014). Although the sectors are affected by climate change, they also contribute to climate change through greenhouse gas (GHG) emissions. This section provides an overview of the impacts of climate change on development sectors including forestry, agriculture, water, energy, transport, water, infrastructure development and tourism.

Learning outcomes

i. By the end of this session, the learner should be able to:
ii. Describe the vulnerability factors and indicators for assessing the dynamics of the main sectors affected by climate change and climate variability; and
iii. Describe the impacts of climate change and climate variability on forestry sector and other sectors of socio-economic development.

Activity 1.5 (Brainstorming) (10 Minutes)
Which development sector do you think is most affected by climate change?

1.3.1 Forestry sector

Forestry sector is positively and negatively affected by climate change (Box 1.1) depending on location and species involved. Some species will go 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. Reduction in habitats and other human-induced pressures expose up to 50% of Africa's total biodiversity to risk (Boko et al., 2007). 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).

Box 1.1. Impacts of climate change on forests

- Changes in the lifecycles of trees (e.g. leaf fall);
- Vitality and productivity of forest ecosystems negatively affected by a combination of rising temperature and decreasing precipitation;
- CO2 fertilisation effect and longer growing seasons may have a temporary positive impact on timber growth (as long as the water supply is sufficient) and could affect wood and fibre qual-ity;
- Changes in site-suitability for species -> thermophilic and drought-tolerant tree species (esp. beech) 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 as a result 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;
- Increased risk of snow breakage due to increased wet snow;
- Decrease in water availability in summer reduces survival rates of young plants;
- Increasing pressure from insect pests and pathogens (e.g. bark beetles, fungi); and
- Increased climate stress can cause destabilisation of protected forests, representing a threat to their protective functionality (Prutsch et al., 2014).

The IPCC (2007b) added that 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. Furthermore, Brown et al. (2004) showed that rising temperatures increase the likelihood, intensity, sizes and frequencies of wildfire in forests, impacting on biodiversity.

The overexploitation of land resources including forests and soils results in desertification and land degradation that also increases threats to biodiversity (UNDP, 2006; Wassie, 2020). Furthermore, attacks by insect 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 the forest sector by increasing the levels of insect herbivory (Currano et al., 2008). Drought frequency changes may have fundamentally different ecological and C-cycle consequences across ecosystems (Teshome et al., 2020; Anderegg et al., 2020). Box 1.2 gives a case study of impacts of climate change on species in west Africa.

Box 1.2 Case study: Impacts of climate change on biodiversity and protected areas in West Africa, Summary of the results of the Protected areas resilient to climate change project in West Africa (PARCC)

The impacts of climate change on biodiversity across the West African Region's Protected area network are expected to increase over the 21st century. Projections have shown that between 2070 and 2099, it is "extremely likely" that 91% of amphibian species, 40% of bird species and 50% of mammalian species will be affected by changing climate. It is also "extremely likely" that no species of amphibian, only three species of birds and one mammalian species will be better suited for the climate in the region over the same period. Projections of future climatic conditions and estimates of the dispersal potential of species show that a significant number of West African species (including amphibians, birds, freshwater fish, mammals and reptiles) will be vulnerable to climate change based on their specific biological traits. It is therefore crucial to first improve the efficiency of the management of existing protected areas to give them a better chance to cope with the impacts of climate change. In this regard, there is need for development of species monitoring and the design or revision of transboundary management plans to consider climate change, as well as the development of a new Management Effectiveness Monitoring Tool integrating elements related to climate change. Adaptation strategies and policy recommendations have been developed for climate adaptation and climate management at national and regional level (West Africa Convergence Plan). In addition, the results of the PARCC project have been integrated into the website of Protected Planet, the web interface of the World Database on Protected Areas, and allows access to the results of vulnerability assessments for each protected area in West Africa (http://parcc.protectedplanet.net).

A regional Observatory for Protected Areas and Biodiversity was also created in Western Africa for effective protected area management. Therefore, considering climate change is essential to maintain the effectiveness of protected areas in time and space. The PARCC project achieved a number of objectives relating to protected areas programmes in West Africa, including: (i) assembling climate data and projections of future climate change, (ii) modeling expected future distribution of bird, mammal and amphibian species, (iii) assessment of species vulnerability to impacts of climate change, (iv) identification of areas resilient to climate change that would be beneficial to protect as refuges for flora and fauna, and (v) the design of systematic conservation planning systems incorporating the aforementioned information. These systems made it possible to carry out gap analyses of the representation of conservation elements in existing protected areas and the identification of priority areas for protection, i.e. where new protected areas could be established, where existing protected areas could be expanded and where connectivity corridors could be established or restored. Results have contributed to development of strategies and tools to increase the resilience of protected areas to climate change and to build capacity in West Africa (Belle et al., 2016).

The forests are important for communities as they are sources of firewood, timber, traditional medicines, staple foods and drought emergency foods. A large fraction of the African population lives in rural areas and depends on the forests for their livelihoods. Furthermore, the forests, trees and shrubs provide ecosystem services of water storage and transpiration of water required for precipitation, maintaining soil fertility, C sequestration and providing habitats for a diverse array of plant and animal species (Muoghalu, 2014).

1.3.2 Agricultural sector

Agriculture is one of the key development sectors since it is a key to global food supply, income and employment. However, the sector is currently being adversely affected by climate change and climate variability, being the main source of food, income and employment and this has implications on global food supply. 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 beings. The impacts of climate change are more severe for those who totally depend on rain-fed activities (Ludena et al., 2015; Pereira, 2017; Kassaye et al., 2021). The agricultural sector supports 80% of the population's livelihood in arid and semi- arid areas of Africa (FAO, 2016a). However, agricultural production is expected to decline by more than 20% by 2020 in some parts of Africa, due to the changing climate, mostly affecting small-scale farmers (Schlenker and Lobell, 2010; Thornton et al., 2011) who are heavily dependent on rain-fed agriculture and natural resources. Humans are mainly linked to land, through agriculture and forestry activities, that also have significant impact on the earth's functional systems by either degrading (through mismanagement) or sustainably utilising the land resources. Despite the impacts, agriculture has always been a key sector targeted for CCA and mitigation activities whilst ensuring food security for a growing population. Currently, food security and ecosystem resilience are the most concerning subjects worldwide. It is suggested that climate-smart agriculture is the only way to lower the negative impact of climate variations on crop adaptation, before it might affect global crop production drastically (Raza et al., 2019).

> Climate change is linked to insect out breaks in Eastern Africa and this was 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 locust and the first-wave of infestations in East Africa was at the end of 2019 destroying 70 000 ha of farmland in Somalia and 2 400 km^2 in Ethiopia respectively (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).

Climatic conditions such as extreme temperatures and extreme precipitation can prevent most crops from growing well although increases in temperature can result in increased yields for certain crops (e.g. Box 1.3). Although the rising CO_2, the main GHG, 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 concentration in some crop species, such as rice, wheat and soybeans (Myers et al., 2014; Zhu et al., 2018). Furthermore, there are many insect pests, weeds and fungi that thrive under the wetter conditions, warmer temperatures and increased CO_2 levels (Ziska et al., 2018). Furthermore, the African continent is expected to see an increase in crop insect pests and pathogens in response to variations in temperature and precipitation, in addition to poor soil fertility (FAO, 2009).

> *The CO_2 fertilisation effect cause 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).*

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 by Moseley (2016) in Botswana showed that international efforts to support CCAwill have a limited effect on smallholder farming livelihoods and rural food security unless such efforts take account of political and economic constraints.

Box 1.3 Case study: Climate change and agriculture in Uganda According to FAO and UNDP (2020), Uganda's climate is largely tropical savannah with pockets of monsoon, equatorial and semi-arid climate regions. It is estimated that 66% of Uganda's population is engaged in agriculture, with 80% of the rural population, mainly smallholders, reliant on subsistence agriculture. Around 96% of farming plots depend on rain as their main source of water, and only 1% depends on irrigation. Given the dependence on rain-fed agriculture, climate change is expected to pose major risks to water availability and production. Since 1960, mean annual temperatures have risen by 1.3^{0}C whilst annual and seasonal rainfall has decreased significantly across the country. More than half of the country is vulnerable to droughts and a third to floods. Smallholder farmers, pastoralists and fishers experience these impacts most acutely. In this regard, climate change increases the risk of food insecurity and poverty.

1.3.3 Water sector

Box 1.3 Case study: Climate change and agriculture in Uganda According to FAO and UNDP (2020), Uganda's climate is largely tropical savannah with pockets of monsoon, equatorial and semi-arid climate regions. It is estimated that 66% of Uganda's population is engaged in agriculture, with 80% of the rural population, mainly smallholders, reliant on subsistence agriculture. Around 96% of farming plots depend on rain as their main source of water, and only 1% depends on irrigation. Given the dependence on rain-fed agriculture, climate change is expected to pose major risks to water availability and production. Since 1960, mean annual temperatures have risen by 1.3^{0}C whilst annual and seasonal rainfall has decreased significantly across the country. More than half of the country is vulnerable to droughts and a third to floods. Smallholder farmers, pastoralists and fishers experience these impacts most acutely. In this regard, climate change increases the risk of food insecurity and poverty.

The water sector will be affected differently in different parts of Africa. In east Africa, flooding creates higher risk of 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). Water resources are therefore closely linked to climate change and are a product of the amount of rainfall and ground water recharge resulting in changing groundwater tables or levels (Taylor et al., 2013). Increase or decrease of rainfall in the wet season affects other sectors (e.g. agriculture, forestry, transport and infrastructure and tourism etc.) resulting in significant economic impacts mainly 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. The floods can also cause contamination of drinking water whilst the rising temperatures can increase surface water temperature associated with disease transmission. Furthermore, reduced precipitation and increased evaporation can also lead to reduction in water yield of near-surface springs affecting forests and agriculture activities. Too much water in form of floods make people vulnerable to flood risks and pollution (Prutsch et al., 2014).

The floods can also cause contamination of drinking water whilst the rising temperatures can increase surface water temperature associated with disease transmission. Furthermore, reduced precipitation and increased evaporation can also lead to reduction in water yield of near-surface springs thus affecting stream flows and availability of water (Zhang, 2015).

Integrated water resource management (IWRC) and watershed management activities 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. The UNDP (2018) showed that communities in some countries in Africa implemented watershed rehabilitation and management and these 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 / rehabilitating low-cost adaptive infrastructure, 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.

1.3.4 Health sector

Climate change can affect the health sector both directly or indirectly. The United Nations Economic Commission for Africa stated that direct impacts include (but not limited to): exposure to extreme temperatures can lead to ultraviolet related cancers and diseases and air quality (UNECA, 2011). Furthermore, increased precipitation can lead to exposure to water borne diseases such as malaria, diarrhoea and tuberculosis (Guernier et al., 2004). 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 unexposed to infection especially in the densely populated areas of east African highlands (Boko et al., 2007).

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).

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). The health sector in Africa is also affected by climate change because of the vulnerability of its people that varies among regions and communities due to differences in socio economic conditions, geographical differences, existing health infrastructure, micro climates and underlying epidemiology. 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).

> Biodiversity-rich forest ecosystems provide edible products that contribute to a healthy diet, such as fruits, leaves and mushrooms, as well as a vast number of medicinal plants in addition to environmental services such as the provision of freshwater resources, soil fertility and conservation, flood control, microclimate regulation and habitat for biodiversity (FAO, 2020b).

The FAO (2020b) confirmed that even commercial pharmaceutical products including drugs used for the prevention of diabetes, malaria, treatment of cancer and prostate conditions are plant based. Although some of the drugs are being synthesised, about 60% are still collected from the wild.

UNEP (2016) showed that about 60% of all human infectious diseases 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, 2020b). Ebola, HIV and COVID-19 are linked to wild animals and originate from the forest with associated viruses (Andersen et al., 2020), for example, emerging from loss of bat habitat through deforestation and agricultural expansion (UNEP, 2016) and Ebola outbreaks in west Africa have been linked to forest loss (Olivero et al., 2017). UNEP (2020a) 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 particular hosts, vectors and/or pathogens.

1.3.5 Infrastructure/construction and housing sector

Climate change is also affecting the infrastructure/construction and housing sector through destruction of infrastructure mainly from heavy rainfall since it directly affects the capacities of residential rainwater and waste-water systems such as gutters and sewage treatment plants (Pudyastuti and Nugraha, 2018). 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 to and loss of property (Pudyastuti and Nugraha, 2018), whilst droughts and other weather-induced catastrophes activate food shortages and migrant movements. In Africa, population in urban areas is relatively low but is likely to rise and pose more problems (Stapleton et al., 2017).

1.3.6 Transport and Energy sectors

The transport sector encompasses road, rail, air and marine transport and 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 and agricultural livelihoods, together with other indirect benefits such as access to education, healthcare, credit, political participation, etc. Roads passing through geographic locations can be few, making each road critical for access to services and other areas. Climatic events such as high temperatures, storms, heavy rains, cyclones, hurricanes etc, and sea level rise can destroy transport infrastructure including roads, bridges, ports and airports. Extreme events such cyclones and floods present an expensive hazard to road infrastructure in terms of degradation, required maintenance and potential reduction of road lifespan resulting from climatic impacts (Schweikert et al., 2014). Higher temperatures soften and expand pavements, creating rutting and potholes and warping of rail tracks.

Fossil fuels including oil, coal and natural gas provide 90% of global energy consumption (Darwishi et al., 2016). The energy sector is among the greatest contributors of emissions because the combustion of fossil fuels releases GHGs (IPCC, 2011; Abdollahi, 2020). However, the sector is also impacted by climate change in the sense that an increase or decrease in temperature leads to more energy requirements for cooling or heating. In addition, the reduction in rainfall affects power generation whilst abundant rainfall is associated with interruptions in power supply (Pudyastuti and Nugraha, 2018). The increase or reduction in temperatures also affects 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.

1.3.7 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 the form of leisure and recreational travel, including coastal and beach tourism (UNWTO, 2018). Climate change affects the tourism 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, although tourism can cause an increase in degradation (Lemelin et al., 2012). 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, affecting eco-tourism (Nicholls, 2014). Changing precipitation will affect water availability and affect holidays which are normally planned to be during favourable weather condition. Heat, cold and rain affect tourist activities.

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

Activity 1.6 In text question (5 minutes)
In what ways can climate change responses be made more effective for the different development sectors?

Summary
WIn this session, we have had an overview of climate change impacts in eight development sectors. The majority of African nations depend on primary sectors such as agriculture and fisheries for food, fiber and income, making vulnerability to climate change evident in these climate-sensitive sectors. We learnt that climate change affects all sectors, with the degree of impacts varying with locality and level of development.

1.4 Vulnerability of forests and people 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 CCA are 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). This calls for consideration of forests when designing adaptation policies and strategies at landscape level. Forests are also key to water infiltration as they reduce runoff and by intercepting rainfall, reducing evapotranspiration and groundwater recharge. They regulate base flows during dry seasons and peak flows during rainfall events. These are services that are important for improving people's adaptation to climate variability and change. Furthermore, forests prevent erosion and landslides by stabilising 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).

Obviously, forest C dynamics cannot be ignored when ways to mitigate climate change are sought (Jandl et al., 2007). Forests play a significant role in reduction of atmospheric C increase, not only by C sequestration, but also and mainly by substitution effect, offsetting permanently fossil fuels gaseous emissions (Nogueira and Trossero, 2004).

On the other hand, forests need to adapt to climate change because climate 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). Forests are exposed to several disturbances that are strongly linked to climate change and are expected to increase the 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 spreading of alien pest species. 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, extended fire seasons and increased forest fire activity (Mortsch, 2006). Storms can cause severe wind throw attracting pest insect populations, for example, bark beetle outbreaks in Europe (e.g. *Ips typographus*).

Climate induced disturbances influence the structure, composition and functions of forests (Dale et al., 2001). The changes in the function or structure of natural ecosystems and planted forests due to climate related hazards or events adversely affect productive function of forest ecosystems, which subsequently can also impact local economies.

Furthermore, when forests are disturbed, biodiversity is also disturbed in several ways (Table 2). Climate change related stress threatens biodiversity conservation. Forest fires are likely to be more intense due to increased fuel loads and longer fires seasons. The ecological impacts of forest fires vary with forest types, climatic and geographical regions, coupled with other disturbances (agriculture, encroachment or fragmentation, 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 pressures are managed (Heikkilä et al., 2010).

Table 1. Impacts of climate change on biodiversity (Source: Prutsch et al., 2014)

- Lifecycles of plants and animals are changed (e.g. migration and breeding behaviours, foliage and 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 function 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); and
- Limited adaptive capacity threatens biodiversity.

The link between humans, climate change and ecosystems is shown in Figure 1. Human activities negatively affect the climate and cause degradation of ecosystems and loss of biodiversity (red arrows). Changes in climate are largely anthropogenic. There are direct and indirect impacts of climate change affecting human societies (blue arrow in Figure 1). When biodiversity is lost, ecosystem services are also affected. The feedback caused by human induced drivers of change cause feedbacks between the climate and ecosystems, amplifying the speed and scale of both climate change and biodiversity loss creating a self-reinforcing feedback loop (Gitay et al., 2002).

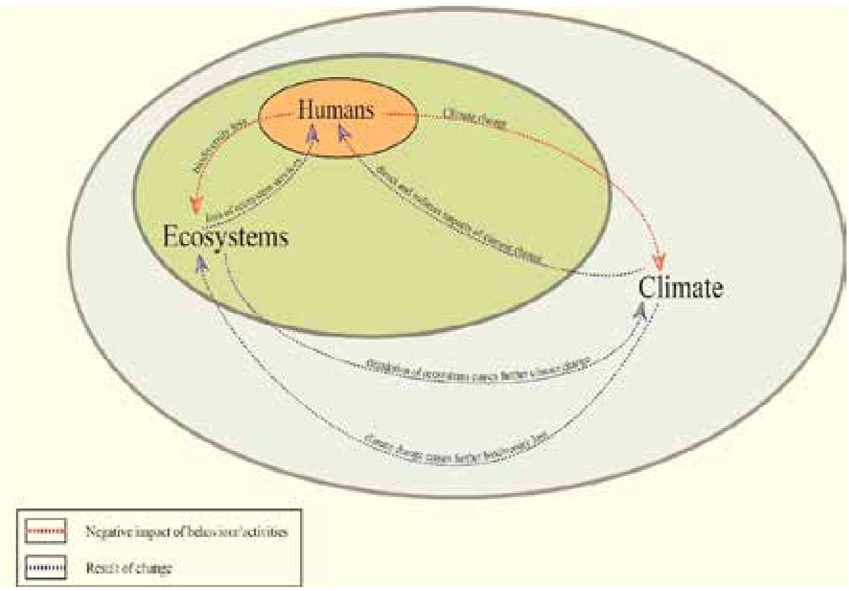


Figure 1. Relationship between humans, ecosystems and climate (Source: Zari, 2014)

1.4.1 Vulnerability assessments

Vulnerability assessment entails a practice of identifying, measuring and ranking the vulnerabilities of a system. Thus, 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). Units of analysis for vulnerability assessments are based on places, institutions and people (Figure 2).

The central concern of vulnerability assessment is to protect people from the adverse consequences of the present climatic variations and the dangerous climate change. The people depend on natural resources (land, water and ecosystems). People are organised into socio-economic groups (whether organisations, sectors or institutions).

Assessment for social-ecological systems is based on two main approaches: (i) 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 (ii) 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).

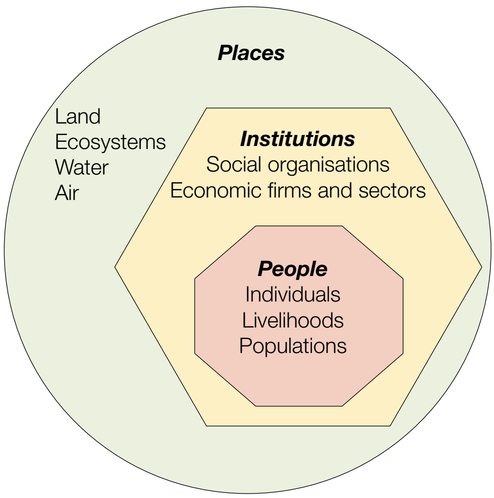


Figure 2. Units of analysis for vulnerability assessments (Source: Downing and Patwardan, 2002)

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

- Identifying the current and potential hotspots;
- Identifying the entry points for an intervention; and
- Tracking changes in vulnerability and monitoring and evaluation (M&E) of adaptation.

However, some of the processes may not be able to capture the complexity and unpredictability of natural systems.

Activity 1.7 Revision (10 minutes)

1. Describe the relationship between humans, ecosystems and climate; and
2. Explain the approaches for assessing vulnerability of socioecological system.

Summary

In this section, we learnt that 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. 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). If the 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 and functions through risk management, it is resilient. The adjustment in ecological, social and economic systems in response to the effects of changes in climate is called CCA. 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 often face an adaptation deficit, characterised by a failure to adequately adapt to existing climate risks. Human activities negatively affect the climate and cause degradation of ecosystems and loss of biodiversity. Climate change vulnerability assessments focus on species, habitats, or systems of interest and helps identify their greatest risks from climate change. Assessments can be impact based or vulnerability based.

Chapter 2 Climate Change Adaptation and Adaptation Options

2.1 Chapter overview

Climate change impacts have been demonstrated through rising sea levels, increased temperatures, rainfall variability, floods, droughts and salt water intrusion. We have already learnt how climate change affects different sectors of development. To survive, humans and ecosystems need to adapt and cope with climate change. Adaptation to the impacts of climate change shows how individuals, communities and nations strive to moderate and cope with the impacts of a changing climate and its variability. In this chapter, 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 concept of adaptation to climate change in the context of forest and people;
ii. Critically analyse the determinants of adaptation to climate change; and
iii. Describe the concepts underlying system's characteristics to adapt to climate change and variability.

Activity 2.1. Brainstorming (10 minutes)

Explain forms of adaptation that you are familiar with.

2.2 Types of adaptation

Adaptation can take place before, during and after future events that may be expected as a result of climate change. The 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, step-wise 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 (UNFCCC, 2015a) 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 GHG emissions as specified in the 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, 2019a). 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 these can be anticipatory, autonomous, reactive, planned, public and private adaptation, long or short term.

2.2.1 Anticipatory and reactive adaptation

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 i n responding to climate challenges in the context of multiple and reinforcing stresses and shocks (Nyamwanza and New 2016).

Adaptation that takes place before impacts of climate change are observed and 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, 2007b). 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, the focus is on both the present and the future e.g. ecosystem conservation. For example, local authorities can prevent construction of houses in areas prone to flooding in the long term.

Several approaches can be used to select the best strategy for adaptation. Stern (2007) and Weitzman (2007) 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 some discounted value frameworks because some of them require spontaneous responses.

IPCC (2007b, 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 understand human impacts on climate change. These include Global Climate Models projecting climate at a coarse resolution, typically 2.5° latitude x 2.5° longitude (77 000 km^2 or larger) and Regional Climate Models or statistical downscaling methods zooming in on smaller areas (at resolutions as fine as 20 x 20 km), using Global Climate Models s as input. The models are used to guide practical project and programme planning and analysis.

Reactive adaptation takes place after impacts of climate change have been observed and is described as corrective. Extreme events will be a feature of climate change in the future, suggesting the importance of improving responses to similar events at the present (IPCC, 2001). Improved responses reduce vulnerability, increases resilience and strengthens adaptation capacity. Reactive 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 destruction of houses by a cyclone, such houses are upgraded to new building standards to enable them to be much stronger (Basyouni, 2017).

2.2.2 Autonomous and planned Adaptation

Autonomous adaptation is 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). Also referred to as spontaneous adaptation, autonomous adaptation is usually unplanned consequential adaptation of both natural and human systems (IPCC 2007a; Malik et al., 2010). Autonomous adaptation includes widely considered initiatives by private actors instead of governments. Thus, autonomous adaptation is related to private, planned, and public adaptation. Autonomous adaptation is often overlooked in international and national efforts to manage the impacts of climate change (Fazey et al., 2010) as most of the reactions only happen after a disaster has occurred.

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. Autonomous adaptation might also include practices such as altering agricultural inputs, introducing water-managing technologies, altering cropping cycles, or diversifying economic activities. They 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.

Planned adaptation is an 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 the desired state. It involves deliberate, anticipatory interventions at different levels and across sectors (IPCC, 2001; Fazey et al., 2010).). Füssel (2007) added that 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 because of climate change-related risks and uncertainties. At the community level, planned adaptation may include diversification of forest-based 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 C 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).

2.2.3 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. For example, constructing a small weir to ensure water availability during a dry spell. There is also some private adaptation with public benefit when an individual or business 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. Public adaptation is usually directed at collective needs (IPCC, 2001).

2.2.4 Other types of adaptation

Short run and long run adaptation: Short-run adaptation is when the decision maker's response to climate change is constrained by a fixed capital stock, so that the principal options available are restricted to variable inputs to production whilst in long-run adaptation, the decision maker can adjust capital stock in response to climate change. National Adaptation Programmes of Action (NAPAs) are examples of short-run adaptation as they focused on urgent and immediate needs. Long-term approach to adaptation is over a long period by facilitating the integration of adaptation into development planning processes and strategies in a coherent manner within all relevant sectors and at different levels, as appropriate within each country. Approaches include adaptation pathways method, ecosystem-based adaptation (EbA), community-based adaptation (CoBA), livelihoods and economic diversification as well as risk-based approaches (UNFCCC, 2019b). An example of a long-term adaptation is the adaptation plan in the climate resilient green economy strategy of Ethiopia, in which CCA strategies are integrated into the country's development plan of achieving middle income economy status by 2025 (CRGE, 2011).

Incremental: A series of relatively small actions and adjustments aimed at continuing to meet the existing goals and expectations of the community in the face of the impacts of climate change. Much of the adaptation facilitates or creates small changes to existing practices, societal norms and institutions. These are seen as incremental, 'no regrets' or safe options that are not too disruptive to societies or economies (UNFCCC 2019b).

Transformational: Adaptation actions which result in a significant change to community goals and expectations, or how they are met, potentially disrupting those communities and their values. Transformational adaptation is generally undertaken when incremental adaptation is no longer sufficient to address the risks. A situation when the vulnerabilities and risks created by climate change may be so large that they can be addressed only through reorganisation of vulnerable systems or by changing their locations. For example, relocating an entire suburb or community including homes, businesses and infrastructure (UNFCCC, 2019b).

Learning outcomes

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

i. Explain the concept of adaptation to climate change in the context of forest and people;
ii. Critically analyse the determinants of adaptation to climate change; and
iii. Describe the concepts underlying system's characteristics to adapt to climate change and variability.

Activity 2. 2 Revision
Explain forms of adaptation that you are familiar with.

Summary

In this section, we learnt that there are several types of adaptations implemented to cope with climate change impacts, with some activities done before and others done after a climate change event. These include: 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.

2.3 Determinants of adaptation capacity

The main determinants of a community's adaptive capacity are the levels of economic wealth, technology, information and skills, infrastructure, institutions and equity. Adaptation to climate change impacts depends on the level of awareness of the risks of climate change and the capacity of individuals/ communities to adapt to climate change. The former can be enhanced by providing relevant information to the vulnerable population about the risk and consequences of climate change, the latter involves technical developments and government support. In this section, we will learn about determinants of adaptation to climate change. In this section of the chapter, we 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; and
ii. Describe the concepts underlying system's characteristics to adapt to climate change and variability.

Activity 2.3 Brainstroming (10 Minutes)

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

2.3.1 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 adequately to existing climate risks. This scenario at the household level is largely affected by the following determinants as outlined by Deressa et al. (2009); Othniel and Resurreccion (2013); Enimu et al. (2018); and Mequannt et al. (2020):

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 increases, willingness to adopt adaptation strategies decreases whilst others found a positive association of age with adaptation to climate changes. The older farmers may be more conservative and more risk-averse compared to younger farmers, resulting in a lower likelihood of adopting new technologies.

Gender: Similar to age of household, gender has no universal response. In Nigeria, male household heads took adaptation measures better than their female counterparts. This was supported by the fact that male headed households were often considered to be more likely to get information about new technologies and take on risks than female headed households. On the other hand, female-headed households are more likely to take up CCAmethods, attributed to the willingness of women to change their livelihood strategy in an effort to support their families.

Household size: Increased households' size and age of head negatively influenced farmer's adaptive capacity. A large family size increases the farmers' vulnerability to climate change as a unit increase in the household size results in a reduction in the probability of adapting to climate change. That is because a large family has high consumption demand, and this put enormous pressure on little resources available during drought periods, and some families may be forced to divert part of the labour force to off-farm activities in an attempt to earn income.

Educational level: There is a strong relationship between educational status (the number of years spent schooling) of household heads and the probability of adopting adaptation measures. Studies show that the higher the educational level of the head of household, the greater the likelihood of adapting to climate change. The lack of knowledge on adaptation strategies is an essential constraint to adaptation as people cannot implement what they don't know.

Farming experience: Farming experience positively relates to the probability of adopting adaptation measures. The higher the years of farming experience, the higher the likelihood of adopting adaptation measures. Most farmers in African countries have observed and experienced long-term increase in temperatures, declining and changing pattern of precipitation including an increase in drought frequencies and floods. They are likely to have more interaction with their environment and they develop intricate and complex systems of first-hand knowledge on weather and climate variability, as well as 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.

Farm/herd size: Diversification improves access to market and basic food and improves resilience to climate shocks than 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.

Membership of cooperative: Belonging to a cooperative increases the likelihood of adopting due to greater awareness of climate risks and better adaptive capacity. Local people with long history take measures due to the need to conform to a priori expectations and works of the group. It can also help to sensitise the farmers on ways of adapting to effects of climate change.

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.

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 and climate change services also 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 so that they can adopt appropriate adaptation 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 e.g. use of different crop varieties.

The role of **institutional framework**s in facilitating farm households' response and adaptation to climate change impacts on their livelihood was assessed by Yomo et al. (2020). They focused on adaptation to drought events associated with crop failure in Semi-Arid Ecosystems in Bongo district in the Upper East region of northern Ghana. Their conceptual framework considered: (i) institutional framework within the context of CCA (institutional landscape, institutional accessibility), (ii) institutional support/function (adaptation options), and (iii) communities' perceptions on the existing framework for livelihood opportunities (institutional impact). Results showed five salient issues with implications on effective local level adaptation:

- Public and civic institutions play key roles in facilitating adaptation;
- Most institutions leading adaptation among the farming community were not directly adaptation related but those intervening in various domains of households' rural life;
- Institutional role included the ability of some institutions to channel or extend the available resources to the beneficiaries in the network;
- Institutional support was more evident in terms of knowledge management, on farm management than farm financial management, livelihood diversification and the investment in infrastructures; and
- Level of institutional support facilitated adaptation within the farming communities through increase in annual income, farm productivity and well-being while reducing households' adaptation.

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

Activity 2.4 In Text Question (10 Minutes)

Explain how the following factors that affect an individual or community's capacity to adapt to climate change:

1. Tenure status;
2. Access to market;
3. Social identity;
4. Fixed assets;
5. Ethnicity and social status;
6. Infrastructure; and
7. Institutions.

Summary

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 a community's adaptive capacity are the 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 climate change. 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. 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, ability of species to migrate, or for ecosystems to expand into new zones..

2.4 Characteristics that influence a system's propensity to adapt

Vulnerability is the extent to which a natural or social system is susceptible to sustaining damage from climate change and the definition of vulnerability was given in section 1.2.5. It has also been shown that the vulnerability of a community is affected by social vulnerabilities associated with poverty, social class and status of health and nutritional levels. In this section, we will learn about climate change vulnerability and its components of potential impact and adaptive capacity, resilience, susceptibility, resistance and adaptability.

Learning outcomes

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

i. Explain components of vulnerability;
ii. Explain factors affecting adaptive capacity; and
iii. Explain adaptation measures that can be used by humans.

Activity 2. 5 Brainstorming (10 minutes)

What are some of the factors that determine the capacity of a system to adapt to climate change?

2.4.1 Vulnerability

Smit and Wandel (2006) 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. In this regard, vulnerability is linked to the adaptive capacity of a system that can either be strengthened or weakened by its sensitivity and exposure to climate impact (Figure 3).

Vulnerability= function [exposure (+); sensitivity (+); adaptive capacity (-)]

The potential impact is therefore determined by exposure and sensitivity, and that overall vulnerability 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 = potential impact (sensitivity x exposure) x adaptive capacity

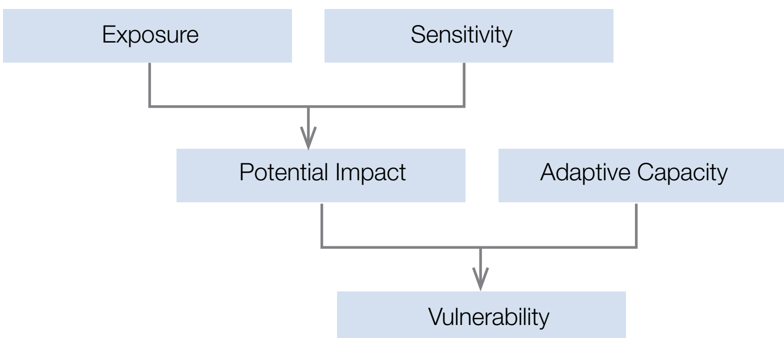


Figure 3. Components of vulnerability (Source: IPCC, 2007b: Fellmann, 2012)

Local vulnerability measures should take into account scale, dynamics and diversity of societies in order to convey information on diverse natural environments and heterogeneous socio-economic structures at multiple scales. **Scale** refers to critical analysis of e.g. the local, national, regional or global scale. 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).

Dynamics consider the assessment taking a dynamic point of view (Frank et al., 2011). Global vulnerability studies on to climate change using static proxy variables such as annual Gross Domestic Product (GDP) may ignore the dynamically changing coping capability at the local scale over a period of time. Individual perception and accumulated knowledge of climate change evolves over time and results from learning through the past experiences of households' response to climate change, because of their attitudes, values and cultural norms. **Diversity** considers dealing with micro-level unit 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). To capture thoroughly the adaptation to the impacts of climate change, the terms in following sections have to be clarified.

2.4.2 Potential impact

Impacts of climate change are the effects of climate change on natural (e.g. water resources, biodiversity, soil, etc.) and human systems (e.g. agriculture, health, tourism, etc.). The Impacts can be potential impacts or residual impacts, depending on the form of adaptation. Potential impacts are all impacts that may occur under a given projected change in climate, 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 of climate change, strictly depending on exposure and sensitivity. Box 2.1 shows other forms of climate change impacts.

Box 2.1: Other forms of climate change impacts

Residual impacts: These are those climate change impacts that would occur after adaptation.

Aggregate impacts: These 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: Impacts that are linked to market transactions and directly affect GDP (a country's national accounts) for example, changes in the supply and price of agricultural goods.

Non-market impacts: These are impacts that affect ecosystems or human welfare, but that are not directly linked to market transactions, for example, an increased risk of premature death (IPCC, 2001).

Activity 2.6 Brainstorming (10 minutes)
Explain factors that determine the capacity of a system to adapt to climate change.

2.4.2.1 Exposure

Exposure to climate vulnerability refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social or cultural assets in places and settings that could be negatively affected by climate change. Components of exposure to climate change and variability include: increase in temperature, changes in precipitation, changes in seasonal patterns, hurricanes and storms, increase in CO_2 levels, sea level rise, land use change, landscape fragmentation, resource exploitation and pollution. Climate exposure indicators may include biophysical factors such as temperature rise, heavy rain, drought and sea-level rise. The IPCC (2007b) predicted that the impact of global warming will continue as the probability of severe heat waves, heavy rain, drought, tropical depression and sea-level rise increases over time.

2.4.2.2 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 (IPCC, 2007a). The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise). The degree of a system's sensitivity to climatic hazards depends not only on geographic conditions but also socio-economic factors such as population and infrastructure (Fronzek et al., 2018; United Nations 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 that are usually critical for the livelihoods of the poor. Components of sensitivity include: changes in disturbance regimes (e.g. fires, insect pests and pathogens), changes in tree-level processes (e.g. productivity), changes in species distribution, changes in site conditions (e.g. soil condition) and changes in stand structure (e.g. density, height). Indicators of sensitivity can encompass geographical conditions, land use, demographic characteristics and industrial structure such as dependency on agriculture and the extent of industrial diversification (Ludena et al., 2015). In forestry, sensitivity can imply the degree to which forest growth, health, structure and composition are altered by a variation in climate.

2.4.3 Adaptive capacity

Adaptive capacity describes the ability of a system to cope with climatic extremes. 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). 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 compose economic capability, physical infrastructure, social capital and institutional capacity, etc. For example, farmers who are more resourced adapt better than the ones without any form of capital (Hassan and Nhemachena, 2008). Economic capability represents the economic resources available to reduce climate change vulnerability. It includes human resources and technological alternatives (Yohe and Tol, 2002).

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, the presence of effective leaders and organisers in a community or the relative abundance of shaded parks in an urban environment), but can also reflect the abilities of an organisation responsible for managing an ecosystem or leading a community to collect and analyse information, communicate, plan and implement adaptation strategies that ultimately reduce vulnerability to climate change impacts (Giordano, 2014). The capacity to adapt and cope depends upon many factors including wealth (resources to invest in adaptation), technology, education (access and ability to process information), institutions, information, flexibility of a system to change in response to climate stimuli, willingness to change and adapt, ability of species to migrate or for ecosystems to expand into new zones, skills and access to resources which are generally scarce in poor countries and communities (Smit et al., 2001; Giordano, 2014).

Determinants of adaptive capacity

Economic resources: The more the economic resources the better the capacity to adapt;

Technology: Lack of technology limits potential to adapt;

Institutions: Policies and regulations constrain or enhance adaptive capacity;

Information and skills: Information is important for timely and appropriate adaptations;

Infrastructure: Well-developed infrastructure can enhance adaptive capacity; and

Equity: Fairness in distribution of available resources increases adaptive capacity (Smit et al., 2001).

Adaptation measures vary according to the way in which climate change is described or experienced, 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 may be adopted in response to climate change (Smit et al., 2001).

How climate change is experienced or described at levels of community or individual, sectorial or departmental, affects the timing and manner of adaptation and the adaptation measures to be implemented in addition to the adaptation capacity. Several possible measures can be implemented to tackle climate change and the following categories of measures were identified by Burton et al. (1993):

Bearing losses: Is implemented when the affected are not able to respond (e.g. underprivileged communities) or when the cost of the adaptation measures is higher than the anticipated damages or the risk.

Sharing losses: When losses from climate change impacts are shared among community members. For example, sharing of losses by way of rehabilitation, relief aid and reconstruction paid through public funds in complex high-tech societies. In this regard, taxation is a system of making all citizens to contribute to climate-induced losses. Sharing losses can be done at local level or it can extend to the global family of humankind. Private insurance arrangements can also be used by vulnerable people by purchasing insurance cover.

Emergency relief and other forms of assistance from other governments and international agencies are given when losses exceed the response capacity of a national government. Similarly, at private level, when insurance companies find that claims exceed their capacity, they turn to reinsurance companies that provide insurance for the insurance industry. It is common for several sharing arrangements to be used concurrently, with more elaborate insurance schemes operating at one level in the formal economy, and the more socially based or traditional forms of sharing operating in the informal economy. In March 2019, southern African countries: Malawi, Mozambique and Zimbabwe were hit by Cyclone Idai, which destroyed human life and infrastructure. Governments from Africa and beyond contributed to emergency relief and rehabilitation of infrastructure.

Modification of the threat: The threat for certain risks can be modified using some level of control on the environmental event. For example, flood control works such as dams, dikes, and levees can be used when natural episodes of events such as floods occur or in cases of drought, cloud seeding can be used to provide additional rainfall. Forests reduce the climate change impacts by ameliorating temperatures, slowing runoff rates and increasing recharge of groundwater.

Preventing the effects: Effects of climate change or variability can be prevented by applying adaptation measures following pre-determined steps. Several techniques are used to reduce the impacts depending on the sectors or regions being affected by climate change. Some of the techniques may be traditional or cultural methods that have been previously used extensively as responses to climate variability or extreme events. In cases like this, new measures can be developed following increases in technological choices. For forestry, measures can include manipulation of silvicultural practices such as using hydrogel, growing drought, pathogen and insect pest- resistant species and controlling fires.

Changing use: A viable activity can be changed when it becomes extremely risky or impossible due to climate change threats. For example, switching to a more drought-resistant crop or crops with lesser water requirements. Likewise, that trees planted are those that grow well in the new and expected climate conditions or that are more resistant to forest fires. In other cases, radical changes can be made such as when coastal development is risky due to sea-level rise and development is withdrawn from exposed sites. Similarly, forested land is converted to open space or public recreation use. As climate change continues, there are many opportunities that are likely to emerge to reduce impacts by changing uses.

Categorisation of measures: CCA can be considered based on the systems and the processes, climate stimuli, or climate change measures. Analysed adaptation activities funded by the Global Environment Facility (GEF) adaptation funds have supported several adaptation activities and Biagini et al. (2014) identified ten types of adaptation categories: physical infrastructure, information, policy, warning systems and observation systems, practice and behaviour, management planning, green infrastructure, technology, financing and capacity building.

Changing location: Is a rather risky response that goes beyond changing use by changing the site of economic activities. Relocation is also suggested as a key response for plant and animal species after some speculation, for example, speculations about shrinking and expansion of farming regions caused by changes in temperature and rainfall patterns. Relocation can also be a result of rising sea-levels, where several “climate change” refugees are created. The creation of special “migration corridors” is suggested for unplanned migrations.

Research: Research into new technologies and new adaptation methods can improve the process of adaptation.

Educate, inform and encourage behavioural change: Dissemination of knowledge through education and public information campaigns can lead to behavioural transformation. This is likely to increase value on the importance as the need to involve more communities, sectors, and regions in adaptation becomes apparent.

Activity 2.7 In text question (10 minutes)
What are the links between the impacts of climate change and vulnerability?

2.4.4 Resilience

Communities become resilient when they are able to timeously and efficiently 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 absorb disruption and restructure while going through change to remain basically with the same state, in a manner that allows for the persistence of system function, structure and feedbacks (Walker and Salt, 2006). IPCC (2014) added that resilience shows the capacity of economic, social and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, structure and identity, while also maintaining the capacity for adaptation, learning and transformation.

Resilience can be categorised as either "engineering resilience" or "ecological resilience". Engineering resilience is associated with the ability of a system to return to a more-or-less particular pre-disturbance condition (Carpenter et al., 2001) with the assumption of only one steady state known as the equilibrium dynamics (Holling, 1996). For example, if there are increased drought conditions, resilient forest ecosystem components are able to recover from drought stress, with little or no alterations of species composition. Ecological resilience is the capacity of any 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 (i.e. prolonged drought) before being converted into a different vegetation ecosystem such as bushland or grassland. However, the systems may go through several other different but stable forest states where new species compositions, provide most or all of the goods and services that were supplied by the initial state (Holling, 1996). In this regard, engineering resilience shows the ability of an ecosystem to return to the original equilibrium in one certain state after disturbance whilst ecological resilience reflects the threshold where the ecosystem state changes (Yan et al., 2011).

For example, a resilient forest ecosystem is able to withstand (absorb) external pressures and return to its pre-disturbance state over time. The ecosystem maintains its taxonomic composition, ecological structure and processes. However, biological and ecological resources in the ecosystem affect resilience and these include: (i) the species diversity, (ii) the genetic variability within species, and (iii) the 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 the resilience of a forest ecosystem (Thompson et al., 2009).

Therefore, maintenance and restoration of forest biodiversity increases forest resilience to anthropogenic pressures and become essential 'insurance policy' and safety net against anticipated climate change impacts. 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).

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 severe to restructure an ecosystem into a short-term (i.e. decades) state with different resistance, or a long-term (i.e. centuries) state that can equally be as resilient as the original state. Forests can also resist certain environmental variations, such as weather patterns over time, owing to redundancy at various levels among the functional species. It is possible to have very resilient ecosystems that have low resistance to a particular perturbation. However, most well-developed forests, especially primary old forests are both resilient and resistant to changes (Holling, 1973; Levin, 2015).

Factors such as redundancy (niche overlap between species) and modularity (the interconnectedness of a system's components) are also important in determining an ecosystem's resilience (Levin, 2015). In forest ecosystems, functional diversity is a principal component of ecosystem functioning (Goswami et al., 2017). Resistance occurs when the capacity of an ecosystem makes it able to absorb disturbances and remain largely unchanged. 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).

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).

2.4.5 Susceptibility

Susceptibility is the physical predisposition of human beings, environment and infrastructure to be affected by a dangerous phenomenon due to lack of resistance including the predisposition of society and ecosystems to suffer harm as a consequence of intrinsic and context conditions making it plausible that such systems once impacted will collapse or experience major harm and damage due to the influence of a hazardous event (World Social Report, 2020).

In forest ecosystems, the maintenance of tree species biodiversity of an area reduces the susceptibility of the area to diseases. For example, the evergreen sclerophyll Oaks (e.g. Holm Oak (*Quercus ilex*), Cork Oak and Kermes Oak (*Q. suber* and *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). There is insufficient knowledge on the resilience of African forests and trees to the impacts of climate change (Kowero, 2011).

In social systems, the assets of those who are impoverished are more fragile than those of their wealthier neighbours. At similar levels of exposure, people in poverty are more susceptible to damage from climate change than those who are better off. For example, differences in housing quality and local infrastructure, including whether adaptation strategies are a major determinant of susceptibility of social systems (World Social Report, 2020).

2.4.6 Responsiveness

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

- Limiting (GHG emissions to slow the rate and limit the extent of climate change;
- Taking adaptation initiatives that reduce potential damages from climate change impacts;

- Expanding research and development to provide better low-C 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;
- Pegional, national and global investments in low-C technologies; and
- Sharing best practice measures for adapting to climate change.

2.4.7 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). Adaptability 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 essentially a situation characterised by volatility, complexity, uncertainty and ambiguity. Adaptability can be at individual, interpersonal or team/group level.

Individual adaptability reflects behaviour change relative to environmental changes 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).

Taxonomy of adaptability has three levels: phenomenon, perspective and approaches (Figure 4). In the taxonomy, the domain-general (oriented towards selection), considers the broad characteristics of individuals and teams that are predictive of adaptation, looking at desirable performance capabilities such as dealing with emergencies, handling stress, managing uncertainty, learning, and being culturally, interpersonally, and physically adaptive. It then examines the kinds of general cognitive, ability and personality characteristics that are broadly predictive of those kinds of capabilities and is therefore, about human capital (National AcademyEngineering, 2018).

Domain specific (oriented towards the process), is more about particular kinds of expertise in a particular context, focusing on how individuals and teams operate in a particular situation requiring response to a change and training and development of certain skill sets. It requires a diagnosis of the situation and development of potential solutions.

Transformability is 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.

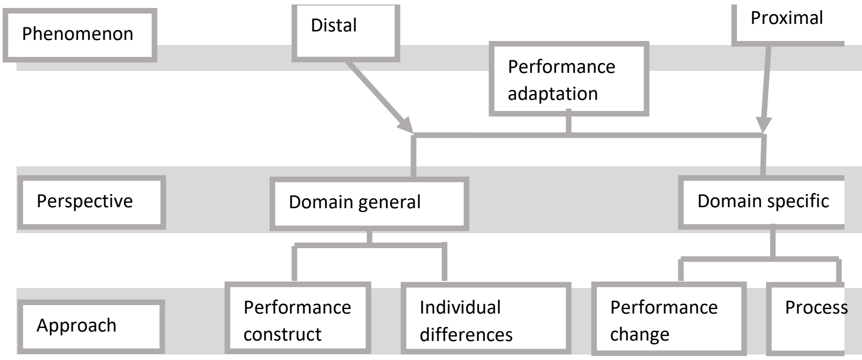


Figure 4. Taxonomy of types of adaptability (modified after Board et al., 2014)

Activity 2.8 Revision (10 Minutes)

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

Summary

In this section, we discussed the characteristics/factors that influence the capacity of a system to adapt to climate change. 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 related to the concept of stability in the sense that, in response to minor perturbations, stability reflects the capacity of an ecosystem to maintain a dynamic equilibrium over time while resisting the change to a different state. The communities become resilient when they are able to timeously 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 the species diversity, genetic variability within species, the regional species and ecosystem pools. 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. Forests are however affected by any changes in their disturbance dynamics. Forests are subject to a variety of disturbances that are themselves strongly influenced by climate. Climate change is expected to increase the susceptibility of forests to disturbances, coupled with the frequency, duration, intensity 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, Tools and Approaches for Adaptation

3.1 Chapter overview

The successful implementation of adaption actions needs enablers from individual, local, national and international levels. These can be in financial or technical forms. In this chapter, we discuss four types of capital/assets and resources for CCA, tools for prioritising adaptation, financing mechanisms, approaches and discussions on mainstreaming CCA into development planning.

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).

Learning outcomes

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

i. Describe assets and resources for CCA;
ii. Apply different tools for prioritising adaptation options;
i. Describe basic analytical tools for identifying mainstreaming opportunities and entry points;
ii. Explain considerations of mainstreaming CCA;
iii. Explain approaches used in mainstreaming CCA into development; and
iv. Describe adaptation financing mechanisms in Africa.

Activity 3.1. Brainstorming (10 minutes)

What do you think are the best assets to facilitate effective adaptation?

3.2 Assets, resources and capital for adaptation

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).

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. The success of adaptation depends on the individual farmers' agility to respond to external pressures, fluctuations and stresses. In this regard, the sustainagility concept can define activities that allow the individual's agility to be sustained and it augments the concept of sustainability because the two determine whether existing systems are able to 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 agility to find and fit in new components. Carney (1998) showed that the resource base for sustainagility can be viewed in the light of the five types of capital, with partial but then incomplete options for exchange between capital types: natural, social, physical, financial and human (Figure 5).

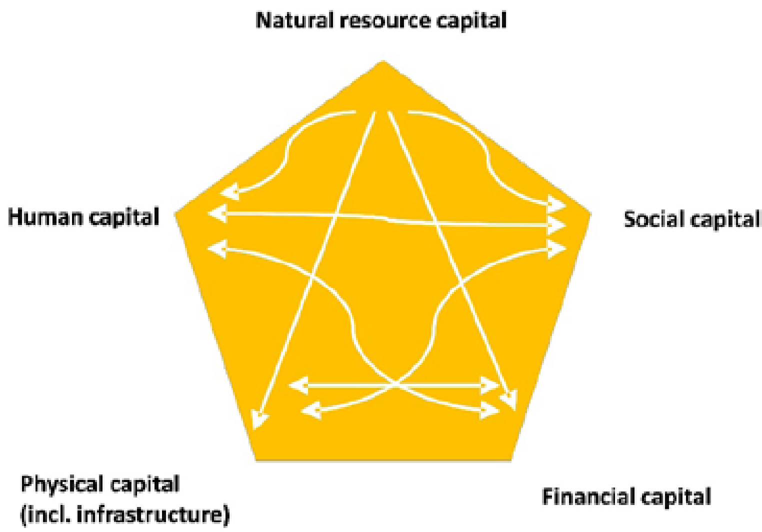


Figure 5. Types of capital affecting development and capacity to adapt (Source: van Noordwjik et al., 2001)

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. It is therefore important to strengthen all the five capitals in order to increase coping capacities to variable and extreme weather events while holistically improving community livelihoods (Carney, 1998).

Natural capital 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). 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 reforestation, restoration/conservation and diversifying incomes through utilisation of available NTFPs and other employment (Chilalo and Wiersum, 2011).

Human capital 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. Communities are able to develop their local coping mechanisms to cushion them against the effects of climate variability and change (Ofoegbu et al., 2017). However, social capital can be affected by social and political networks. However, social barriers to communication within and between communities can also need physical capital such as basic infrastructure of power, roads, bridges and means of communication. These facilitates greater access to resources and networks, transforming communities and improving wellbeing. Box 3.1 shows some case studies related to social capital.

Box 3.1 Case studies

In Ethiopia, small holder farmers adapt to climate change by using several measures where the planting alternative crops understood to be heat or drought- resistant was the most common (Bailey et al., 2019). They added that social capital and community networks operate in diverse ways to serve as critical resources for adaptation to drought across contexts. Wuepper et al. (2018) 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 CCA were positively associated whilst also working in Ethiopia.

Physical capital is about access to and quality of local infrastructure and physical assets and is positively associated with food security and agricultural adaptation (Mbukwa, 2014) whilst **financial capital** is also key based on regularity, level and diversity of household incomes. For improved adaptation, diversification of income facilitates resources through engagement or investment in other livelihoods' 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).

"Agro-ecosystems, especially those rich in agro-diversity and biological resources (natural resource capital), can adapt (depending on their human and social capital) by increasing the use of currently under-exploited local resources, or based on (locally or globally) new technology (new crops, new cultivars, new management practices, new external inputs), depending on their financial, human and social capital" (Verchot et al., 2007).

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

Summary

In these sessions, 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 capital types: 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. International Institute for Environment and Development. London. Available at: 22073490 (osti.gov).

3.3 Tools for prioritising adaptation strategies and options

Adaptation options are the choices made among possible courses of action to help decrease the vulnerability to climate change and build resilience. Once options are chosen, they are incorporated into plans and activities (UNDP, 2010a). Adaptation options can be categorised into discrete and integrated options. Discrete adaptation options directly address impacts of climate change whilst integrated options are adaptation activities that form part of a larger development project. Examples of discrete adaptation include: response of Kenya to frequent droughts and building resilience through implementation of weather-based insurance scheme or support farmers to grow more drought-tolerant maize. An example of an integrated adaptation option would be for Kenya to attempt to climate- proof its agriculture development policy. Deciding on discrete or integrated options is influenced by country priorities, decision-making criteria and the tools used to make adaptation decisions. Institutional options for adaptation include the use of several decision-making and adaptation planning tools, such as iterative risk management, community-based adaptation options, adaptive management and Integrated Coastal Zone Management. Some of the tools are used to select best options and they include: cost-benefit analysis (CBA), multi- criteria analysis (MCA) and cost-effective analysis (CEA) among others (Noble at al., 2014). A few of these are discussed in the following sections. In this session, we learn about tools for prioritising adaptation strategies and options.

Learning outcomes

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

i. Apply different tools for prioritising adaptation options; and
ii. Distinguish between discrete and integration options.

Activity 3.3 Brainstorming (10 minutes)

Identify some tools that can be used to prioritise adaptation strategies and options.

3.3.1 Cost-benefit analysis (CBA)

CBA is an economic instrument that can be used to determine economic efficiency of a project or policy by comparing the net present value of the costs of planning, preparation and implementation of adaptation interventions relative to benefits. The benefits relate to the damage costs avoided or the benefits accrued after adopting and implementing an intervention. The CBA is a decision-support tool that compares monetised costs and benefits of policy/investment options. Adaptation options can be prioritised by comparing costs and benefits using a variety of metrics including net present value (discounted benefits minus costs) or benefit- cost ratio. These tools help decision makers to understand the economic repercussions of the decisions. CBA enables the planners to compare monetary costs and benefits of several options and select the option that offers the greatest benefits at the least cost (Tröltzsch et al., 2016).

The tools require monetised values for costs (capital, labour, transaction, operating and maintenance) and benefits (economic, environmental and social). The use of the tool requires an understanding of economic valuation methods and statistical techniques for sensitivity and risk/uncertainty analysis for particular projects. CBA is better suited to address the allocation of resources than for the analysis of the efficiency of policies/investments or distributional impacts. CBA can be used to identify future low and no-regret options. It is useful when climate risk probabilities are known, sensitivity is low and where clear market values can be applied. The main challenge, however, comes when non-market sectors/non-technical options are included and the uncertainty that is confined to probability risks/sensitivity analysis. Box 3.2 shows a CBA case study.

3.3.2 Cost effective analysis (CEA)

The CEA is a methodology used to compare different options that aim to achieve similar outcomes. It is particularly attractive in the adaptation context because it allows for benefits to be valued in non-monetary terms, opting for quantification in physical terms instead. CEA is generally most useful for short-term adaptation assessments. CEA is also a helpful tool when dealing with sectors which include significant non-market dimensions such as biodiversity protection. The main challenge is that the tool uses a single headline metric which is difficult to identify and less suitable for complex or cross-sectoral risks. There is low consideration of uncertainty. Although it does not explicitly deal with uncertainty, it can be combined with sensitivity testing and probabilistic modelling (Tröltzsch et al., 2016).

3.3.3 Multi-criteria analysis (MCA)

MCA offers a systematic approach to rank adaptation options alongside a range of other decision criteria. The various criteria can be weighted to reflect their relative importance. The weighted sum of the various selected criteria is then used to rank the options. The MCA can be applied to analyse alternative adaptation strategies or for individual projects or investment decisions. In addition, the approach encourages engagement with stakeholders and allows the consideration of stakeholder preferences in the scoring and weighting of criteria (Tröltzsch et al., 2016).

MCA considers both qualitative and quantitative information and is especially applicable for scenarios that combine factors that must be considered for ranking of adaptation interventions. In this regard, MCA can complement other tools and capture qualitative aspects that rely on subjective expert judgement or stakeholder opinion and uncertainty is integrated as an assessment criterion (Tröltzsch et al., 2016).

Box 3.2 Case study: Assessing agroforestry practices and soil and water conservation for climate change adaptation in Kenya: A cost-benefit analysis.

CBA was used to analyse the financial and economic worthiness of soil and water conservation and agroforestry adaptation measures using primary data from a survey of 642 households spread across five counties in Kenya. The results showed the following:

- The CCA options were economically worthwhile as they generated positive on-farm net benefits resulting from reduced soil erosion, better water retention, higher crop yields and ultimately higher incomes. Positive externalities include public benefits such as mitigation of C emissions and reduced siltation of dams;
- The costs of establishing terraces and grass strips were considerably high for most farmers and therefore this became a major barrier to adoption. Labour cost was also a major constraint for promoting on farm adoption. One possible solution is the deployment of National Youth Service staff to undertake terracing as part of their public service;

The demonstrated profitability of these adaptation options is not enough to guarantee adoption. Governments at the national and county level can increase adoption of economically worthwhile measures by addressing the drivers for adoption;

- Potential areas of government support for adoption of these agricultural technologies include enhancing access to agricultural extension to increase awareness amongst farmers on climate change and educate;
- Improvements on land tenure security, including land titling and prompt resolution of land disputes, ensures that farmers are incentivised to invest in longer term, more expensive soil and water conservation and forestry measures. Given that gender is also a driver of the adoption of adaptation actions, gender should be mainstreamed into adaptation programmes. The unique challenges faced by female and male farmers must be addressed in all stages of project design; and
- Increasing uptake of analysed adaptation practices also requires continued agricultural productivity. Investing in farmers' access to productive inputs is also crucial. This can be accomplished by creating conducive macro-economic environment for the private sector and improved targeting recipients (FAO and UNDP, 2020).

3.3.4 Assessing Scaling Potential (ASP)

Assessing Scaling Potential (ASP) is a tool designed by the World Resources Institute (WRI) to help in assessing the framework of testing the scalability of the project from the design phase to post - implementation phase using five steps. The objective of the tool is to help users prioritise options or projects that have the potential to scale and create transformational change and paradigm shifts. Prioritisation takes place through a scoring and ranking system that involves a wide range of stakeholders. The tool can be used at any stage of project implementation to determine if it has scaling potential (Chaudhury et al., 2013).

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3.3.5 Business Sector Prioritisation and Engagement (BSPE)

The Business Sector Prioritisation and Engagement (BSPE) can be used by businesses for determining areas that need adaptation, using ranking to scale the most economically important climate vulnerable economic sectors. BSPE was also developed by WRI and United Nations Development Programme (UNDP) to assist small businesses to adapt to climate change. Some of the principles that the public sector can use to promote adaptation by medium scale enterprises (MSEs) were given by Dougherty-Choux et al. (2015) (Figure 6).

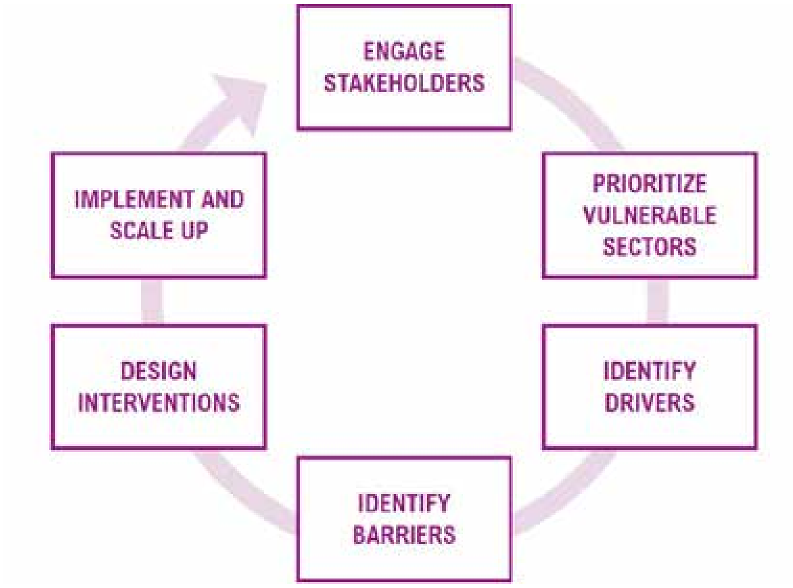

Figure 6. Principles of private sector adaptation (Source: Dougherty-Choux et al., 2015)

Economically important but vulnerable sectors should be prioritised because of their diversity. Climate change will directly and indirectly affect most economic activities for those exposed. To target indirect risks that affect all sectors, policies need cross-sectoral approach in order to create a general supporting environment for business growth. However, non-specific policies aiming at engaging the private sector will not likely succeed because the drivers and barriers to successful adaptation differ among sectors and even within a sector. Therefore, when designing policies to enable MSE engagement, policymakers need to select sectors for engagement.

Furthermore, the drivers of investment in adaptation need to be identified. Understanding what drives private sector investment in adaptation in a sector is important as it determines the design of interventions and associated regulations. Not only drivers but also the barriers preventing investment in adaptation need to be identified. Policy makers must identify barriers to effective adaptation before designing interventions to create an enabling adaptation environment for small businesses (Crawford and Church, 2019).

The public sector needs policies and interventions creating an enabling environment for adaptation by MSEs. This facilitates successful private sector engagement, and can be important in addressing the barriers that are faced by MSEs.

The final step is to implement the plan and scale-up. There are various ways through which interventions can be scaled, either bottom-up starting with several pilot projects or top-down through a nation-wide programme of reforms. Developing new successful approaches require investment in a wide range of possible adaptation activities to test what works while identifying critical barriers and success factors. Box 3.3 shows private sector engagement in climate action.

Box 3.3 Example of private sector initiatives for climate change adaptation

The Centenary Bank of Uganda developed an Agricultural Finance Department in 2013 that introduced a new initiative to provide preferential interest rates on loans for farmers who bought climate-resilient seeds and/or irrigation kits. They aimed at incentivising climate risk management and CCA actions for local farmers. For this initiative, the bank partnered with a domestic seed company and a company with expertise in irrigation technologies. Although the scheme was established before Uganda's draft National Adaptation Plan (NAP) document, the Centenary Bank scheme supports NAP through priority actions focusing on climate-resilient crops and strengthened irrigation farming. These initiatives by Centenary Bank, facilitate direct financing to farmers in Uganda and contributes to adaptation efforts (Parry et al., 2017).

3.3.6 Participatory Scenario Development (PSD)

Participatory Scenario Development (PSD) is a tool useful for adaptation planning as decision-makers consider all kinds of future uncertainties into the planning process and applicable at any decision-making scale, regional to the local scales. The PSD enables decision-makers to use scenarios in their decision making or develop multiple scenarios that are able to resist future uncertainties (Chaudhury et al., 2013). PSD can be used by multiple disciplines to create multidisciplinary scenarios in a participatory manner. This facilitates planning to address both climate and socioeconomic uncertainties. Scenarios represent future what-if stories, expressed in numbers, words, maps and/or graphics (Wilkinson and Eidinow, 2008).

- Scenarios describe plausible futures based on a logical and internally consistent set of assumptions about key drivers and relationships;
- Scenarios do not offer any certainty about future developments because uncertainty is a characteristic of a complex world; and
- Scenarios can help identify and prioritise adaptation options over time (Chaudhury et al., 2013)

The PSD approach to planning allows co-creating of scenarios among participants from diverse backgrounds allowing collaboration and incorporation of different perspectives to create a shared vision for the future. In the PSD process, participants are encouraged to link their experiences with quantitative (e.g. economic analysis) and qualitative information (e.g. experience, policies), to give scientific credibility to the established scenarios. The multi-disciplinarity makes the scenarios relevant to participants and their needs for decision making. The PSD process goes through five steps: (i) drivers of change, (ii) visioning, (iii) back-casting, (iv) barriers and enablers, and (v) prioritising (Figure 7).

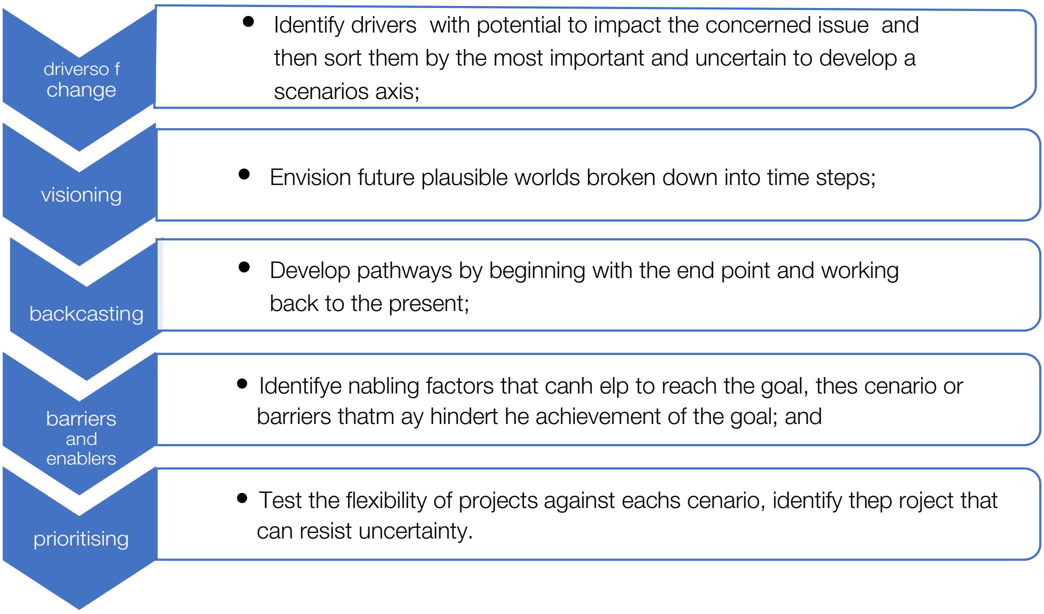

Figure 7. Overview of PSD process (Source: Chaudhury et al., 2013)

The co-development of plans in the PSD process produces scenarios and plans useful to all participants. Furthermore, PSD creates legitimacy where those involved are able to create a common vision of the future and plans in a participatory manner. The process is highly creative, enabling users to “think out of the box”, as they envision their next 100 years or more years to come. Going through the PSD process is a platform for building capacities for thinking creatively, making PSD a tool for decision making (Chaudhury et al., 2013; Vervoort et al., 2014).

3.3.7 Strenghts, Weaknesses, Opportunities and Threats (SWOT)

A Strenghts, Weaknesses, Opportunities and Threats (SWOT) analysis is an easy process where several factors are assessed and categorised relative to the organisation and its enabling environment. The analysis involves identification of factors characterised as internal or external to an organisation or positive or negative. Strengths and weaknesses include all internal factors and qualities of the organisation whereas, opportunities and threats are represented by factors that are external and associated environmental attributes. The analysis provides information used to match resources and capabilities with the competitive environment. Strengths and opportunities help in achieving objectives and are beneficial to the organisation. Weaknesses and threats are detrimental to achievement of objectives and are damaging for the organisation. An example of SWOT analysis for climate change action is given in Table 2.

Table 2. An example of SWOT analysis for climate change adaptation projects

STRENGTHS	**WEAKNESSES**
• Awareness about climate change helps us to seek for solutions to reduce the impacts and adapt; and • Advances in climate science enables us to adapt and manage climate change consequences	• Climate change awareness has not reached all communities; • Poor early warning systems (EWS); • Private sector less excited about climate change; • Climate unpredictability; and • Procedures for accessing climate finance.
OPPORTUNITIES	**THREATS**
• International climate finance; • International coordination; • Training and research opportunities; • Government support; • Diversification; and • Technology transfer.	• Health problems (Vector- borne and water borne disease e.g. Malaria, cholera, • Deaths from heat waves; • Food insecurity; • Erosion of genetic diversity; • Invasive invasion; and • Plant pests and pathgens.

3.3.8 Other tools

Iterative risk management: Useful where long-term and uncertain challenges, especially with clear risk thresholds. It is challenging when dealing with multiple risks acting together when their thresholds are not always easy to identify.

Real-option analysis (ROA): This can be used in adaptation to gain insight into the risks associated with investing in physical (real) assets. It is particularly useful when considering when to invest into an adaptation intervention or the value of adjusting adaptation interventions over time in response to changing events. ROA provides an economic analysis of the value of flexibility and future learning. ROA is particularly useful in considering large-scale, long-lived and costly adaptation interventions such as dyke flood protection or dam-based water storage. The analysis can be used to support the scoping of such adaptation interventions projects and the value of securing investments for future development. It can also help explore how to incorporate flexibility into the design of these interventions and how the project value will evolve over stages of development. Large irreversible decisions, where information is available on climate risk probabilities requires economic valuation (e.g. CBA), probabilities and clear decision points (Tröltzsch et al., 2016).

Robust decision-making: This is used when uncertainty and risk are large. Can use a mix of quantitative and qualitative information. Requires high computational analysis and large number of runs. Explicitly incorporates uncertainties and risks, in particular, systemic dependent risks, to derive robust solutions (Tröltzsch et al., 2016).

Portfolio analysis: This is used when there is a number of complementary adaptation actions and good information. Requires economic data and probabilities. Has issues of interdependence. Deals explicitly with uncertainty by examining the complementarity of adaptation options for dealing with future climates (Tröltzsch et al., 2016).

Activity 3.4 Revision (10 minutes)
Describe at least three tools for prioritising adaptation options.

Summary

In this session, we were exposed to tools that can be used for prioritising adaptation options. Adaptation options are the choices made among possible courses of action to help decrease the vulnerability to climate change and build resilience. The adaptation options can be categorised into discrete and integrated options. The tools used include CBA, CEA, MCA, ASP, BSPE and PSD.

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. International Institute for Environment and Development. London. Available at: 22073490 (osti.gov).

3.4 Adaptation financing mechanisms

Financial resources and technical support are necessary to plan, implement, maintain and evaluate activities that advance CCA. All countries, rich and poor, need to adapt to climate change, and this will be costly. Article 4 of the United Nations Framework Convention on Climate Change (UNFCCC) highlights that developed country Parties provide financial resources to assist developing country Parties adapt to climate change. Developing countries are already hardest hit by climate change, but they have little capacity (both in terms of human capacity and financial resources) to adapt. The UNFCCC has mechanisms in place for funding to fill the financing gaps of developing countries, while new and innovative ideas continue to emerge (Biagini et al., 2014). Funding is required by all developing countries starting from the development of national adaptation strategies or action plans at all levels: local, provincial and national. Funds are provided through multilateral channels, within and outside of the UNFCCC financial mechanism and progressively through bilateral, regional and national climate change channels and funds.

Learning outcomes

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

i. Describe some types of financing mechanisms for adaptation projects; and

ii. Describe implementation modalities for climate finances.

Activity 3.5 Brainstorming (10 minutes)

Describe your experiences with any global initiatives for CCA.

The funding mechanisms outlined at the Copenhagen Accord, declared the scaling up of climate finance for developing countries with US$ 30 billion of fast-start finance for the period 2010–2012 and US$ 100 billion per year from 2020 onwards. The initiative identified the private sector as one of the major funding sources of the Global Climate Fund (GCF). Furthermore, the Cancun Agreements transformed much of the Copenhagen Accords' content on climate finance into a decision of the Conference of the Parties (COP).

Pauw et al. (2016) outlined ten criteria for assessing adaptation finance: adequate, predictable, sustainable, scaled up, new and additional, provided with improved access, balanced allocation between adaptation and mitigation, prioritised to the most vulnerable developing countries, mobilised by developed countries and transparent. Further funding opportunities currently available for developing countries to fund adaptation projects include: The Future Adaptation Fund under the Kyoto Protocol, funds from other multilateral environmental agreements (MEAs), and bilateral and multilateral funding from governments, national and international organisations and agencies. The funding can be from private sector, national, bilateral or multilateral. Some examples are given in the next paragraph.

Climate funds 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 and these include: The Adaptation Fund (AF), Forest Investment Programme (FIP), Forest Carbon Partnership Facility, Clean Technology Fund (CTF), 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.

3.4.1 Private sector

Climate change poses a number of 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. In addition to their own funding, the UNFCCC also has a centralised platform to support private-sector investment for adaptation activities, the Private Sector Initiative (PSI), supported by the Nairobi Work Programme focusing on 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: water, insurance, food and agriculture, consultancy, environmental management, infrastructure and transportation, tourism and the financial sector (Biaginia and Millaer, 2013).

The initiative provides a platform for businesses to contribute to a strong and effective response, in a sustainable and profitable manner both in their adaptation efforts and importantly, in those of the most vulnerable countries and communities around the world. The types of private sector engagement are illustrated in Figure 8

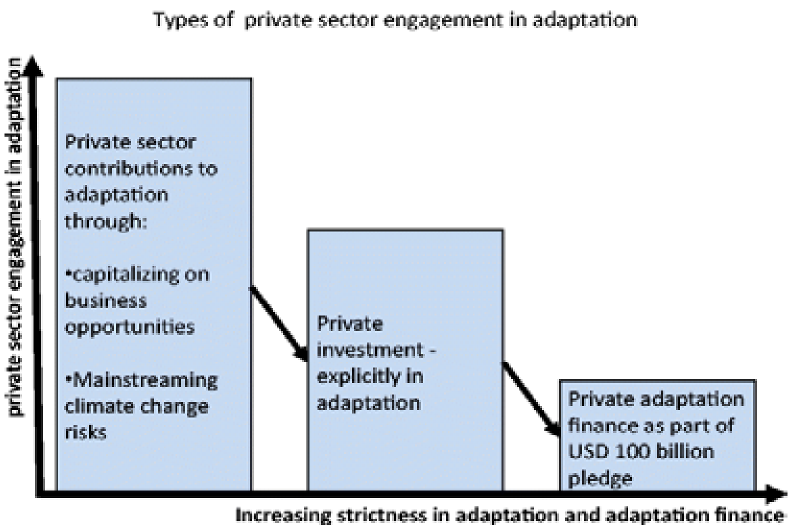

Figure 8. Types of private sector engagement in adaptation (Source: Pauw et al., 2016)

Private companies are implementing actions that 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; and
- Enhancing their corporate social responsibility.

Box 3.4 shows some projects that have been implemented by the private sector.

Box 3.4 Examples of projects that have been successfully implemented by the private sector

The Cisco System Strategy and Innovation group has a research initiative to reduce emissions from deforestation in developing countries with co-benefits for CCA and the conservation of forest ecosystems.

The BASF's researchers were developing stress-tolerant plants, more resistant to extreme weather conditions such as drought in order to optimise crop production for plants such as corn, soy and wheat. BASF also offers innovative and environment-friendly solutions for effective and stable coastal protection through a specially developed elastomer polyurethane system (Elastocoast) where dikes are protected by absorbing the force of the breaking waves and slowing down the water masses.

RICOH implements nine forest ecosystems conservation projects in eight countries. In Africa, Climate Compatible financing has worked in Uganda and Namibia's energy sectors and Zambia and Tanzania's agricultural sectors (UNFCCC.int, 2021).

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 also implemented by multinationals (such as Allianz, Anglo American, GlaxoSmithKline, Nestlé and Siemens), with few 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). 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), initiated and co-financed by multilateral or bilateral organisations such as the World Bank or the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the UK Department for International Development (DfID) or United States Agency for International Development (USAID)(Troilo, 2011).

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

3.4.2 National level

Some governments in Africa finance for 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. Benin, Ethiopia, Mali, Rwanda and South Africa have dedicated national climate change funds with some climate action programmes partly funded through national budgets whilst others 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).

3.4.3 Bilateral level

The Africa Adaptation Programme was launched in 2008 by the UNDP in partnership with the United Nations Industrial Development Organisation, the United Nations Children's Fund and the World Food Programme (WFP) and with US$ 92.1 million support from the Government of Japan. The African Adaptation Programme 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 in May 2008. Support was given over a 3-year period to enhance the adaptive capacity of the 20 African Adaptation Programme 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).

Bilateral development players largely grant financing to the public sector and civil society organisations. Their activities include capacity building, facilitating dialogues with the private sector, supporting enabling conditions and matching grant schemes. These include USAID, Swedish International Development Agency (Sida), GIZ and DfID. Bilateral donor governments and their agencies contributed an additional US$ 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-programmes 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 and expertise, and management and financial capabilities of implementing organisations. The main bilateral climate initiatives and programmes are:

- International Climate Initiative (ICI), Germany;
- French Global Environment Facility, France;
- International Climate Fund (ICF), United Kingdom;
- Hatoyama Initiative/Fast-Start Financing, Japan;
- The UK's support for energy in developing countries; and
- African Adaptation Fund (Japan-UNDP).

3.4.4 Multilateral level

There are twelve multilateral implementing entities with only three housed in Africa, namely; African Development Bank (AfDB), 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 Mechanisms had also provided about US$ 200 million to the AF over its lifetime (Micale et al., 2018).

The GCF under UNFCCC is considered as the main potential mechanism for organising a share of international climate finance. The GCF complements many of the existing multilateral climate change funds, such as the GEF, the AF and the 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 the 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. Large-scale GCF projects focusing on adaptation initiatives were approved for Malawi, Uganda and Zambia (Green Climate Fund, 2020).

The GEF was established in 1992 at the Rio Earth Summit to deal with environmental problems. By October 2018, the GEF had 183 international partnerships countries, civil society organisations, international institutions and the private sector working on global environmental issues (UNDP, 2018). The GEF houses the Strategic Priority on Adaptation (SPA) which was established in 2001, dedicated US$ 5 million to pilot projects on community adaptation initiatives through the Small Grants Programme. Since then, the GEF has provided over US$ 17 billion in grants and mobilised an additional US$ 88 billion in financing for more than 4000 projects in 170 countries. The GEF Trust Fund and its SPA support activities addressing adaptation while generating global environmental benefits. The Trust Fund comprises LDCF and the 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 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 US$ 41.7 million was approved for the LDCs' NAPs as at 30 June 2017. Since the establishment of GEF in 1991, 343 adaptation projects were funded with over US$ 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, 2019a). As of July 2017, about 80% of adaptation funding had targeted LDCs, Small Islands Developing Countries (SIDS) and African States.

CIF was established in 2008 as one of the largest global fast-tracked climate financing instruments with US$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, MDBs and other sources. Five MDBs – the AfDB, European Bank for Reconstruction and Development, Asian Development Bank, Inter-American Development Bank and World Bank Group support the implementation of CIF-funded projects and programmes. The CIF include two key programmes; CTF) and Strategic Climate Fund(CIF, 2019):

CTF (about US$ 4.9 billion with 85 projects) - promotes scaled-up funding for demonstration, distribution and transfer of low-C technologies that have substantial potential for long-term savings of GHG emissions. Projects supported are mainly in three sectors: power (reducing C intensity through renewable energy and highly efficient technologies), transport sector (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).

Strategic Climate Fund-supports three programmes: FIP, PPCR and SREP.

- **FIP**: Is one of the three programmes under the Strategic Climate Fund 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 US$ 740 million. It also finances programmes addressing underlying causes of deforestation and forest degradation and overcome problems that hindered progress of past efforts. African countries that have benefited from the AF include Burkina Faso, Cameroon, Congo Republic, Cote d'Ivoire, Ghana, Mozambique, Rwanda, Tunisia and Zambia (CIF, 2019).
- **PPCR**: Became the first operational programme under the Strategic Climate Fund 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 US$ 1.2 billion was invested in pilot programmes (CIF, 2019).
- **SREP**: Investment of about US$ 740 million to demonstrate economic, social and environmental feasibility of low C development pathways in developing country 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 Reducing Emissions through Deforestation and Forest Degradation (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 AF under SREP include Benin, Ethiopia, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Sierra Leone, Tanzania, Uganda and Zambia (CIF, 2019). Some of the adaptation fund projects are shown in Box 3.4.

Activity 3.6 Revision (10 minutes)

1. Outline some of the adaptation financing mechanisms that can be applied at regional level; and
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 CCA. Long term policy approaches under the UNFCCC can be planned using any of the five approaches: adaptation pathways method, EbA, CoBA, livelihoods and economic diversification as well as risk-based approaches. We concluded the section by highlighting some case studies from the African continent.

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

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 the 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 learn about mainstreaming CCA.

Learning outcomes

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

i. Explain considerations of mainstreaming CCA;

ii. Explain approaches used in mainstreaming CCA into development: and

iii. Explain characteristics of good policy approaches.

Activity 3. 7 Group discussion (10 minutes)

What is the meaning of mainstreaming CCA into development policies and plans?

Mainstreaming CCA is a process that considers the consequences of climate risks in all areas of national development and includes integration of adaptation considerations into policy-making, 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. Adaptation objectives, strategies, policies, measures or operations should be integrated as part of the national and regional development policies, processes and budgets (UNDP, 2004). 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/managers in sectors such as agriculture, water resources and coastal 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, the 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). For example, if the agricultural sector neglects development and natural resource management efforts in marginal areas or if there are no markets for agricultural products.

There are other sectors where mainstreaming may be required at regional level. For example, 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).

At global level, climate change actions need the 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 Sustainable Development Goals (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. sustainable forest management (SFM), CCA 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 to formulate 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 using Asian projects and they identified five approaches and four key adaptation policy characteristics. Approaches include Scenarios, Strategic (spatial) planning, Robust Decision Making, Adaptation pathways and Adaptive Governance. Table 3 describes the five long-term policy approaches under the UNFCCC and their characteristics. Approaches include adaptation pathways method, EbA, CoBA, livelihoods and economic diversification as well as risk-based approaches.

Good adaptation policy approaches have the following characteristics:
- Flexible;
- Scalable;
- Considers uncertainties;
- Resilient;
- Incremental or gradual change;
- Time -oriented;
- Local, national or international scale; and
- 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; and • Can use models.
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.
CoBA	• 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; and • Approach includes four steps: identification of relevant risks, characterisation of those risks, selection of policy options to address the risks, and feedback to respond to developing risks.

Source: UNFCCC (2019b)

National adaptation response should be formulated as part of broader development policies, including areas not exactly linked to climate change. Integration of NAPs into national development planning processes and strategies will help reduce vulnerability to the adverse effects of climate change (UNFCCC, 2019b). The process of mainstreaming CCA is iterative, multi-year, multi-stakeholder process integrating climate change into policy-making, 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).

Frameworks used by developing countries for planning and implementing responsive adaptation include: NAPA, CoBA, Adaptation Policy Framework (APF) and EbA (UNFCCC, 2019b). Effective CCA to climate change should therefore incorporate potential impacts into ongoing strategies and plans at sectoral and national levels (Huq et al., 2003). When 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. Mainstreaming adaptation into development therefore requires the main development actors (governments, international development funding agencies, non-governmental organisations (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 (Box 3.4).

Box 3.4 Framework for mainstreaming climate change adaptation

- 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;
- Mainstreaming CCA into policy processes through its integration into ongoing policy processes such as national development planning or sectoral strategies based on country-specific evidence (i.e. vulnerability, impact and adaptation assessments, socio-economic investigations and pilot projects); and
- Meeting the implementation challenge by ensuring that CCA is mainstreamed into budgeting and financing, implementation and monitoring and mainstreaming should be standard practice (UNDP-UNEP, 2011).

National policies aiming at promotion of forests 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; for example, 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 (Hansen et al., 2003). Climate change should be explicitly considered as a driver that can change conservation policies (Killeen and Solórzano, 2008). For example, designing national systems for protected areas and biological corridors considering the vulnerability of the protected ecosystem and the role of corridors for facilitating the migration of species under different scenarios of climate change (Hilty et al., 2019). Furthermore, the policies should promote forest adaptation information sharing and create monitoring systems to assess impact of

climate change on forests. Communities should be the 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); and

- Financial and institutional capacities limit adaptation options at the local scale (Agrawal et al., 2008), and policies should therefore, include the strengthening of local institutions, through funding and capacity building.

Box 3.5 shows case studies of adaptation to climate change.

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

Zambia's project on strengthening climate resilience of agricultural livelihoods in agro-ecological regions I and II

Zambia got support of US$ 137 million (2018-2025) from the GCF, under the UNDP and its partners (Food and Agriculture Organisation of the United Nations (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 addresses the entire value chain and provides the initial trigger for poor and vulnerable farmers to shift on to a resilient trajectory for agricultural livelihoods. The project also responds to Zambia's climate change strategies and NDC-commitments to reduce GHG and strengthen resilience to climate change (www.adaptation-undp.org).

Climate Change and Development – Adapting by Reducing Vulnerability

This is an initiative funded by the Government of Denmark and delivered in partnership with the UNEP. The programme provides US$ 9 million to support climate risk management initiatives in sub-Saharan Africa. The initiative provides technical support to countries to create opportunities for integrating CCA into national development planning and decision-making frameworks.

Use of Open Standards-Based Framework for Planning and Implementing Ecosystem-based Adaptation projects (Schumacher et al., 2018)

A German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety and International Climate Initiative funded and GIZ-led consortium explore the use of Open Standards-Based Framework for Planning and Implementing EbA projects to help people adapt to the adverse impacts of climate change. It aims to strengthen the provision of ecosystem services and thereby enhance the livelihoods of the population depending on them. Although the application of potential ecosystem-based measures in Central Asia is not new, typically relevant climate risk information on people and ecosystems is not considered and thus, has a higher risk of introducing maladaptive interventions. This project used a modified form of the Open Standards for the Practice of Conservation to systematically develop and test an integrated planning framework that used climate risk information to identify key vulnerabilities of people and ecosystem services under several plausible climate change scenarios and developed potential adaptation options.

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

Activity 3.8 In text question (5 Minutes)

How is CCA integrated into national, sectorial or subnational policies in your country?

Summary

In this session, we learnt that adaptation policies or strategies should be mainstreamed into broader development policies because climate change is a cross cutting issue. Mainstreaming CCA is a process that considers the consequences of climate risks in all areas of national development and includes integration of adaptation considerations into policy-making, budgeting and implementation processes at the national, sector and subnational levels. Mainstreaming may also be required at regional level (e.g. river basins) or global level (e.g. attaining SDGs and UNFCCC goals). The international policies facilitate conformity of parties to integrate agreed protocols and treaties into appropriate regional and national policies. There are several approaches that can be used to formulate national adaptation policies or climate strategies. The use of cross-cutting, integrated policy approaches however, yield long term results. The approaches include adaptation pathways method, EbA, CoBA, livelihoods and economic diversification as well as risk-based approaches. These should conform to desired characteristics and should be adaptive. For planning and implementation of adaptation in developing countries, there are frameworks that can be used and these include the NAPA, CoBA, APF and EbA. Mainstreaming CCA follows a three step process. The session concluded by giving examples of forest-based adaptation objectives and some case studies.

3.6 Development of adaptation projects

In developing adaptation projects, several approaches can be used depending on whether its short or long-term and depending on the level of depth required. Effective CCA will however, require long-term planning approaches at the regional, national and local levels. Reacting to changes in the short-term or medium-term, without attention to changes that will occur and remain over the long-term, will result in poor investment decisions, the costs of which could exceed the direct local costs of climate change impact. Generally, the adaptation project cycle follows the processes of: impact, risk and vulnerability assessment, planning, implementation and M&E (Box 3.6).

Traditional impact assessment-based frameworks do not meet the needs of decision-makers for practical adaptation implementation. Policy-based and community-based frameworks can be used for designing CCA projects. Schumacher et al. (2018) reported the use of Open Standards-Based Framework for Planning and Implementing EbA projects.

Box 3.6 Components of the adaptation cycle under the UN climate change regime

Assess impacts, vulnerability and risks

An initial assessment is needed of the extent to which climate change is affecting or will affect natural systems (e.g. by altering water availability, thus negatively affecting agriculture and food security) and human societies (e.g. by increasing temperature, thus encouraging the spread of climate-sensitive diseases).

Plan for adaptation

Identification of adaptation activities and their appraisal including through assessing costs and benefits is undertaken in order to choose appropriately between the options available. Comprehensive planning should ensure avoiding the duplication of activities, preventing maladaptation and enhancing sustainable development.

Implement adaptation measures

Implementation takes place at various levels, including national, regional and local and through different means including projects, programmes, policies or strategies. It may be a stand-alone process or be fully integrated or mainstreamed with sectoral policies and sustainable development plans.

Monitor and evaluate adaptation

These steps can be undertaken throughout the adaptation process, and the knowledge and information gained can be fed back into the process to ensure learning and that future adaptation efforts are successful. While monitoring seeks to keep a record of progress made in implementation, evaluation seeks to determine the effectiveness of the adaptation effort (unfccc.int).

Activity 3.9. Brainstorming (10 minutes)
In what ways has CCA been managed at the local and national levels in your country?

3.6.1 Policy-led project framework

The European Union funded research to develop a policy-led framework (ECONADAPT) aiming at addressing limitations of impact assessments by providing a set of decision-making steps and rules that focus on adaptation decisions, including management of uncertainty (Tröltzsch et al., 2016). The framework provides guidelines to help with the early scoping, phasing and prioritisation of adaptation, as well as later, more detailed economic appraisal. This policy-led framework endeavours to re-adjust analyses towards adaptation decisions with much greater attention given to early steps around identifying the existing policy context and objectives. The primary objective of the analysis is framed around adaptation, coupled with a greater emphasis on integrating (mainstreaming) adaptation into current policy and development. There is also an analysis of the phasing and timing of adaptation, with an increasing recognition of uncertainty and the use of iterative risk management approaches, over the short, medium and long term. This includes three phases of:

- Taking speedy actions to mitigate existing risks associated with weather and climate extremes (the adaptation deficit) and building resilience to expected climate change. Activities such as capacity-building and introduction of low, no-regret actions which provide early economic benefits together with expected benefits under a changing climate;
- The integration of adaptation into immediate decisions or activities with long life-times, such as infrastructure or planning (climate-smart development). This involves different options because of future climate change uncertainty. It involves a greater focus on climate risk screening and the identification of flexible or robust options that perform well under uncertainty; and
- Early research, monitoring, and learning to facilitate preparation for future climate impacts. The focus being on adaptive management and learning, information generation and expected option values so that appropriate decisions can be made sooner or later depending on emerging evidence and knowledge.

These three categories can be consolidated to design an integrated adaptation strategy, also called an adaptation pathway or a portfolio (Figure 9).

3.6.2 Community -based adaptation (CoBA)

- CoBA is an approach that integrate traditional knowledge with innovative strategies for addressing existing vulnerability while building capacity for adapting to emerging and dynamic challenges. There are four inter-related strategies integrated into CoBA (Care International, 2014);
- Promotion of climate-resilient livelihoods strategies in combination with income diversification and capacity building for planning and improved risk management;
- DRR strategies for reducing impacts of climate hazards, especially for the vulnerable individuals and households;
- Capacity development for local civil society and governmental institutions so that they can provide better support to communities, households and individuals in their adaptation efforts; and
- Advocacy and social mobilisation for dealing with underlying causes of vulnerability, such as poor governance, limited access to basic services or lack of control over resources. An enabling environment improves the effectiveness of CoBA in promoting community transformation.

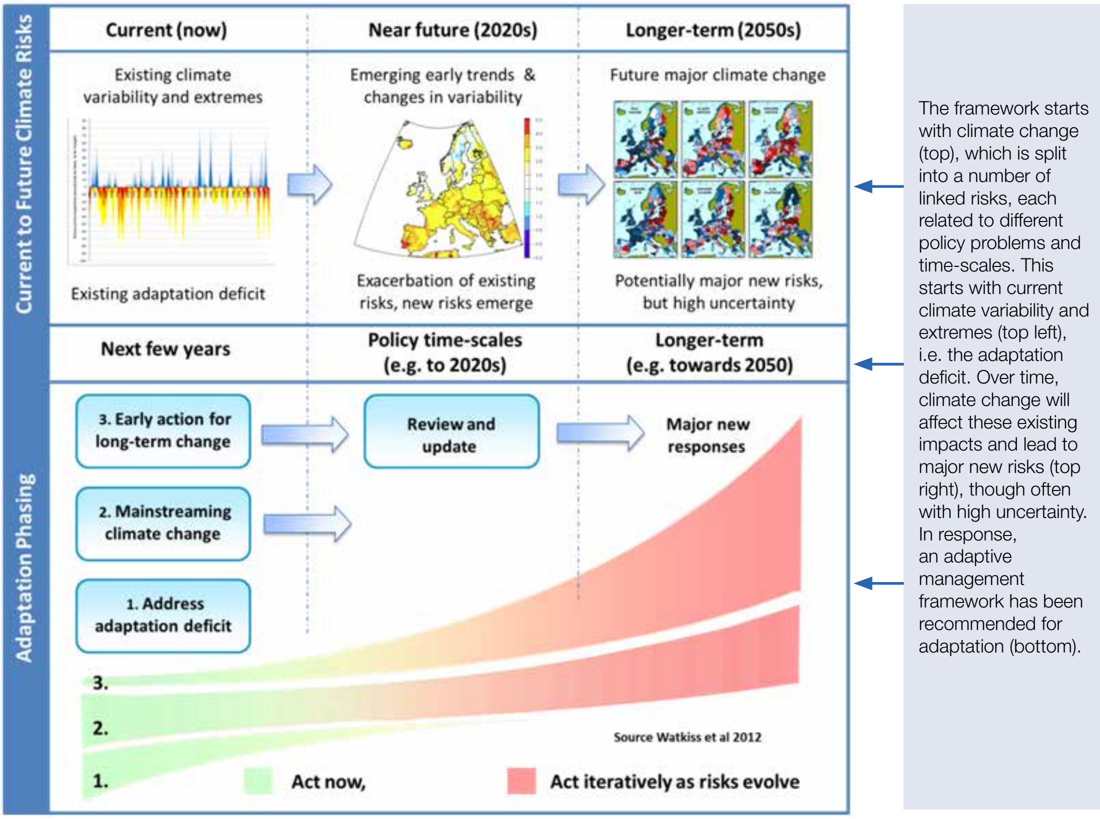

Figure 9. The ECONADAPT policy framework (Source: Troltzch et al., 2016)

3.6.3 The UNDP toolkit

The UNDP adaptation initiatives toolkit provides step-by-step guidance for designing measurable, verifiable and reportable adaptation initiatives. Successful adaptation needs approaches that incorporate both policy and investment issues in planning and decision-making processes. Preparation for an adaptation initiative can be simplified through the use of simple but sequential steps with a logical structure (Figure 10).

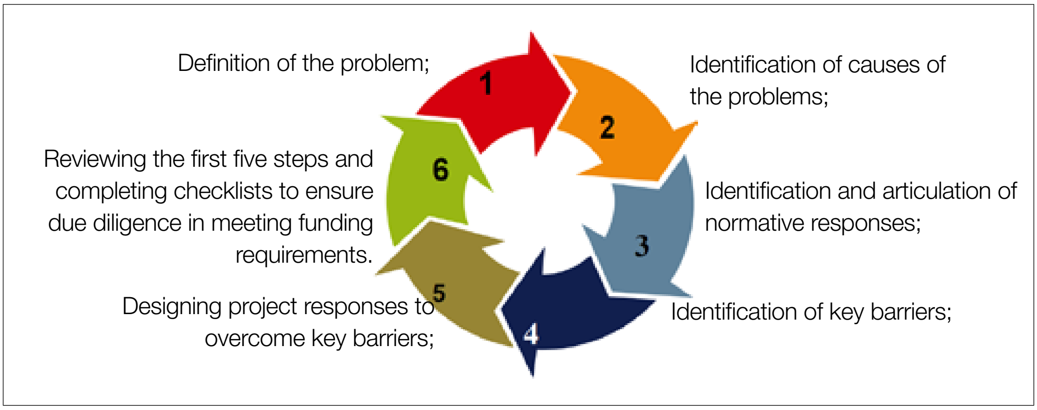

Figure 10. Steps for developing an adaptation initiative (Source: UNDP, 2010b)

Other approaches can also be considered depending on the adaptation problem.

3.6.4 Biodiversity conservation approaches

Schmitz et al. (2015) developed a framework that integrates biodiversity conservation and promote natural adaptation in land use plans. The framework is a synthesis of six adaptation approaches (from a total of 42) related to biodiversity (Table 4). The six were selected due to their focus on climate-adaptive conservation plans for conserving biophysical features, processes of ecosystems, landscapes, species and their habitats. They provide unique opportunities for species persistence and resilience. The framework is expected to strengthen current conservation efforts and to anticipate and respond to future climate. All approaches carry levels of uncertainty stemming from quantifiable errors in the measured or modelled data, assumptions of models used to project future climate change and effects of climate change on species and ecosystems.

Table 4. Six key climate change adaptation approaches for conservation planning at three levels of ecological analysis showing assessments needed to support adaptation planning action

Adaptation	**Ecological level**		
Approach	**Species and population**	**Ecosystem**	**Landscape**
Protect current patterns of biodiversity	• Assess population sizes, viability, conservation status and phenological trends; and • Map species occurrences.	• Map terrestrial and aquatic ecosystems and their associated services.	• Map genetic patterns across the landscape; • Map beta and gamma diversity; and • Map biodiversity hotspots.
Protect large intact, natural landscapes	• Forecast climate change effects on species viability; and • Forecast climate change effects on pests, diseases or invasive species.	• Map potential pattern of fire, hydrology, C sequestration and ecological integrity; and • Map locations where ecosystem services operate and provide human value.	• Analyse projected trends in climate variables (precipitation, temperature etc.); and • Map factors related to ecological integrity (e.g., fragmentation, distance from disturbance).
Protect geographic setting	• N/A	• Map areas of high ecological integrity; • Map land facets in relation to current climate patterns; and • Map areas of high topographic complex.	
Maintain and restore ecological connectivity	• Identify areas critical to species movement in current conditions and in a changing climate; and • Map movement corridors for species life-history and migration.	• Map connections between current and projected future locations; and • Anticipate species invasions along planned corridors.	• Map connections between land facets, ecological land units, refugia or areas of high ecological integrity.

Adaptation	Ecological level		
Approach	**Species and population**	**Ecosystem**	**Landscape**
Identify and appropriately manage areas that will provide future climate space for species expected to be displaced by climate change	• Forecast species and rare community vulnerability to climate change based on their capacity to adapt biologically; and • Map future range distribution of species.	• Forecast ecosystem vulnerability to climate change; and • Map locations that would support shifts in vegetation types and biomes.	• Forecast land use change; • Project sea level rise; • Project climate change; and • Map future biodiversity hot spots.
Identify and protect climate refugia	• Identify areas that would harbour current species into the future; and • Identify where species populations will remain stable or increase with climate change.	• Map habitats with high natural resilience to climate change (e.g. spring-fed streams); and • Map areas projected to experience little change in vegetation.	• Map drought refugia; and • Map areas projected to maintain stable climate.

Source: Schmitz et al. (2015)

3.6.5 Climate compatible development

Climate compatible development (CCD) is defined as “development that minimises the harm caused by climate impacts, while maximising the many human development opportunities presented by a low emission, more resilient future. It is a framework for guiding policies, programmes, projects or strategies towards “triple-wins” in development, mitigation and adaptation. CCD seeks to develop the synergies and overlaps amongst components besides reducing conflict among them (Mitchell and Maxwell, 2010). Governments and donors are now choosing to invest in CCD in order to minimise vulnerabilities (Stringer et al., 2014), that are determined by exposure to (political, socio-economic and environmental (including climatic)) shocks, sensitivity to shocks and stressors and adaptive capacities (Gaillard, 2010).

Activity 3.10 Revision (10 minutes)

1. Explain the steps in the adaptation project cycle;
2. Distinguish between policy based and community based project design frameworks; and
3. Explain some of the available toolkits for designing adaptation projects.

Summary

In this session, we learnt that development of effective adaptation programmes or projects requires long term planning at all scales. Several methods can be used to develop adaptation projects and these generally follow the project cycle of: assessing impacts, vulnerabilities and risks; planning for the adaptation; implementing adaptation measures; and eM&E of the adaptation. The cycle can be followed using any of the frameworks such as policy-led framework, UNDP toolkit, adaptive capacity, community-based approaches, biodiversity conservation approach or CCD..

PART II:
FOREST-BASED CLIMATE CHANGE ADAPTATION

Chapter 4 Forests Aand Climate Change

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 refuge and migration corridors. They indirectly support economies to adapt to climate change by reducing the costs of climate-related negative impacts. Forest ecosystems provide goods and services during extreme events (droughts and floods, and are key assets for reducing vulnerability to the effects of climate change. For instance, planting forests 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 immobilising 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. This chapter will introduce learners to forests' response to climate change, role of forests in adaptation to climate change, resilience of forests and people to climate change, forest-based adaptation mechanisms/strategies, EbA, forests and livelihoods, indigenous coping and adaptation mechanisms and strategies and challenges associated with CCA. The chapter concludes by looking at Intended Nationally Determined Contributions (INDC) and adaptation in Africa, including the Adaptation Benefit Mechanism.

Learning Outcomes

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

i. Explain how forests are affected by climate change;
ii. Describe the role of forests in CCA;
iii. Explain how forest and tree-resources respond to climate change and climate variability;
iv. Discuss interventions of enhancing resilience of forest ecosystems to cope with impacts of climate change and variability;
v. Explain guiding principles for landscape restoration;
vi. Explain applicability of thematic elements of SFM ;
vii. Determine appropriate forest-based initiatives that could help forests and people to adapt to climate change;
viii. Design appropriate forest-based CCA interventions;
ix. Analyse the challenges to CCA; and
x. Evaluate the role of forest ecosystems services in the adaptation of vulnerable social systems.

4.2 Forests response and resilience to climate change

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 the resilience of forest ecosystems include rehabilitation of degraded lands, landscape restoration guided by six principles and SFM actions to prevent degradation and disappearance of forests guided by seven thematic elements of SFM. In this session we learn about how forests and trees respond to different climatic factors.

Learning Outcomes

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

i. Explain how forests are affected by climate change;
ii. Describe the role forests in CCA; and
iii. Explain how forest and tree-resources respond to climate change and climate variability.

Activity 4.1 (Brainstorming) (5 Minutes)

Are forests and trees really important in CCA? Support your answer.

4.2.1 Forests and tree responses to climate change

Forests and other ecosystems, including woodlands are anticipated to be disturbed by unforeseen combinations of climate change-related disturbances such as droughts, floods, insect pests and pathogens and wildfires. These will be exacerbated by other non-climate drivers of global change such as land use and land cover change, pollution, overexploitation of natural resources and habitat fragmentation. Biodiversity causes forest ecosystems to have natural capacity to adapt to climate change because some of the ecosystem components have critical roles in ecosystem processes such as seed dispersal, pollination and herbivory. When such species are lost, ecosystem resilience is affected negatively. The increased concentration of atmospheric CO_2 and associated climatic effects affect the function and structure of ecosystems, ecological interactions of species and their geographical ranges, resulting in serious consequences on ecosystem services and biodiversity (Malcolm et al., 2006). In this regard, adaptive capacity of the forest is linked to genetic diversity depending largely on in-situ genetic variation within each population of a species.

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. Biological diversity in forest ecosystems stabilises ecosystem functioning in the face of environmental fluctuation and there is variation among species response 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 get extinct (Saxe et al., 2001). 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 plasma source ion implantation and photo inhibition (Saxe et al., 2001). Korner and Basler (2010) showed vegetation phenology as 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 (e.g. Jolly et al., 2005), as minimum temperatures in spring and autumn are particularly important drivers in increasing growing season and subsequent vegetation growth (Hwang et al., 2018). Furthermore, projected increase in temperatures can have significant impacts on rates of soil organic C decomposition and will enhance nutrient mineralisation and availability (Saxe et al., 2001).

Under a changing climate, forest species can either adapt to climate change, migrate to suitable habitats or become extinct. Resilience in ecosystems is the ability of a system and its component parts to absorb, anticipate, accommodate or recover from the effects of a hazardous event timeously and efficiently including restoration, preservation or improvement of essential basic functions and structure (IPCC, 2012). This shows the capacity of biological diversity in a system to maintain ecosystem processes.

Activity 4.2. Brainstorming (15 Minutes)
Clarify how forest and tree resources respond to impacts of climate change and variability.

4.2.2 Vegetation response to climate change

Climate change impacts on forest ecosystems depend on particular influences including those from natural processes, human activities and some components of climate (drought, temperature, wind, etc.) (Kirschbaum and Fischlln, 1996). Vegetation is an important component of climate feedback that regulates the exchanges of water and heat and connects the land surface with the atmosphere (Lemordant and Gentine, 2019). Responses of vegetation to climate change will differ depending on type of forest with the primary forests normally being more resilient (more adaptive, stable and resistant) than altered normal forests or plantations (Thompson et al., 2009). However, adaptive capacity can be reduced by stresses outside the forest.

Some forest ecosystems such as boreal Pine forests, although they have naturally low species diversity, they have a high level of resilience (Thompson et al., 2009). The dominant tree species have a broad genetic variability which gives them greater tolerance to a wide range of environmental conditions, making them highly adapted to severe disturbances. The wet tropics are also stable, self-organising and more complex ecosystems that can resist small environmental changes as long as they remain intact (Malhi et al., 2008).

When forest ecosystems are driven past their ecological ‘tipping point’, they are likely to be changed into another forest type, and under extreme conditions, a new non-forest ecosystem state may emerge (e.g. from forest to savannah). Normally, the new ecosystem state would have poorer biological diversity and fewer ecosystem goods and services. Under such circumstances, plantations and other modified forests will be more affected by climate-related disturbances and risks than primary forests, because of their generally low biodiversity (Kirilenko and Sedjo, 2007).

Climate change is likely to affect population dynamics, timing of reproduction or migration and growth of forest ecosystem components. Increased temperature causes faster rates of photosynthesis but only up to the tolerance limit. Variations in precipitation can affect the growth and survival of species, including even extinction. Adaptation of species to climate change effects can be through phenotypic plasticity (acclimatisation), adaptive evolution, or migration to suitable sites. Without these, the number of species will be reduced and they will eventually be extinct (Noss, 2001).

Phenotypic plasticity: This is the ability of an organism to change in response to stimuli or inputs from the environment and involves a change in gene expression or gene-product use (morphological, physiological and behavioral traits always being products, in part, of gene expression (West-Eberhard, 2008). For example, there may be changes in physiology due to adjustments of optimal temperature for photosynthesis. There is however a limit to plasticity depending on the ranges of movement. Range shifts can be by altitude or elevation. Divergence in plasticity has a major role in adaptation to spatial climatic gradients, signifying that evolving plasticity can also be important in adaptive responses to climate change through time. Furthermore, genetic plastic responses to the environment can be a key predictor of vulnerability of species to climate-driven deterioration or extinction (Kelly, 2020). Changes in physiology such as timing of life cycle events such as flowering or budding can change with changing season and environmental conditions. This affects synchronisation with other organisms e.g. pollinators.

Changes in species composition: Under changing climate some plants can become rare or extinct while others become abundant. There may also be a shift in the dominant species. This is facilitated by the species ability to germinate, survive and reproduce under the conditions. In this regard, the functional germination traits, growth rate and water use efficiency (WUE) and how they interact with the environment determines ability to thrive. In some cases, survival will depend on ability to tolerate stress. Ecosystem resilience is directly related to redundancy of functional species which is common in complex forest ecosystems. Redundancy offers protection to counter changing climatic conditions and species that have limited functions under one set of conditions may turn into driver species under a changing circumstance (Thompson et al., 2009).

4.2.3 Species resistance to climate change

Resistance and resilience of species in an ecosystem are a function of species richness and diversity, due to the redundancy given by multispecies membership in crucial functional groups (Walker, 1995). Ecological resistance is also promoted by the diversity of species within groups together with diversity of functional groups (Noss, 2001). In this regard, resistance becomes linked to the concept of stability because a forest ecosystem can remain within a range of variation around a specified ecosystem state in response to minor perturbations. Stability reflects the ability of an ecosystem to sustain a vibrant balance over time while resisting modification to a different state. A stable ecosystem can persist if its capacity to absorb disturbances remains unchanged over long periods of time (Thompson et al., 2009).

4.2.4 Eco-physiology of tree growth

Atmospheric conditions such as temperature, solar radiation, air, light, precipitation, wind, atmospheric humidity and lighting affect distribution of vegetation and growth. Solar radiation is important for tree growth through illumination, heating, chemical and electrical effects on the surface of the earth. The most important effects of solar radiation on tree growth are light and temperature. Light is one of the most important requirements for plant growth and changes in light intensity affects plant growth, morphology, photosynthetic capacity, various aspects of physiology and biochemistry and ultimately productivity (Dai et al., 2009). Light intensity affects tree growth directly together with the duration of light and its quality. Light quality cannot be manipulated but light intensity can be manipulated through thinning and selective harvesting to control species dominance and differentiation into crown classes. Photosynthesis is an important process in plant biomass production and its activity varies with wave lengths of the absorbed light spectrum (Pan and Guo, 2016).

A suitable temperature is required for many plants physiological activities including respiration, transpiration and photosynthesis. Optimum air temperatures facilitate seed germination. Higher air temperatures increase soil microbial activities resulting in increased organic matter decomposition, the release of nutrients and the formation of humus. Temperature also affects enzymatic activities and cell division and expansion, which are generally more sensitive to environmental variability than respiration and photosynthesis (Körner, 2003). In this regard, projected climate change through rising temperature is likely to affect all plant physiological processes.

Water determines the global distribution, seed germination, growth and development of vegetation and can be too little, too much or just enough. In plants, water constitutes approximately 90% of the cell wall and 80% of protoplasm and is an important constituent of cell sap and cell vacuoles. Water is also essential for all critical plant processes including nutrient absorption and translocation of sucrose to different parts of the plant. Under a changing climate, some plants may not grow well under the new precipitation regimes, while others thrive. Furthermore, more sensitive species are more affected by climate-related disturbances such as cyclones, fires and storms.

4.2.5 Intra- and inter-species genetic variation

Genetic diversity defines the variation of essential species eco-physiological tolerances by governing inter-specific competitive interactions, that constitute the fundamental determinants of potential species responses to climate change concurrently with dispersal mechanisms (Halpin, 1997). In a changing climate, genetic diversity in forested ecosystems determines their capacity to adapt based on *in situ* genetic variation contained in the population of each species (Bradshaw, 1991).

Furthermore, genetic diversity controls inter-specific competitive relationships that constitute fundamental determinants of potential species responses to change, in conjunction with mechanisms of dispersal (Halpin, 1997). After a disturbance, differences in survival due to natural selection pressures can reduce the gene pool to promote genotypes that survive best after a disturbance e.g. climate event, toxic chemicals, pest infestations or other types of interspecific competition or soil nutrient and water deficits.

The effects of functional diversity on the productivity of an ecosystem can be quantitatively explained by the sampling effect model and the niche differentiation model. The sampling effect model predicts that the increase of diversity in an ecosystem increases the productivity rate whilst decrease in diversity results in a decrease in productivity rate (Goswami et al., 2017). This shows that dominant competitors in a forest ecosystem (regional species pool) play a critical role in ecosystem functioning where increase in diversity results in control of ecosystem function by dominant species due to their increased likelihood of existing in a diverse system because they are the best competitors within the system (Huston, 1997; Thompson et al., 2009). On the other hand, niche differentiation model assumes that a habitat is spatially or temporally heterogeneous or diverse and that the species residing in a particular habitat exhibit diverse traits which ultimately determine their response to this heterogeneity (Goswami et al., 2017). The model predicts species interactions through interspecific variation as direct responses to the competition for resources. This includes the concept of facilitation, where the capacity of another species to reproduce and survive is enhanced by one or more species (e.g. mutual relationships between ectomycorrhizal fungi on tree roots or legumes) (Thompson et al., 2009).

4.3 Stress physiology

Homeostasis is the ability of plants to maintain a constant internal environment in response to environmental changes.

Plant stress is a condition where some biotic and abiotic factors induce adverse effects on the physiology of a plant. This is an abrupt alteration from some optimal environmental condition where homeostasis is maintained to some suboptimal condition which disrupts this initial homeostatic state. Plant stress can be divided into two primary categories:

Abiotic stress represents some physical (e.g. light, temperature) or chemical offense imposed by the environment on a plant. Plants are continually affected by several abiotic stresses that reduce productivity and growth such as salinity, drought, temperature extremes, heavy metal toxicity, nutrient deficiency, Ultraviolet B radiation and high-light intensity.

Biotic stress represents biological offenses (e.g. insect pests, pathogens) to which a plant may be subjected throughout its lifetime (Figure 11).

Some plants may exhibit one or more metabolic dysfunctions after being injured by a stress factor. The injury may be temporary if the stress is moderate and short term and the plant is able to recover after removal of the stress. However, severe stress may hinder important growth processes such as flowering, seed formation and seed germination and can induce senescence and eventually death of the plant. These plants are regarded as **susceptible**. Some plant species have mechanisms to escape stress for example, the ephemeral species, the short-lived species and some desert plants.

Ephemeral plants complete their life cycle before the onset of the dry season by germinating, growing and flowering/reproducing immediately after the seasonal rains. They therefore do not experience drought stress or low temperatures. The plants endure environmental stress through **stress avoidance**. Although the stress is present in the environment, avoidance mechanisms decrease the stress impact. Other plants can tolerate certain stress factors and are regarded as being **resistant** to stress. Resistance calls for the organism to exhibit the capacity to adapt or to adjust to stress.

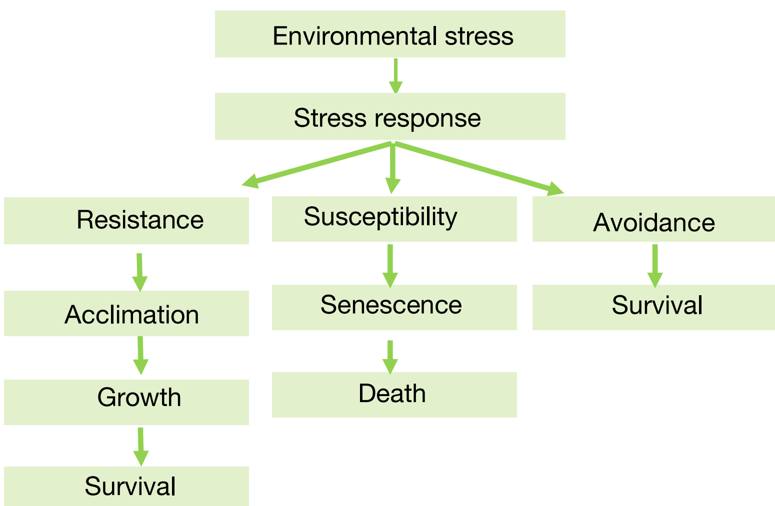

Figure 11. The effects of environmental stress on plant survival (Source: Hopkins and Huner, 2009)

The undesirable effect of some biotic and abiotic stress factors is a result of their anticipated or probable increased rate of recurrence factors such as heat and drought, or insect pests and pathogens. Climate change is also expected to cause losses of biodiversity, mainly in more marginal environments.

Excessive light intensities influence generation and accumulation of reactive oxygen species (ROS) as a result of altered antioxidative system which can turn into oxidative stress (Tiwari et al., 2002). Stresses to environmental factors are revealed at the molecular level as ROS are exceptionally responsive in nature due to their ability to interact with some cellular molecules and metabolites, causing irreversible metabolic failures and death. The ROS include Superoxide ($O2^{\bullet-}$), singlet Oxygen ($^1O_2$), Hydroxyl radicals ($OH^{\bullet}$) and Hydrogen peroxide (H_2O_2) (Yadav and Sharma, 2016). Plants possess advanced enzymatic and non-enzymatic scavenging pathways or detoxification systems to respond to the deadly impacts of ROS accumulated under abiotic stress conditions (Table 5). In this regard, ROS performs critical roles in abiotic stress responses of crop plants by activating stress-responses and defence pathways. The manipulation of ROS levels offers an opportunity for enhancing stress tolerances of crop plants given a variety of unfavourable environmental conditions (You and Chan, 2015).

Specific ROS-producing and scavenging systems in plant cells are located in various organelles and the ROS-scavenging pathways from the various cellular compartments are coordinated. Low levels of ROS operate as signalling molecules stimulating abiotic stress tolerance by controlling expression of genes responsible for defence. Furthermore, plants with higher levels of antioxidants (constitutive or induced) have higher resistance to diverse environmental stresses.

Table 5. Plant scavenging pathways to respond to the effects of reactive oxygen species

Enzymatic (Noctor et al., 2014; You and Chan, 2015)	**Non enzymatic (Gill and Tuteja, 2010)**
Monodehydroascorbate reductase (MDHAR)	Ascorbate (ASA)
Catalase (CAT)	Glutathione (GSH)
Ascorbate peroxidase (APX)	Carotenoids
Superoxide dismutase (SOD)	Tocopherols
Dehydroascorbate reductase (DHAR)	
Glutathione reductase (GR)	
Glutathione S-transferase (GST)	
Glutathione peroxidase (GPX)	
Peroxidases (POX)	

4.4 Applied plant genetics and tree improvement

Genes in a plant determine the type of qualitative or quantitative traits it will have. Plant breeding is the skill of manipulating plant traits in order to achieve the desired traits. Many techniques can be used to accomplish plant breeding and the techniques range from simple selection of plants with desirable characteristics to propagate, to methods that make use of genetics and chromosome knowledge, to more complicated molecular procedures. Plant breeders strive to create a specific outcome of plants and potentially new plant varieties (Hartung and Schiemann, 2014). Plant breeding can be used to improve nutritional quality of human and animal food. In a changing climate, plant breeding should focus at new crop varieties that are drought tolerant, higher yielding, insect pest/pathogen resistant or adapted to different environments and growing conditions to ensuring food security. During plant breeding, the use of biotechnology can give advantages such as:

- Protection of threatened species against disease or climatic threats;
- Eradication of invasive species;
- Increasing genetic diversity in small populations of threatened species;
- Restoration of proxies of extinct species; and
- Remediation of degraded ecosystems, or replacing the products.

In forestry, tree breeding is based on selection criteria that is based on coexistence, persistence (recruitment), herbivory, niche evolution and population response to invasive species and herbivory. Similarly, developing new crops from the wild also needs a basic appreciation of the adaptations, reproductive biology, variation patterns and importance of natural enemies. Assembling genetic resources and preliminary domestication phases require some knowledge of genes that control necessary traits such as seed retention at maturity. The use of quantitative genetics can give yield improvements or adaptation of a particular crop to regional and agroecosystem space (Jain, 1992). Several plant breeding methods have been used and they vary from traditional selective methods to genome editing. Some of these are:

Line breeding (autogamous crops): This is used for plant varieties e.g. barley, wheat, oats and peas that usually breed through self-pollination. Such plants are fertilised by their own pollen, even before they leave the flowering stage. The breeding involves targeted crossbreeding of two parental lines, complementing each other as much as possible in terms of the desired properties. Plants that display the desired performance traits are selected after several selection cycles, to build a new variety from the best plant e.g. in terms of plant health, yield and quality (selection). Self-fertilisation is used to breed the plant resulting in very uniform plants (homogeneous). The process can be quickened by using the double haploid technique, where pollen cell cultures are created for tissue growth which eventually grows into a plant. A reduplication of the chromosome set creates a homozygotic doubled haploid plant. This technique requires less time than the traditional line-breeding with repeated self-fertilisation.

Cross breeding: This is an original and fundamental type of plant breeding where parental crossing is done using parent plants with the desired characteristics to create a filial generation. The desired properties can include better yields, insect pest/pathogen resistance or drought resistance. Some of the new plant breeds or cultivars are propagated by asexual means while others are propagated by seeds. Seed propagated cultivars require specific control over seed source and production procedures to maintain the integrity of the plant breeding results. Isolation is necessary to prevent cross-contamination with related plants or the mixing of seeds after harvesting. Isolation is normally accomplished by planting distance but in certain crops, plants are enclosed in greenhouses or cages. The cross breading of *Eucalyptus* and *Pinus* species in southern Africa has targeted traits of disease and pest resistance, drought and frost resistance and faster growth (e.g. van den Berg, 2017; Zimbabwe Forestry Commission, nd).

Selection breeding/ screening: This involves purposeful selection of seed from the largest and most productive plants. These seeds are then sown again the following year, while all other plants are excluded from the breeding process to allow the desired plant properties to affirm themselves more and more over time. Traditionally, crop yields were increased through this method. Although the early farmers did not know genetic principles, they managed to carry out selective breeding through accurate observations and through their experiences.

Hybrid breeding (mostly allogamous crops, some autogamous crops): Hybrid breeding is used worldwide for many crops. To breed hybrid seeds, two homozygotic but as genetically different as possible parental lines are crossed with each other. Because of the heterosis effect, the resulting heterozygous offspring ("hybrids") are much more productive (higher yields) than both parents. The hybrid vigour makes plants bigger, more fruitful and more resilient than their parental lines. The main drawback is that it is maintained only for one generation.

Marker technology: Plant characteristics are analysed using molecular markers. Genetic markers are short segments of Deoxyribonucleic acid (DNA) with a known location within the genome and are associated with a trait of interest. By using molecular markers, traits (genes) can be quickly and easily identified early in the plant's development. For example, fungal resistance can more easily be determined in seedlings. Molecular markers make plant breeding significantly more efficient.

Genomic selection: This is an advancement of the traditional marker technology, giving a better and more reliable selection when selecting optimal crossing partners and future varieties. Because the cost of detecting genetic markers has significantly decreased, several markers can simultaneously be analysed from one plant by creating a marker profile with several thousand markers for each individual plant. Each plant has a specific marker profile, comparable to a fingerprint. Statistical and mathematical models can be developed for predicting the breeding value of the plants and their suitability for the subsequent development of varieties, based on the marker profiles of seed or young plants. Complex software is used for determining the plants that are most promising for crossing from the marker profiles of other individual plants not tested in the field. Furthermore, complex characteristics that are not based on individual genes but on networks of genes can be analysed and accurately adapted using genetic research.

Tissue and cell culture: Cell and tissue cultures play an important role in the genetic transformation of plants offering extensive plant genetic variation which can be incorporated in plant breeding programmes. They allow quick generation of a genetically identical offspring from a single plant in the laboratory. Tissue fragments or individual cells are taken from a plant and grown on special growth media in the laboratory, where the cells can grow and further divide. Eventually, an entire plant is regenerated from the laboratory-grown tissue. Mutants with useful agronomic traits, such as drought resistance, or salt tolerance or pathogen/insect pest resistance can be isolated using in vitro selection over a short period (Jain, 2001). However, different crops/plants and tissue types require specific procedures that are unique to each of them.

Genome editing: The term "genome editing" includes a number of different methods that can change individual building blocks of DNA in a precise and targeted manner. The new plant varieties can be bred more rapidly and precisely than ever before and in most cases no genes are incorporated. Examples are Zinc fingers, TALEN and CRISPR/C. Genome editing can be used to ensure yield progress, improved resistance of plants against pathogens, insect pests and abiotic stresses, produce high quality seeds, reduce the use of resources and boost energy and nutrient content.

Genetic engineering: This is a highly targeted method to provide plants with new genetic properties. It involves transferring genes or other sections of the genetic material (DNA), for instance from bacteria to the genetic material of plants. Once the gene involved in the manifestation of a certain characteristic has been identified, the second step is to develop plant varieties that possess exactly this characteristic. Genetic engineering methods enable a very targeted approach: only the gene for the new, desirable characteristic is transferred directly to the crop. Genetic engineering methods can be used to insert genetic material into individual genes or DNA sequences from other organisms. This allows for the targeted transfer of the desired characteristics. It is also possible to "turn off" certain genes. Other methods include phynotyping breeding and clone breeding (vegetatively propagated crops).

4.5 Monitoring of species growth, mortality and recruitments

The responses of forest ecosystems to climate change are driven by local site conditions and the adaptive potential of the trees. Growth, mortality and recruitment in forest ecosystems are a function of environmental conditions and disturbances. Species growth in forest ecosystems can be monitored through measurements of diameter at breast height, height, shoot length, number of shoots, crown size, branch size, leaf size and leaf area index. Tree mortality refers to the death of trees that is not a result of harvesting and provides a measure of forest health. A healthy forest ecosystem sustains its processes, function, structure, productivity, composition and resilience over time and space. An assessment of these conditions depends on the existing knowledge and can be affected by cultural values, human needs and land management objectives. Premature death of healthy trees can be caused by factors such as drought and other extreme weather events, or by climate-induced outbreaks of insect pests and pathogens in vulnerable forests (FAO, 2020a).

Mortality of trees in forest ecosystems is a result of complex processes resulting from interactions between biotic and abiotic factors. The rates of mortality reflect the health of a forest ecosystem. Climate change is expected to increase mortality rates in forests, especially in areas where extreme weather events such as severe drought and cyclones become more common. Droughts cause premature death of healthy trees. Increased tree mortality affects forest ecosystem functioning, C balance, timber supply and forest age structure. Mortality of different species causes a change in the structure and composition of the forest. C budgets are also affected at local, regional and global levels because standing trees take up CO_2 through photosynthesis, whereas dead trees release the CO_2 when they die and decay on the forest floor.

When climatic conditions go beyond physiological thresholds of species or if the climatic conditions trigger insect pest outbreaks, tree mortality can occur at regional scale. Extensive mortality events and reduction in forest areas have been observed after major drought and heat waves, sometimes associated with insect pests and pathogen outbreaks (Anderegg et al., 2015). In some cases, it may be difficult to attribute mortality of trees to climate change due to the complex interaction between climatic variation and forest ecological processes. In relation to insect abundance, climate change can either promote outbreaks or disrupt trophic interactions and decrease the severity of outbreaks. There is good evidence that some recent outbreaks of bark beetles and defoliating insects are influenced by climate change and are having a large impact on ecosystems as well as on communities of forest insects (Pureswaran et al., 2018). Some parts of sub-Saharan Africa are expected to be affected by frequent droughts and this can increase tree mortality.

To reduce tree mortality, options such as assisted migration are used. Assisted migration defines a variety of concepts and practices at several scales, but three types of assisted migration can be distinguished, each with a different level of risk and uncertainty (Ste-Marie et al., 2011):

- **Assisted population migration:** Humans assist movement of populations within a species' known range—*Lower risk*;
- **Assisted range expansion:** Humans assist movement of species to areas just out of their known range, facilitating or mimicking normal range expansion—*Intermediate risk*; and
- **Assisted long-distance migration:** Humans assist with movement of species to areas far from their known range (beyond areas reachable through normal seed dispersal)—*Higher risk*.

Ogden and Innes (2007) suggested several adaptation options that can reduce tree mortality and improve adaptive capacity in boreal forests and include:

- Maximising forested areas by quickly regenerating any degraded areas;
- Allowing natural regeneration in forests after a disturbance;
- Enhancing the recovery of forest after disturbances;
- Maintaining or restoring natural fire regimes where historical fire cycles have been disrupted by past fire exclusion and made them more vulnerable to severe future fires;
- Minimising the fragmentation of habitat and maintaining connectivity; and
- Maintaining a diverse and heterogeneous landscape (mixture of stand age, composition and structure) by applying various silvicultural techniques, assist changes in the distribution of species by introducing them to new areas.

Monitoring is based on forest inventory, assessment of physiological mechanisms of mortality, use of remote sensing and modelling.

4.6 Tree phenology feedback to climate change

Phenology deals with studying seasonal timing of plant and animal life cycles relative to weather and climate. Climate change results in long-term consequences for ecosystem processes including biogeochemical cycles, productivity, evapotranspiration, runoff, mineralisation, decomposition and other processes at local, regional and global levels (Richardson et al., 2013). Global temperature increases, shifting rainfall patterns, rising atmospheric CO_2 concentrations and other aspects of global change affect the timing of phenological processes of species and ecosystems. Changes in phenological characteristics is a response to seasonality of a plant's environment, assumed to be a product of natural selection. The timing of life-history incidents is based on selection pressure facilitating evolution idiosyncratic phenology of the plant. Abiotic pressures can be in the form of unfavourable seasonal temperatures or erratic rainfall whilst biotic pressures can be in form of seasonal presence of pollinators, dispersal agents and predators. Phenological shifts are mediated by the degree of warming in spring, beginning of cold temperatures, extent and duration of winter cold and photoperiod mediate phenological shifts (Figure 12).

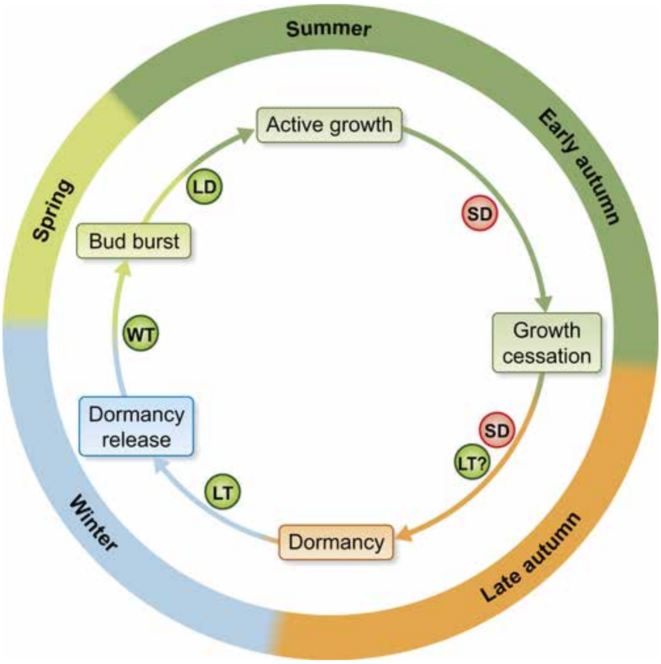

Figure 12. Annual tree growth cycle. LD=long days, LT = Low temperatures, SD = Short days, WT = Warm temperature (Source: Singh et al., 2017)

The alterations of plant annual cycles and the extension of some seasons affect many ecological processes and sectors such as forestry, agriculture, health and the economy at large. Tree phenology also depends on water availability in addition to other environmental characteristics. Flowering and leaf emergence are some of the processes likely to have phenological shifts after seasonal changes due to climate change. In African forests, there are several factors affecting plant growth with photoperiod being the dominant factor controlling the onset and end of vegetation growing season (Adole et al., 2019). The shifts can also affect pollinator cycles which may not be in synchrony with flowering. Shifting of tree phenology is manifested by changes in the timing of bud bursting, flowering, fruiting, leaf-out, leaf-expansion, abscission, fertilisation, seed-set, fruiting, seed dispersal and germination or senescence. The timing of fruiting is also important for controlling the abundance and variety of obligate frugivores.

Climate warming is consistent with the various indices that indicate changes in the plant phenological patterns such as date of frost, length of growing season and growing degree totals and many more complex indices. Indirect indices for assessing tree phenology include degree days, day length, number of frost-free days and spring indices. Temperature influences the development timing of plants and in this regard, global climate change has been associated with significant alteration of the plant phenological patterns. Changes in temperature are represented by pheno-climatic measures that are appropriate for different stages of plant development. Cold temperatures that are followed by high temperatures during the dormancy period stimulate spring tree phenology. The trees need cold temperatures during the winter period to break endo-dormancy and then enter the phase of eco-dormancy during which the rate of ontogenetic development increases with increasing air temperature resulting in budburst. Therefore, inadequate cooling may reduce bud growth and therefore delay budburst (Chen et al., 2007). Furthermore, monitoring of phenological processes can be done using satellite remote-sensing, air-borne remote sensing including the use of drones and aerial laser scanner systems for ecosystem production and atmospheric CO_2 concentrations to provide indications related to C uptake through photosynthesis.

Activity 4.3 Revision (15 Minutes)

1. Explain the impacts of climate change on forest ecosystem functions;
2. Explain forest species respond to climate change;
3. What are the ways in which forest species adapt to climate change?
4. What causes accumulation of ROS?
5. What is the advantage of genetic diversity in ecosystem functioning? and
6. What are the methods that can be used to maintain or improve forest species diversity?

Summary

In this session, we learnt 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, $CO_2$are important factors for plant growth and development and climate change alters optimum requirements for plant growth-inducing stress. High light intensities influence generation and accumulation of ROS caused by the alteration of antioxidative system which can lead to oxidative stress. Plant stress is a condition where some biotic and abiotic factors induce adverse effects on the physiology of a plant. 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, migrate to suitable habitats or become extinct. Adaptation of species to climate change effects can be through phenotypic plasticity (acclimatisation), adaptive evolution, or migration to suitable sites. Tree phenology depends on optimum temperatures, water availability in addition to other environmental characteristics. Plant breeding can be used to maintain and improve a selection of plants with desirable characteristics using genetics and chromosome knowledge, and even more complicated molecular procedures. 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.

4.7 Forest resilience to climate change

Resilience is defined in several ways but the meaning remains the same, that of a system's capability to recuperate after a disturbance. The United Nations Office for DRR 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.

Learning Outcomes

Learning Outcomes

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

i. Discuss interventions of enhancing resilience of forest ecosystems to cope with impacts of climate change and variability;
ii. Explain guiding principles for landscape restoration;
iii. Explain applicability of thematic elements of SFM;
iv. Determine appropriate forest-based initiatives that could help forests and people to adapt to climate change;
v. Design appropriate forest-based CCA interventions;
vi. Analyse the challenges to CCA; and
vii. Evaluate the role of forest ecosystems services in the adaptation of vulnerable social systems.

Activity 4.4 Brainstorming (10 minutes)

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

Forest resilience can also be linked to resilience approach to sustainable development which puts emphasis on building capacities to tackle unexpected events. The approach considers interaction of people 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. People also transform the biosphere in numerous ways through activities such as timber poaching, agriculture, settlements and road construction and expansion of cities. A resilience thinking approach attempts to explore best management options for these interrelating systems i.e people and nature (social-ecological systems) to guarantee a sustainability and resilient provision of necessary ecosystem services that sustain human existence. Biggs et al. (2015) identified seven principles critical for fostering resilience in social-ecological systems and these include:

- Maintenance of diversity and redundancy;
- Management of connectivity;
- Management of slow variables and feedbacks;
- Fostering complex adaptive systems thinking;
- Encouraging learning;
- Broadening participation; and
- Promotion of polycentric governance systems.

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 cover with larger and less fragmented being better than fragmented and small in addition to the character and condition of neighbouring landscape.

Adaptation measures in forestry depend on a variety of related factors, such as forest type, management goals, climatic threats and non-climatic pressures. Forest ecosystems will be altered by global climate changes, because biophysical rates and physiological tolerances of species are likely to be exceeded. There is therefore a need to restore or maintain the resilience of a forest as an important societal CCA measure.

4.7.1 Forest restoration and rehabilitation of degraded forests

The Global Landscapes Forum (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. Development models that improve human well-being without damaging the environment are needed to curb problems associated with deforestation, desertification, water shortages, biodiversity loss, pollution and climate change (Besseau et al., 2018). Degraded landscapes affect livelihoods and wellbeing of some 3 billion people across the world, costing 10% of the global economy. The global landscapes community targeted to restore more than 2 billion ha of degraded land worldwide, a mark greater than South America. The initiative requires annual investment by private and public sectors of up to US$ 350 billion (WRI, 2014). The World Business Council for Sustainable Development advocated for land degradation neutrality, encouraging a business case for halting land degradation (WBCSD, 2015).

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 (CBD), the United Nations Convention to Combat Desertification (UNCCD), theUNFCCC and the SDG 15 (Protection, restoration and promotion of the sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss) (UN, 2015).

By 2018, more than 50 countries and other entities including India, Ethiopia, Mexico and Peru had committed to restore more than 160 million ha.

There is a global recognition 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. This was supported by the New York Declaration on Forests which outlines other ambitious goals, including elimination of deforestation from agricultural commodity supply chains and strengthening forest governance. The Great Green Wall (GGW) is a Sahel and Sahara Initiative that received at least US$ 14.326 billion in new funding in 2020 to fast- track efforts to restore degrading land, save biological diversity as well as create green jobs and build resilience of the Sahelian people (UNCCD, 2020). The GGW extends up to 156 million ha in 11 African countries (Burkina Faso, Chad, Djibouti, Eritrea, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal and Sudan).

Other initiatives include the African Forest Landscape Restoration Initiative (AFRI100) that targets to restore 100 million ha of degraded landscapes by 2030 in Africa (FAO, 2020c). Twenty-six 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 and these include: Ethiopia (15), Sudan (14.6), Cameroon (12), Mali (10), Democratic Republic of Congo (8), Tanzania (5.2) and Kenya (5.1). The rest of the countries (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) target areas below 5 million ha (AUDA-NEPAD, 2020).

The AFRI100 initiative is supported by nine financial partners and 12 technical partners. Support includes the World Bank Africa's Climate Business Plan (US$ 1 billion) and nearly US$ 481 million from private sector 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).

Restoration activities in Africa

Ghana: Restoration effort that includes establishing commercial Teak plantations and reintroducing native tree species, having planted 190,400 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).

Forest and Landscape Restoration (FLR) was initiated in 2003, by the global partnership of governments, organisations, research institutes, communities and individuals aiming at the restoration of degraded forests and their surrounding landscapes. FLR is defined as a process targeting to regain ecological functionality and enhance human well-being in deforested or degraded landscapes. FLR aims at reversing the degradation of soils, agricultural areas, forests and watersheds to regain their ecological functionality. In this regard, FLR aims at restoration of ecological integrity and improving productivity and economic value of degraded forest landscapes, which may comprise other land uses in addition to forests. FLR contributes to SDGs 1 ("no poverty"), 6 ("clean water and sanitation") and 15 ("life on land") while encompassing internationally 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. FLR 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 (IISD, 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). 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 development of mosaics of complementary, productive land uses (Winterbottom, 2014).

About two 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 FLR 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.

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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 FLR are outlined in Table 6.

Table 6. Principles of Forest and 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 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 to restore multiple ecological, social and economic functions across a landscape and 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, traditional and indigenous knowledge and applies that information in the context of local capacities and existing or new governance structures.
Manage adaptively for long-term resilience	FLR enhances resilience of landscape and its 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: http://www.bonnchallenge.org/content/forest-landscape-restoration

Benefits of restoration include the following:

- Environmental and social benefits of clean water and food security;
- Conservation of biodiversity and climate protection;
- Indirect and direct economic benefits-jobs can be created in tree nurseries, on the land, farms and timber industries;
- Costs of repairing flood damage to infrastructure, dredging lakes and rivers to remove silt are removed;
- 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; and
- Makes landscapes more hospitable to endangered species and more resilient under climate change.

4.7.2 Adaptation actions in forest management

The best management practice for forest ecosystems would be to leave them intact. This may not be 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 the forests. The activities that can promote some improvements in forest management systems are mainly based on the control of deforestation, reforestation and afforestation. Furthermore, the forest stock needs to be correctly measured, monitored and reported (Thompson, 2011).

Forest management involves the design and implementation of caring and utilising forests and other wooded lands to meet particular economic, socio-cultural and environmental objectives. Forest management 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 specific socially or economically valuable species or groups of species for improved productivity. 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).

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 the reducing of rotation age (Yousefpour et al., 2020; Cosofret and Bouriaud, 2019). Thinning is a silvicultural operation that focuses on stimulating growth of large residual trees, improves drought resistance and provides greater resilience to future climate-related stress (Kerhoulas et al., 2013). The reducing of the rotation period of tree crops can decrease their exposure time to risk and also reduces the risk of wind throws by limiting the height to be reached. These adaptive management techniques generally reduce uncertainty and allows better adapted species to be replanted (Cosofret and Bouriaud, 2019). Nyika (2021) suggested a five-step implementation plan on sustainable ecosystem management based on adaptive management and holistic consideration of ecological resources.

Application of the principles and practices of SFM gives a sound basis for addressing climate change challenges. 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 of the 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.

The management of forests based on the concept of SFM is dynamic and evolves 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. 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. There are seven thematic elements designed as non- legally binding instruments of SFM (FAO/ITTO/INAB, 2003) (Table 7).

Table 7. 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 C sequestration in forests, other wooded lands and trees outside forests and assign forests for different purposes.
Forest biological diversity	Covers the diversity of life forms, genetic diversity and species ecological roles. Biological diversity in forest ecosystems allows species to evolve and dynamically 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, pathogens, 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 the 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)

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, 2020d). However, the 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 SFM (FAO, 2016c). As atmospheric GHGs increase, forest C sequestration becomes an important mitigation measure but also 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).

Activity 4.4 Group discussion (15 Minutes)
What are other methods or interventions carried out in your country aimed at enhancing the resilience of the forest ecosystem to respond to the challenges of climate change and climate variability?

4.7.3 Creation/expansion and adaptive management of parks/reserves, protected areas and biodiversity corridors

Protected areas are represented by geographical spaces that are clearly defined, dedicated and managed, through legal or other effective ways, to realise the long-term conservation of nature with related ecosystem services and cultural values (Gross et al., 2016). Protected areas offer a broad array of ecosystem services (provisioning, regulation, supporting and cultural services) that benefit human populations and support national and global biodiversity conservation efforts. Adaptive management is an iterative process that serves to reduce uncertainty, build knowledge and improve management over time in a goal-oriented and structured process (Allen and Garmestani, 2015).

The areas are remnants of large natural habitats in many regions, extending over 14% of the global land area. They are an essential part of the global reaction to climate. They also help societies cope with the impacts of climate change through provision of essential services necessary for human survival. Six global categories of protected areas are given in Table 8.

Protected areas help protect vulnerable communities by reducing risks and impacts from extreme climatic event such as:

- Floods-protected areas provide space for dispersion of floodwaters whilst the vegetation absorbs impact;
- Landslides -vegetation stabilises soil and snow reducing or stopping slippage;
- Drought and desertification-protected areas reduce grazing pressure and protects water and watersheds;
- Storm surges-mangroves, coral reefs, marshes and barrier islands can block storm surges; and
- Fire-protected areas limit the encroachment into protected areas (Dudley et al., 2009).

Climate is expected to affect protected areas in Africa by affecting water resources (decreased river flow, decreased surface warming and stratification in large lakes and decreased soil moisture due to droughts), terrestrial ecosystems (increased wildfires, reduced tree density and shifts in species range), coastal and marine resources (decreased productivity in coastal reefs), food and livelihoods (reduced productivity for fruit-bearing trees, reduced fisheries, mainly in large lakes and increased cases of diseases such as malaria. Given all these effects, adaptation to changing rainfall patterns is inevitable. Partnerships have been used as management options to improve species by addressing the hostile effects of socio-political boundaries on conservation and managing conservation and planning at biologically relevant scales (IPCC, 2014; Dudley et al., 2009).

Table 8. Categories of protected areas in the world

Category	Description
Ia Strict nature reserve	Areas strictly protected for their biodiversity and also sometimes geological/geomorphological features, human use and visitation allowed, controlled impacts and safeguarding conservation values.
Ib Wilderness area	Large primary or slightly modified areas, maintaining natural character and influence. Protected and managed for conservation of natural state without permanent or substantial habitation by humans.
II National park	Large natural or near-natural areas guarding large-scale ecological processes composed of representative species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
III Natural monument or feature	Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
IV Habitat/species management area	Areas for protecting specific priority species or habitats. Most of them require regular, dynamic interventions to satisfy the needs of specific species or habitats, although not a requirement of the category.
V Protected landscape or seascape	Interaction of nature and humans over time produced a distinct character with substantial ecological, cultural, biological and scenic value. Safeguarding the integrity of the interaction is crucial for the protection and sustainability of the area and associated values.
VI Protected areas with sustainable use of natural resources	Conservation of ecosystems, simultaneously with associated traditional natural resource management systems and cultural values.

Source: Gross et al. (2016)

Apart from C storage in protected areas, some of the specific benefits include:

- Maintaining ecosystem integrity and biodiversity;
- Increased resistance, resilience and reduced vulnerability of livelihoods against climate change;
- Source of clean water and improved water flow;
- Source of sustainable food for communities;
- Prevention of land use change from forests to other land uses;
- Conservation and rebuilding of fish stocks in marine and freshwater areas;
- Reduction of impacts of extreme climatic events, such as floods, storms, droughts and sea-level rise;
- Absorb flood impact with natural vegetation and provides space for dispersing floodwaters;
- Stabilise soils as well as prevent and mitigate natural hazards such as floods, avalanches, landslides and erosions; and
- Provide benefits such as NTFPs (medicines, fruits, berries, mushrooms, fibres) to local communities.

4.7.5 Development of forest fire management plans

Fire management is a central component of SFM, which sequentially should be part of the broad land use plans, considering the views of all stakeholders. Forest fires are sometimes beneficial and have been part of the African savannah landscape since time immemorial. Most African woodlands have evolved with fire and rely on fire to regenerate. Sporadic fires can also keep down fuel loads that feed larger, more destructive bushfires. The degraded forests and woodlands are however, subjected to annual burning or even semi-annual. Forest fires also kill people, destroy livelihoods and homes, wildlife and their habitats and pollute water catchments.

Climate change increases fire risks in forest ecosystems. For example, Mediterranean Europe was predicted to have greater fire danger due to extended dry season with higher fire risk that could result in larger, more intense and recurrent fires.

Fire management promotes land management objectives, by keeping and safeguarding life, property and resources from fire through the prevention, detection, control, restriction and suppression of fires. In the process, fire management plans provide statements of fire policy and prescribed action to protect people, prevent fires, protect property and forests from fire and to use fire to achieve forest management and other land-use objectives in a specific area. Effective fire management programmes should reflect the fire history and the ecology of the area.

Fire management is an essential part of forest management that includes planning, preventing and fighting fires to protect people, property and the forest resource base. A fire management plan is a statement, for a specific area, of fire policy and prescribed action to prevent fires, protect the people, property and forests from fire and using fire to achieve forest management and other land-use objectives. The plan is an essential element for the prevention, suppression and management of fire within forests and adjacent lands and must be part of the existing forest management plan. The plan identifies and integrates all wildland fire management and related activities (wildfire and prescribed fire) within the context of approved land/resource management plans. The plan is complemented by other plans such as prevention plans, preparedness plans, pre-planned dispatch plans and prescribed burning plans to achieve fire management goals.

The cycle of fire management has components of fire prevention, fire detection, fire suppression and post-fire management activities (Figure 13). **Fire prevention** aims at minimising fire damages and avoiding unwanted fires, while maximising the environmental benefits of fire. Fire prevention includes public education/awareness/training, early response to fires, fire management plan, early warning and fire danger rating systems, reduction of hazards and law enforcement. Other activities include clearance of fire lines and fire breaks, controlled burning to limit fuel loads, good silvicultural practices e.g. selective thinning and planting and planting fire-adapted tree species in fire- prone areas.

Fire detection includes detection, communication and dispatch mechanisms. These can include: satellite-based systems, ground-based systems, observation towers, video-based systems and aerial surveillance. **Fires suppression** is about eliminating fires and reducing their impact. Methods include: direct attack, indirect attack and parallel attack. Activities include initial-attack strategies and tactics designed on the basis of local resources, local situations, cultural, economic and ecological objectives and policies. In suppressing fires, knowledge of the interactions between environmental factors and vegetation cover should be appropriately considered in the planning and implementation of fire use. Fire management plans and policies should also be adapted to changes associated with burning conditions, fuel and vegetation type or other fire risks imposed by climate change. **Post-fire management** entails collection of data after the fire, assessing fire impacts and reporting.

Figure 13. Fire management cycle

4.7.6 Silviculture for climate change

In forestry, activities such as diversification of species and management of invasive species have been used to manage forest areas. Silvicultural activities vary with management objective. To improve adaptive capacity, forest stands have been manipulated to match changing environmental conditions. Some of the activities include the following:

Shortening rotation cycles: Rotation length is the time elapsed between two final harvestings and is dictated by biophysical factors and the goals of forest management. Rotation lengths have been shortened for several species for example*, Pinus* species rotation length in Zimbabwe has been reduced from 35-40 to 22 – 25 years whilst in America, rotations were also shortened by 10 years (Curtis, 1997). In New Zealand, rotation was reduced from 40-50 to 25-30 years (Brockerhoff et al., 2008) and this can reduce risks associated with storms. In Sweden, a reduction of 10–15 years on Norway spruce (*Picea abies*) was recommended to decrease the risk of storm and root rot damage (Södra, 2012). Modifying rotation lengths affects thinning regimes, with potential impacts on a range of other forest values. Shortening rotation lengths implies fewer thinnings than those of existing rotation cycles and becomes more if the cycle is extended. Thinning schedules can be modified to stabilise forests against drought, storms and diseases and may also help capture added growth from CO_2 fertilisation (Bernier and Schoene, 2008). Selective thinning can also be done to remove weak, dead and suppressed trees to improve resource availability for the remaining trees. Furthermore, sanitation harvesting can also be done to remove diseased or susceptible trees to prevent future outbreaks and improve productivity.

In drought prone areas, seedlings can be planted with hydrogels just before the rainy season to improve field establishment and survival. Biodiversity should be conserved and protected at all levels (bioregional, landscape, local) and should include all elements (genes, species, communities). The focus of conservation can be those populations that are isolated, disjunct, source habitats, at margins of their distributions or refuge networks. These types of populations are generally representatives of pre-adapted gene pools that can be used for climate change responses and possibly become core populations under the changing climate conditions. There may be need to maintain seed trees. In other cases, uses of DNA technologies have the potential to improve crop productivity, nutrition or resistance to insect pests and pathogens. In forestry, breeding is mainly done for growth, resistance to drought, insect pests and pathogens and on coral species, the plant breeding can focus on resistance to warming oceans.

4.7.7 Pest management

A pest is any organism including vertebrates (ground squirrels, mice, baboons, rabbits, birds, etc.), invertebrates (insects, mites, spiders, etc.) and weeds while pathogens are microorganisms that cause plant diseases that are injurious to the trees. Forest pests damage both indigenous and exotic tree species with the exotics becoming more severely affected because of their commercial values and also because of absence of natural enemies in areas where they are introduced. Damage to forest species can be in form of defoliation, stem boring, root destruction, flower/seed and fruit destruction, gall making, leaf rolling and sapsucking (AFF, 2019). For example, *Cinara cupressi, Eulachnus rileyi* and *Pineus boerneri* have caused outbreaks in eastern and southern Africa.

Management of insect populations, ecosystem conditions and ecosystem services in a changing climate should be prioritised because the development of insect pests and their natural enemies depends on climatic factors such as precipitation, temperature, solar radiation, relative humidity and CO_2. Similar to plants, insect life history traits, rates and cycles of development and metabolic rates are affected by climate change, causing the life stages to be earlier or later (Bale and Hayward, 2010). Climate change has direct and indirect effects on insect development (Reineke and Thiery, 2016) and can affect interactions between insects and their hosts. Heat and cold accumulation above the base temperature drive metabolism of insects. Warmer temperatures in winter and spring affect pupal overwintering, lengthens growing season and increases pest survival (Forrest, 2016). Warmer conditions may hasten the rate of growth through accumulation of heat earlier and faster than usual (Honêk, 1996) and increases insect voltinism. However, insects have excellent capacity to adapt to temperature fluctuations but timing of their physiological processes is susceptible to any severe temperatures. Moisture availability also affects pest management options because pests such as *Sirex noctillio* (Sirex wood wasp), *Hylastes ater* Paykull (Pine bark beetle), *Ips grandicollis Eichoff* (Ips bark beetle) and *Phoracantha* spp (Eucalypt borer) are attracted to trees that are stressed (Wardlaw and Bashford, 2007).

Photoperiod and CO_2 increases affect feeding and hosting patterns of sensitive herbivorous insects and their oviposition schemes. Some nocturnal insects have a receptor-cell detecting CO_2 stimuli that they increase their rate of egg-laying under high CO_2 concentrations (Guerenstein and Hildebrand, 2008). Photoperiod can also induce early diapause and decreased periods of metabolic action (Reineke and Thiery, 2016).

The success of conservation and restoration programmes can be affected by insect populations. Insects are important food resources for insectivorous vertebrates and a changing climate may shift their population distribution, increase population growth rates, affect the number of generations and strengthen the risk of invasion by exotic pests (Chuine, 2010). Additionally, the likelihood of pest establishment in new locations and severity of impacts of both native and introduced pests are expected to increase. Climate change can modify the insect pest and pathogen disturbance dynamics of native forest.

Integrated Pest Management is used as a sustainable approach for managing pests using a combination of cultural, biological, physical and chemical methods, taking care by minimising economic, social, health and environmental risks. The multidisciplinary approach gives emphasis to protection, underpinning natural regulatory procedures for managing crop, medical/veterinary, forest and urban pests to minimise adaptation of insect to specific control strategies. Integration entails the congruent use of multiple methods for controlling single pests or pest complexes. Procedures require knowledge of the pest and the affected plant for use in the pest management plan. Management, includes a set of decisions making up a strategy or plan to control a pest based on ecological principles and economic and social considerations. The management of pests calls for the evaluation of benefits to ecosystem services and on non-target species that may be important to long-term ecosystem sustainability.

Making informed pest management decisions involves assessments of population of the pest for the following:

- **Economic injury levels:** Smallest pest population that will cause economic damage-the treatment costs are covered by the resultant yield and quality saving from using the treatment;
- **Economic threshold:** Population of a pest that is large enough to start a treatment response to prevent the population from attaining the economic injury level; and
- **General equilibrium position:** This is the average density of a population over time. It helps to track peaks and crashes of a particular pest population.

Several cultural methods are used to change host and habitat conditions consequently, reducing the likelihood of pest outbreaks. They include use of rotations, sanitation cultivation and other farming systems that reduce tenacious pest problems. Rotation of crops helps to break pest life cycles, while improving soil fertility and tilth. Sanitation includes the removal or destruction of debris and other sources of pest infestation. Another cultural method is that of species-site matching, where the planting is only done on suitable sites for a particular species. For example, avoid planting in areas historically known for being infested with an economically injurious pests. Regular scouting facilitates early identification of potential pest problems.

For long-term plant protection, the use of biological controls, genetic modifications and host plant resistance becomes important. Biological control uses beneficial organisms (parasites, predators, pathogens) to destroy pest organisms. Examples are the ladybird beetle on aphids and the parasitic wasp. Another way of managing pests is through selecting plant varieties resistant to familiar pest species (host plant resistance) and choosing resistant plant materials (genetic control). Furthermore, use of transgenic crops, pheromones, biological control and precision application techniques can reduce targeted insect population levels below resource injury thresholds and reduce the need for insecticides. In forestry, biological control agents (e.g. *Beddingia siricidicola* and *Ibalia leucospoides*) were used to control *Sirex noctilio* (the sirex woodwasp) pests in *P. radiata* plantations of Australia and highlighted the need for identification of effective strains for the control agent using Random Amplification of Polymorphic DNA (Collet and Elms, 2009). In Africa, outbreaks of *Cinara cupresii* on Cypress species were controlled by a parastoid *Pauesia juniperorum* whereas, *Tetraphleps raoi* Ghauri was used to control *Pineus boerneri* Annand.

On the other hand, pesticides that are exceptionally toxic to the biological control agents can induce pest outbreaks (Bartlett, 1964). The most serious pest upsets occur when pesticides destroy natural enemies with no significant damage to the host and persisting residues or when repeated applications restrict successive natural enemy activity.

4.7.8 Nursery techniques

Adaptation to climate change can also be achieved through manipulation of nursery techniques. As the forest industry continues to rely on the current set of plantation species, the management of drought risk or rainfall variability continues to depend on site selection, silvicultural techniques and genetic diversity, that can either shield plants against climate effects or facilitate resistance. Guarnaschelli et al. (2003) showed that hardening (drought) of seedlings in the nursery can build resistance and enhance field survival of newly planted *Eucalypt* plants. In other cases, the removal of a portion of the stem and leaves promoted drought hardening by reducing evapotranspiration and improving the root: shoot ratio. However, potential negative effects are on modification of tree form and survival. Frost and browsing resistance can be promoted through nutritional hardening in the nursery for southern Australian *Eucalyptus globulus* and *E. nitens* seedlings that were planted during dry period.

Seed germination, survival and vigour of seedling development can be affected by temperature regimes. Anti-transpirants can be used to reduce evapotranspiration. Water retentive gels (Hydrogels) have been extensively used in some plantation estates and afforestation programmes to extend planting into times under less-favourable conditions. These allow field survival for seedlings planted just before the beginning of the rain season.

Containerised/potted seedlings or cuttings have better survival rates than open-rooted and planter flat seedlings because they can survive during sporadic rainfall occasions. In some instances, controlled release fertilisers application has been used during establishment instead of broad scale fertilisers.

4.7.9 Management of invasive species

Invasive species can be shrubs, weeds, animals or microorganisms threatening ecosystems, habitats and other species after their establishment, spreading and colonising habitats. Many of the species that become invasive are not native and should be managed. The spread of invasive species has been attributed to globalisation, climate change and human mobility. Tourism, travel and cross boarder transportation facilitate movement of species into new environments, where many have established and proliferated. 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. The species can colonise grazing lands or compete with crops for limited resources, resulting in significant effect on yields. Invasive species have the following effects:

- **Economies:** Attempt to control invasive species costs a lot of money adding to the losses through resource destruction and possible devaluation of the land;
- **Biodiversity:** Native vegetation is crowded by invasive plants/weeds reducing the diversity of plant and animal species. Native plant richness can actually be reduced by up to 90%;
- **Health:** Invasive species affect human and animal health. For example, allergenic pollen of some species, toxic sap of the **giant hogweed caus**ing skin burns, and the thorns of *Opuntia* fruit causing stomach abscesses in livestock that consume them;
- **Infrastructure:** Invasive species, especially weeds, can damage buildings, railway lines, drainage canals and other structures. These require additional funding to manage them; and
- **Water and fisheries:** Food chains in aquatic ecosystems and fisheries can be altered by invasive weeds that grow in and beside water bodies. Water hyacinth is a common invasive plant that has been growing in Lake Victoria, Kenya, Lake Chivero in Zimbabwe and Lake Tana in Ethiopia.

Effective management strategies against invasive species should be developed and implemented considering the stage of the invasion process before taking any action as each stage requires a different strategy (Table 9).

Table 9. Stages of biological invasions and their potential management strategies

Stage (Lockwood et al., 2007)	**Management** (Liebhold and Tobin, 2008)
Arrival	Analyse the risk; Check international standards; and Inspect.
Establishment	Detect; and Eradicate.
Spread	Quarantine; and Create a barrier zone.
Impact	Suppress; and Adapt.

T

o successfully implement management against invasive species, there is also need to manage the divisions among perceptions of different stakeholders concerning the problem and its reality. In most cases, industry is aware of regulations limiting trafficking of invasive species but the public is not aware and hence become non-compliant.

4.7.10 Increasing Carbon sequestration through improvement of forest management systems

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. Forest areas can either be C sinks or sources depending on age of trees. For example, 1 m^3 of wood is expected to store about 0.92 tCO_2, assuming a specific wood density of 0.5 g dry matter/cm^3 and a C content of 0.5 g C/g dry matter. Accumulation of C in biomass after afforestation varies greatly by tree species and site, and ranges globally between 1 and 35 t CO_2/ha/yr (Richards and Stokes, 2004). The selection of mitigation strategies in the forest sector should reduce net GHG emissions as the potential role of forests in contributing to GHG reductions through C sequestration is widely recognised.

Reducing forest degradation together with activities such as site preparation, tree improvement, tree planting, fertilisation, uneven-aged stand management or other appropriate silvicultural operations can increase stand-level C stocks. Harvest operations can focus on maintaining partial forest cover, minimising losses of dead organic matter or soil organic C and avoiding burning can reduce emissions from forests. Reforestation after a harvesting operation or after a natural disturbance accelerates tree growth and reduces C losses when compared to natural regeneration. Activities such as forest conservation, fire management, increasing rotation age and protection of forests from insects, increase landscape-level C density. Increasing rotation lengths will increase certain C pools (e.g. in the tree bole) while harvesting wood products decrease the pools (Kurz et al., 1998). However, the impacts of forest management on C stocks should be evaluated at landscape level so that landscape-level C stock changes are determined accurately.

There is need to increase product and fuel substitution for high fossil fuel consuming products, with forest-derived biomass-derived energy. This results in reducing emissions through the use of wood products instead of more fossil-fuel intensive construction materials such as steel, concrete, aluminium and plastics (Petersen and Solberg, 2002).

Other options available in forestry include agroforestry and urban forestry to increase the C density in farmlands and settlements, respectively. GHG emissions can also be reduced through reducing the use of fossil fuels in all forest activities e.g. nursery operations, tending operations, transportation and industrial activities.

4.7.10.1 Control of deforestation

Deforestation is the long-term or permanent change of forest to other land uses, such as agriculture, pasture, water reservoirs, infrastructure or cities, mainly accompanied by instant reductions in forest C stock that are linked to land conversion. Deforestation can cause serious socioeconomic outcomes such as threatening of livelihoods, values and survival of forest- dependent communities, weakening local and national economies, triggering social conflicts over natural resources, increasing the impact of natural disasters and causing migration (FAO, 2022).

Drivers of deforestation can be direct or indirect. The main direct global drivers of deforestation are:

- Commercial agriculture for food, feedstock, fibre and biofuel (e.g. palm oil, soybeans, beef, maize, rice, cotton and sugar cane);
- Infrastructure expansion;
- Local or subsistence agriculture;

- Urban expansion; and
- Mining.

Underlying/indirect drivers of deforestation include complex interactions of economic, social, political–institutional, cultural and technological factors affecting the direct drivers. Indirect drivers act at multiple scales and at the following levels:

- Local level: such poverty, unclear and asymmetric rights, alterations in household activities, (landlessness, technological change in agriculture and inadequate investment in SFM;
- Global level drivers include commodity prices, markets forces and international agreements or their enforcement; and
- National-level includes growth in population or migration, domestic markets, unreliable policies, weak governance and institutions, contradictory cross-sectoral policies, market failures, illegal activities, absence of law enforcement, diverging interests, civil conflict, unequal power relations and centralisation of services).

Forest degradation is the reduction in forest biomass through non-sustainable harvest or land-use practices. Selective logging, fire, fuelwood collection and other anthropogenic disturbances cause forest degradation, which can also result in significant reductions in forest C stocks.

Reducing deforestation and forest degradation are important mitigation options having greatest short term C stock impact. The protection of forests from all forms of harvesting maintains and/or increases forest C stocks, although it also reduces the supply of wood and other societal goods. Deforestation can be reduced through reinforcement and expansion of protected areas, adopting agroforestry, afforestation and reforestation and managing existing plantation forests sustainably to meet demand for wood and reduce pressure on natural forests. The identification and analysis of the drivers is the first step to address deforestation. The analyses require the following:

- Identification of deforestation hotspots and extent. Remote sensing can be used if complemented by historical data, local knowledge, relevant reports and statistics and an evaluation of potential future threats to help anticipate and minimise risk;
- Analysing specific drivers based on data from existing monitoring systems, local knowledge and other available sources of information;
- Evaluation of the impact of drivers at all scales (e.g. local, national and/or global scales) and going further than the forest sector and bearing in mind the connections of the drivers with land-use activities;
- Analyse the underlying drivers, particularly those at the international level. This may need to be done using economic and social indicators, statistical analyses and modelling. It should include the mapping of the main actors associated with specific deforestation drivers and with forest restoration drivers; and
- Collecting qualitative information from all stakeholders to understand the dynamics of the drivers, especially those living or working in deforestation hotspot areas. Information can be gathered using participatory tools.

4.7.10.2 Reforestation and afforestation

Afforestation affects the net GHG balance at landscape level, especially if it involves land use change. Afforestation/reforestation activities reduce emissions by sources and/or to increase removals by sinks in the forest sector through maintenance or increase in the forest area while decreasing deforestation and degradation. Afforestation/reforestation represents direct human-induced conversion of non-forest area to forest land through planting, seeding, and/or the human-induced promotion of natural seed sources.

Afforestation usually contributes to biomass increases, additions to the dead organic matter C pools and small, slow increases in soil C pools. Forest biomass C in trees is transferred into wood products after harvesting and is stored for years to many decades. C storage in wood products ranges from days (biofuels) to centuries (e.g. roof trusses and furniture).

Community-based seed saving initiatives have different names depending on where you are and these are: community gene bank, seed savers group, seed wealth centre, farmer seed house, seed hut, association or network, community seed reserve, seed library and community seed bank. Community seed bank climate change adaptation practices have been implemented in Bangladesh, Bhutan, Bolivia, Brazil, Honduras, India, Mali (two case studies), Mexico, Nepal, South Africa, Uganda, USA and Zimbabwe. The seed banks have improved access to, and availability of diverse, locally adapted crops and varieties and enhanced related indigenous knowledge and skills in plant management, including seed selection, treatment, storage, multiplication and distribution (Vernooy et al. 2017).

Restoration activities in Africa

Ghana: Restoration effort 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).

4. 7.10.3 Development and maintenance of seed banks

In order to achieve management objectives related to conserving biological diversity of forests and agricultural systems, under and above-ground seed sources (i.e. seed banks or trees) should be maintained. Seed banks act as storehouses of genetic materials that are normally adapted to predominant climate conditions and biotic stresses, such as crop pests. The setting up of seed-banks initially focused mainly on conserving seed stocks of agricultural or horticultural seeds. Preference was given to current, obsolete, or primitive strains that were maintained as gene-pools for future breeding. Human capacity to adapt to climate change can be strengthened through management of plant genetic resources through the use of multiple germplasm sources, facilitating access to diverse, locally adapted crops and varieties. Furthermore, selection of seed and its treatment, storage, multiplication and distribution can be improved using local knowledge and skills.

Adaptation to climate change can be enhanced by exploiting inter- and intra-crop genetic diversity for their resistance to biotic and abiotic stresses resulting from changing climatic conditions. In Africa, community seed banks have been used as part of community-based CCA strategies for improving the resilience of farmers through availability of diverse, locally adapted seed varieties and indigenous knowledge and skills (Vernooy et al., 2017). A community seed bank is a locally governed and managed, mostly informal institution whose core function is to maintain seeds for local use (Development Fund, 2011). Community seed banks are repositories of local genetic diversity that is often adapted to prevailing climate conditions and biotic stresses. Some community seed banks strictly focus on conserving agricultural biodiversity as well as reviving lost local varieties and giving priority to conservation, access and availability of various types of seeds and planting materials that can be grown in various agro-ecological domains.

Jarvis et al. (2015) showed that genetic resources were important because they facilitate diversification of species and varieties, permit revalorisation of under neglected and underutilised plants, permit broad and intensified collections, allow characterisation and utilisation of crop wild relatives, improve targeted plant breeding and create better linkages between in-situ and ex-*situ* conservation actions. Crop diversification practices include the use of varietal diversity in monocultures, mixing crops with non-crop vegetation, crop rotations, polycultures (including wild varieties), agroforestry and mixed landscapes.

> Community-based seed-saving initiatives have different names depending on where you are and these are: community gene bank, seed savers group, seed wealth centre, farmer seed house, seed hut, association, or network, community seed reserve, seed library and community seed bank. Community seed bank climate change adaptation practices have been implemented in Bangladesh, Bhutan, Bolivia, Brazil, Honduras, India, Mali (two case studies), Mexico, Nepal, South Africa, Uganda, USA and Zimbabwe. The seed banks have improved access to, and availability of diverse, locally adapted crops and varieties and enhanced related indigenous knowledge and skills in plant management, including seed selection, treatment, storage, multiplication and distribution (Vernooy et al., 2017).

These strategies facilitate insect pest and pathogen reduction, increase production, stability and buffers climate stress. These activities can also reduce the future vulnerability of plants to pests and diseases caused by changing climatic conditions (Jarvis et al., 2011). To ensure continuity of plant genetic resources in a changing climate, several activities should be done and these include:

- Supporting on-farm crop conservation;
- Preserving seeds of plants that survive under severe weather conditions; and
- Policy support for several types of in situ and farm-based conservation.

Botanical gardens have often facilitated repositories of plant material in seed-banks to avoid problems associated with genetic erosion or selective changes in genetic constitution that occurs when plants are grown under synthetic environments (Thompson, 1974). This is achieved through freezing cuttings from the plant, in vitro storage, or stocking of seeds (e.g. in a seedbank). For animals, freezing of the sperm and eggs is done in zoological freezers until when required. Maintenance of germplasm includes maintenance of seed viability and seed quantity in the gene bank. The main objective is to improve storage methods and to maintain viability of conserved genetic stocks that are either threatened or getting extinct. Some of the organisations participating in gene conservation are Royal Botanic Gardens, Kew, International Crops Research Institute for Semi-Arid Tropics, Japanese National Seed Storage Laboratory, Gene-banks in Western Europe and Turkey and the US National Seed Storage Laboratory. The Consultative Group on International Agricultural Research (CGIAR) has the most widely spread collection of genetic diversity accessible under the Multilateral System of the International Treaty on Plant Genetic Resources for Food and Agriculture. The CGIAR has 11 gene banks (5 in Africa) conserving 768,576 accessions of cereals, forages, grain legumes, tree species, root and tuber crops and bananas. Several of them are accessions of crop wild relatives.

4.7.10.4 Mixed species forestry

Mixed species forests are an important option for adapting forests to unknown future instabilities such as those from climate change. Successful adaptation depends on the characteristics of species in the mixture relative to the specific disturbances. Mixed forests reduce impacts of abiotic disturbances and ecosystem damages compared to monocultures of susceptible or less resilient species. Mixing more resistant or resilient species with less susceptible and less resilient species reduces vulnerability of the forest ecosystem. However, disturbances such as fire, storms or drought may not discriminate individual species.

The impact of insect herbivores on individual susceptible tree species is reduced in mixed forest plantations or forests where the community is dominated by specialist herbivores. Tree diversity also reduces the impact of specialist pathogens on host tree species. In most cases, mixing tree species reduces the impact of disturbance agents due to their differences in susceptibility to specific disturbances, and is insurance against a total loss or damage. Furthermore, mixing tree species reduce temporal difference in growth and stabilises productivity. Macpherson et al. (2017) studied the effects of insect pests and pathogens in mixed stands and found that the diversification of species composition reduced the economic losses arising from disease, although the economic gains from the resistant species was low.

4.8 Forest governance

Governance rests on effective promotion of democratic and participatory principles as well as on ensuring access to information, knowledge and networks. Institutional strengthening and capacity building has been highlighted as a priority need in developing countries (Kumamoto and Mills, 2012). For example, in the 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 new 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.

Activity 4.5 Brainstorming (5 minutes)
What is the role of traditional leaders in governance of forests and other natural resources?

Forest governance represents the *modus operandi* by which administrators and institutions obtain and exercise authority for managing forest resources. Forms of governance differ from one country to the other, but involves the interaction of private and public actors normally connected through various networks to create opportunities to solve societal problems. Governance encompasses the design and use of principles that guide the interactions while caring for enabling institutions (Kooiman and Bavinck, 2005). Actors, rules and practices are the main components of governance. The policy development process, general governance strategies, institutional co-ordination and mechanisms can determine how people adapt to climate change. Good governance is important in forest and environmental management, especially under the CBD, UNCCD and UNFCCC. The UNDP (1999) identified five principles of good governance:

- Participation and consensus orientation are the basis of legitimacy and voice;
- Having a direction that is based on strategic vision;
- Performance that is based on responsiveness;
- Efficiency, effectiveness, accountability and transparency; and
- Equity and the rule of law are the basis of fairness.

In fulfilling these principles, five factors that must be considered:

- Accountability, transparency and public participation;
- Forest institution stability and conflict management;
- Forest administration quality;
- Coherence of forest legislation and rule of law; and
- Equity, economic efficiency and incentives.

These need to conform to other principles related to global requirements, market forces, decentralisation, individual motivated instruments and governance across scale in order to allow emerging hybrid modes of governance to operate across the state market-community division. Three main mechanisms are used: public-PPP, private-social partnerships and co-management.

PPP is a collaboration between the state agencies and market actors. The market actors can either be in form of payments for ecosystem services (PES) schemes that pay readily or pay after service delivery. PES has benefits for both buyers (i.e. market actors) and sellers (i.e. communities) while improving the resources base particularly in marginal areas having moderate opportunity costs for conservation. However, PES includes the reduction of poverty as a key aim but not as the principal objective. Wunder (2005) classified individuals or companies and partnership into forms of: business management of state property, service contracts, risk sharing and co-production among state and market players. In forestry, activities such as logging and concessionaires' contracts should satisfy goals related to economic, technical, social and environmental factors (Skelcher, 2005).

Private-social partnership is a collaboration between the public and market actors where the communities supply forest goods and services to the market actors. This form of partnership also includes arrangements such as PES focusing on activities based on issues of C sequestration and storage, biodiversity protection, watershed protection and ecotourism (Wunder, 2005).

Co-management is a form of collaboration in the management of natural resources between state agencies and communities through agreements of power-sharing by which communities function as either a co-manager or designated manager with clear benefits and responsibilities (Luukkanen et al., 2006). Co-management arrangements are appealing for governments because they create opportunities for participation of locals in resource governance and fair benefit-sharing whilst holding on to some level of state control. Co-management can however place more burden on community level actors with no corresponding benefits (Cronkleton et al., 2012). Co-management can be implemented as Community-Based Forest Management (CBFM), Joint Forest Management or community forestry and can include rehabilitation of degraded lands, afforestation/reforestation or conservation of forest resources. However, the success of co-management depends on how institutions, forest regulatory frameworks and agencies adjust to allow more community-level freedom to develop forest management plans (Cronkleton et al., 2012).

Activity 4.6 Revision (15 Minutes)
Explain management options that can be used to improve resilience of forest ecosystem components.

Summary
In this session, we learnt that forest resilience can be linked to resilience approach to sustainable development where capacities are built to tackle unexpected events and people interact with the biosphere (sphere of 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 the resilience of forest ecosystems include rehabilitation of degraded forests, forest landscape restoration, fire management, creation/expansion and adaptive management of parks/reserves, protected areas and biodiversity corridors, fire management, silvicultural manipulations, pest management, forest governance, nursery techniques and control of invasive species. Invasive species threaten biodiversity by decreasing species diversity, causing economic losses and affecting 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. Seed banks act as storehouses of genetic materials that are normally adapted to predominant climate conditions and biotic stresses, such as crop pests. Adaptation to climate change 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 important options for adapting forests to unknown future instabilities such as those from climate change. Above all, good governance is important for achieving the goals of forest and environmental management. We concluded the session with some highlights of seven principles of good governance and three mechanisms that can be applied.

Chapter 5 Forest-Based Adaptation Strategies/Measures

5.1 Chapter overview

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, the learners are introduced to the role of forest and tree resources in CCA and defines the meaning of technological adaptation before outlining the forest-based technological options. Furthermore, we discuss broad categories of how forest and tree resources support social systems to respond to climate change and variability and associated challenges.

Learning outcomes

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

i. Describe the role of forests in CCA;
ii. Identify appropriate forest-based initiatives that could help forests and people to adapt to climate change; and
iii. Develop forest-based CCA interventions.

Activity 5.1 Brainstorming (15 Minutes)

Share your views on the role of forests in adaptation to climate change and climate variability.

5.2 Role of forests in the adaptation of social systems to climate change

There are four types of services 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 such as** primary production, habitat, nutrient cycling etc. (Table 10). 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).

Table 10. Examples of forest 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 were used as safety nets; and • Improved forest management.
Central America	• Increasing rainfall intensity and soil erosion; and • Sedimentation of hydroelectric dams.	Upstream soil conservation and forest protection.
South East Asia	Vulnerability of coastal areas to storms, waves and sea- level rise.	Protecting mangroves and provision of goods; and Enhanced mangrove management.

Source: Locatelli et al. (2008)

Forest cover facilitates resilience of hydrological ecosystems services (e.g. conservation of base flow) to climate change impacts increases rainwater infiltration, reduces surface run-off and controls soil loss, consequently reducing the negative impacts of floodwaters. Forests can also be sources of natural water recharge replacing stream flows that can be threatened by drought. The role of forest and tree resources in CCA can be considered as either technological adaptation or socio-economic adaptation. The following subsections provide key highlights on these categories but before we discuss the options, we will define and discuss the meaning of technological adaptation.

5.2.1 Technological adaptation

The UNFCCC (2010) defined technological adaptation as the application of technology to reduce the vulnerability or increase the resilience of natural or human systems to the impacts of climate change. The paths of technological development in developed countries differ greatly from that of the developing world. The differences are mainly caused by the availability of critical factors that promote technological advancement such as the availability of local capital, labour, education, technological capability, industrial infrastructure, receptiveness of management skills, government industrial policy and entrepreneurship. Technological adaptation improves its capability following three stages of development:

Acquisition and Implementation → Assimilation → Amprovement.

Forest-based technological adaptation includes agroforestry, urban forestry, use of renewable energy, plant water relations, soil and water conservation and intensification of production systems. Social and economic adaptation includes: sustainable and diverse livelihood options, social systems, gendered systems and indigenous coping and adaptation mechanisms. These will be discussed in the following chapters.

Activity 5.2 Brainstorming (10 Minutes)

1. What is agroforestry?; and
2. What is the role of agroforestry in CCA?

5.2.1.1 Agroforestry systems

Agroforestry includes a combination of trees/shrubs with crops and/or livestock now increasingly being recognised as an efficient approach to minimise risks of production under climate variability and change. Trees planted in cropping areas can maintain production under variable climate and also shelter crops against extreme climate events. The deep roots of trees explore deeper soils for water and nutrients that can be beneficial to crops during dry spells. Tree litter increases soil porosity, reduces runoff, increases water infiltration and retention and reduces moisture-stress during drought episodes (Rao et al., 1998). On the other hand, excess water is pumped out of the soil more rapidly in agroforestry plots due to their higher evapotranspiration rates.

Maize grown in agroforestry in Zambia (300 000 ha) and half a million farms in Malawi showed increased maize yields as high as 400%. The leguminous trees and shrubs (mainly *Faidherbia albida, Sesbania sesban* and *Glirisidia sepium*) adding between 100 and 250 kg of Nitrogen per ha to the soil in two to three years. The growing of maize with leguminous trees and shrubs generates higher net returns than growing maize with subsidised mineral fertilisers. The system uses water more efficiently and is more resilient to drought. Furthermore, agroforestry provides fuelwood and fodder, improves water infiltration and sequesters C (FAO, 2016b).

Agroforestry is one of the intense land-use management systems combining trees and/or shrubs with crops and/or livestock. The products of agroforestry help small holder farmers to obtain multiple products, markets and farm income while the soil and water quality are improved (Lin, 2010a). Furthermore, soil erosion is reduced, non-point source pollution is reduced 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 be managed to strategically provide more resilience to extreme weather events (e.g. drought, floods etc.) by facilitating flexible responses to rapid shifts in ecological conditions (Lin, 2011).

Agroforestry systems are defined as multifunctional systems that can provide a wide range of economic, sociocultural and environmental benefits. There are three main types of agroforestry systems:

- **Agrisilvicultural** systems are a combination of crops and trees e.g. alley cropping, improved fallow, windbreaks or homegardens;
- **Silvopastoral systems** combine forestry and grazing of domesticated animals on pastures, rangelands or on-farm; and
- The three elements, namely trees, animals and crops, can be integrated in what are called **agrosylvopastoral** systems and are represented by practices such as homegardens 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 (Figure 14). 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, taungya, improved fallows or mixed strata agroforestry (Akinnifesi et al., 2010; Sjöberg and Jativa, 2019).

Nitrogen-fixing trees improve drought-resilience in agriculture due to enhancements of soil nutrients and water infiltration mainly in degraded lands. In Malawi and Zambia, maize yields improved where conservation farming was practiced incorporating *Faidherbia albida*. The tree sheds leaves early in the rainy season resprouting at the end of the wet season, limiting competition crops. In Malawi, farmers who integrated *F. albida* and *Gliricidia* and crops harvested modest yields during drought seasons, while farmers without the practices experienced total crop failure. In Niger, Farmer Managed Natural Regeneration (FMNR) programme with *F. albida* improved 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 FMNR was absent (Akinnifesi et al., 2010).

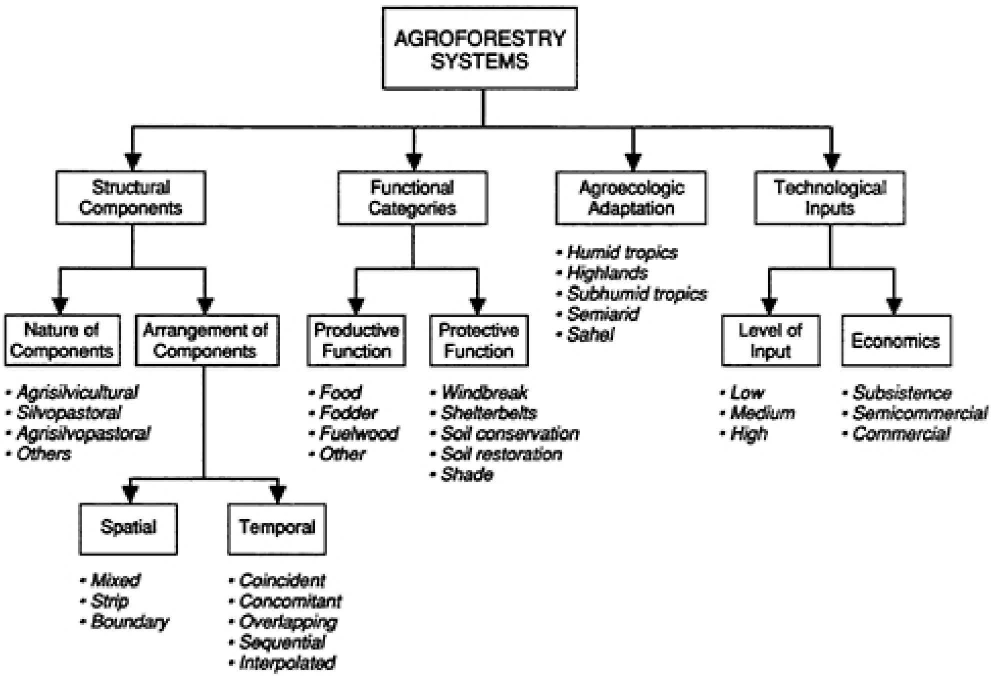

Figure 14. Classification of agroforestry systems (Source: nzdl.org)

For a system to be called agroforestry, it should have the characteristic 4"I"s of being intentional, integrated, intensive and interactive(Box 5.1).

Box 5.1: 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: Intensively managed agroforestry practices maintain their productive and protective functions and generally involves cultural actions such as cultivation, irrigation, fertilisation, pruning and thinning.

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 CCA although they also contribute to global efforts of reducing atmospheric GHG concentrations. 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 the potential to increase resilience of smallholder farmers to climate change risks (Kerr, 2012; Schoeneberger et al., 2012). Furthermore, soil resources and water storage are affected by a changing climate, coupled with intricate interactions of winds, local heat and hydrological feedbacks, adding more stress on the farming system. When there is limited water availability, agriculture competes with other uses of water, worsening the stress (Boko et al., 2007. Agroforestry practices that have been practiced throughout the world include the following:

Nitrogen-fixing trees improve drought-resilience in agriculture due to enhancements of soil nutrients and water infiltration mainly in degraded lands. In Malawi and Zambia, maize yields improved where conservation farming was practiced incorporating Faidherbia albida. The tree sheds leaves early in the rainy season resprouting at the end of the wet season, limiting competition crops. In Malawi, farmers who integrated F. albida and Gliricidia and crops harvested modest yields during drought seasons, while farmers without the practices experienced total crop failure. In Niger, Farmer Managed Natural Regeneration (FMNR) programme with F. albida improved 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 FMNR was absent (Akinnifesi et al., 2010)

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 fallow is 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. Longer fallows are better for soil improvement than shorter ones (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 the 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, Mucuna pruriens, Callopogonium mucunoides* and *Tephrosia vogelii* using two-year fallows and maize rotations. Partey et al. (2017) showed that the nutrient use efficiency and soil fertility improved after using improved fallows, resulting in increased maize yields up to about 6 Mg ha^{-1}, which was as good as conventional maize yields under inorganic fertilisers in the same areas. 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. In this regard, improved fallows can contribute to climate change mitigation and adaptation, food security and the sustainable conservation of natural resources (Prinz, 1986; Mbow et al., 2014).

Alley Cropping: This 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 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 modify the crop microclimate by reducing extreme temperature and wind speeds, increasing humidity around the plant surface and in so doing they reduce water loss. Crops protected by fast-growing hedgerows have increased photosynthetic rates and WUE (AGFOWARD, 2017). Tree/shrubs planted as hedgerows shelter crops and soils from extreme weather events. The diversification increases the productivity of the land and protects the farmer in case of total crop failure (Schoeneberger et al*.*, 2012; FAO, 2016b). Figure 15 gives an illustration of some of the agroforestry practices.

Figure 15. Agroforestry practices (A) Alley cropping, (B) Windbreak, (C) Riparian buffer, (D) Silvopasture, (E) Forest farming (Source: Bentrup and MacFarland, 2020).

Riparian and Upland Forest Buffers: Riparian Buffer Strips are linear bands of stable vegetation neighbouring aquatic ecosystems intentionally grown to preserve or improve water quality, reduce run-off of sediments and pollutants from both overland and shallow subsurface flow and they contribute to reducing vulnerability to floods (Climate ADAPT, 2015). They are therefore expected to 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 the recharge of groundwater. Vegetated and unfertilised buffer zones alongside watercourses improve micro-climatic conditions and are shields against overland flow from agricultural fields. 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. 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).

Adopting agroforestry practices helped smallholder farmers in eastern and southern Africa by providing a constant soil cover. The trees growing on farms provide enough biomass to both meet livestock needs and improve maize yields (FAO, 2016b). The trees also provide 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)

The success of vegetated 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. Benefits go well beyond pollution control, including increased biodiversity and aesthetic value, increasing people's enjoyment of the environment and providing green recreation spaces. As a CCA measure, the key benefits are linked to the cooling of water body, increased air humidity, temperature stabilisation and water retention (Climate ADAPT, 2015; Rempel and Buckley, 2018).

.**Windbreaks and shelterbelts:** These are agroforestry practices where vegetative barriers are planted to reduce or eliminate impacts of excessive wind. They comprise one or more trees or shrub rows adjacent to buildings or in open field areas. Shelterbelts can be created by planting species that are adapted 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 moderate microclimates (Chavan et al., 2014). Shelterbelts retained in pastures could moderate losses in forage quality and quantity over the dry season.

Silvopasture: This is a 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). To get maximum benefits, the areas may need water supplies and to be fenced off, creating an additional cost.

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

Taungya: This 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 crop. It involves a special arrangement between a forest organisation and farmers to simultaneously grow tree crops and agricultural crops respectively. Taungya has a high potential to reduce vulnerability due to short-term food production and long-term plantation establishment (Kalame et al., 2011) and is able to reduce the conflicts associated with land hunger (Adegeye et al., 2010). Adegeye et al. (2010) found higher crop yields under Taungya than non Taungya areas. The resilience of the Taungya system is associated with economic and social factors that show the cultivation of crops as an adaptive strategy of land use for communities around plantation forests.

5.2.1.2 Urban forestry, greening and their contribution to urban development

Urban green spaces include lands covered with natural or man-made vegetation but are located in built-up areas (Phan and Nakagoshi, 2007; Hernandez et al., 2018) and associated with sustainable urban development. Urban green spaces are important components of intricate urban ecosystems providing several ecosystem services, both environmental, aesthetical, recreational and economic benefits to urban communities (Hernandez et al., 2018) (e.g. Figure 16). Urban forests, like other forests can be instrumental in mitigating and adapting 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 16. Urban green space in Harare city

Compared to developed countries, urban green spaces in developing countries are not as prevalent and there are no serious efforts to have them. Urban green spaces can also be important in biodiversity conservation, protection of water resources, microclimate amelioration, reducing urban air pollution load, provision of purified air, acting as heat absorber during the hot summer and provision of fresh food for urban dwellers (Lovell and Taylor, 2013). Urban forestry or greening improves the quality of life and environment for urban dwellers. Urban forests and trees provide environmental, economic and social benefits (Frigeri et al., 2017). Figure 17 shows the contribution of forests and trees to urban sustainability.

Environmental benefits include reduction of urban air pollution, reduction of urban heat island effects, air purification, improved biodiversity, soil fertility improvement, soils conservation, reduction of noise and being a barrier against natural disasters.

Economic benefits include employment opportunities for the urban poor, food and medicines, increased property value, 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. They can also have positive impacts on physical and mental health by providing opportunities for refreshment, reducing stress and physical exercise. Moreover, recreational areas in cities provide urban inhabitants particularly the poor with recreation (Konijnendijk et al., 2013). For example, Karura Forest, Nairobi, Kenya and Mukuvisi woodlands in Harare, Zimbabwe.

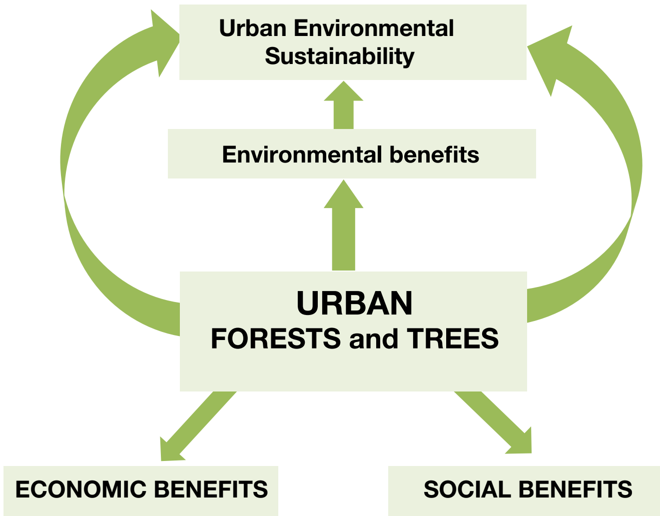

Figure 17. Relationship between urban forests and trees and sustainability

5.2.1.3 Use of renewable energy and energy efficiency

Renewable energy is a kind of energy that is capable of returning to nature unlike non-renewable energies. There are a variety of renewable energy technologies available, with technology-specific advantages and disadvantages. Renewable energies are important because they provide the following benefits. They are a clean energy source, have less environmental impact, resources are endless, resources reduce dependence on fossil resources and provide energy security (Abdollahi et al., 2019). Some technologies for example can provide baseload power (e.g., hydro, geothermal and biomass) while others are more variable in nature (such as solar and wind energy) and require additional grid balancing services. Renewable energy sources are being promoted at meaningful scale in many countries and are key to the replacement of power generation from fossil fuels. The use of renewable energy and the improvement in energy efficiency can lead us towards the achievement of the 1.5°C ambitious Paris Agreement target of 2016. Indeed, the power sector needs to limit or eliminate emissions from fossil fuel combustion. The fossil fuel capacity will need to be largely phased out by mid-century, 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 as non-methane options and decarbonisation technologies are developed (Stern, 2017).

IRENA (2019) reported growth of renewable power capacity from 1,136 GW in 2009 to 2,351 GW in 2018. This is facilitated by the decrease in the cost of renewables such as solar PV and wind energy

(IRENA, 2019) and in some countries shortage of grid power supplies. More innovation is needed to improve the efficiency and capacities of storage technologies, such as batteries and thermal storage for concentrated solar power. Another alternative source of renewable energy is nuclear power but this is hindered by rising costs and limited provision of co-benefits compared to renewables (Climate Analytics, 2019).

Limitations of renewable energy are linked to geographical location, weather conditions and annual and seasonal fluctuations. Nuclear energy also faces considerable resistance from civil society, not least 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: oil, coal and gas.

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

Activity 5.3 Group discussion (10 minutes)

1. What are the dynamics of wood energy use in your country?; and
2. How can we reduce emissions from wood energy use in rural communities?

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 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 the demand for wood. In 2014, traditional renewable energy in Africa represented over 85% of renewable energy consumption with 76.6% of energy for heat applications coming from renewable energy. There is however, a relationship between traditional biomass consumption and population growth, especially in poorer countries (World Bank and the International Energy Agency, 2017). Kenya, Uganda, Tanzania and Sudan are the African countries where 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 expand the use of renewable energy that is sustainable and at the lowest costs. In this regard, the use of more renewable energy including bioenergy can be an effective tool in adapting to climate change (Bull, 2018).

5.2.1.4 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 tonoplast. The symplastic and transcellular pathways are the cell-to-cell pathways under fine regulation of transportation via plasma membranes (Barberon and Geldner, 2014). In the root cortex, the water movement is mainly 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 are able to modify the apoplastic and "cell-to-cell" pathway contributions depending on the environmental conditions and transpiration demand (Taiz and Zeiger, 2010). Water potential affects several plant physiological processes (Figure 18).

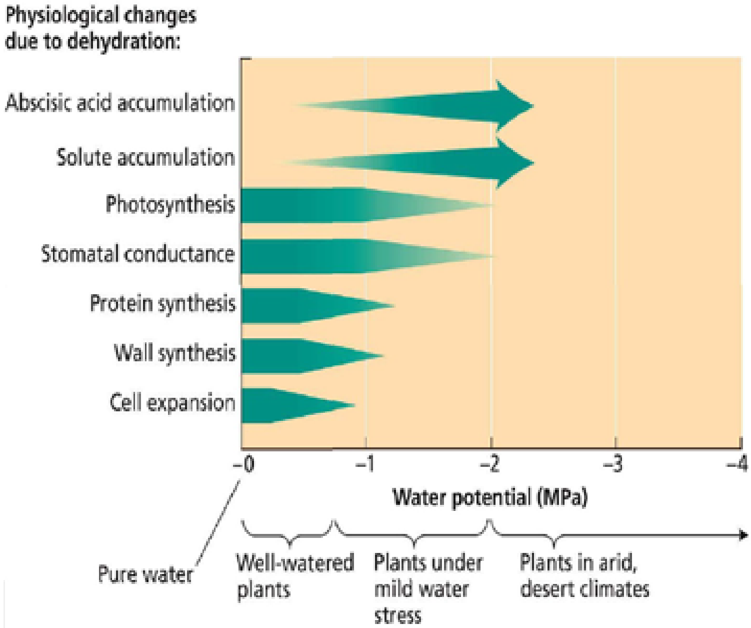

Figure 18. Effect of water potential on physiological changes caused by dehydration (Source: Taiz and Zeiger, 2010)

Elevated CO_2 concentrations stimulate photosynthesis, modifying water and nutrient cycles leading to increased plant productivity (Soussana and Lüschert, 2007). 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 price for WUE and soil water content, reduced stomatal conductance and its effects on leaf water potential. WUE is often taken as an important factor of yield during stress and as an element of crop drought resistance. Furthermore, under normal growth conditions, elevated CO_2 can improve the WUE of crops although impaired stomatal control may increase the vulnerability of plants to water deficit and high temperatures (Haworth et al., 2016).

WUE 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 the highest soil moisture captured for transpiration and also involves reduction of non-stomatal transpiration and negligible water loss through soil evaporation. EUW is the opposite acronym of WUE thus high WUE is achieved at the expense of reduced EUW (Blum, 2009). Capacity of root systems for water uptake depends on rooting volume (or rooting depth), activity and fine-root area (Wullschleger et al., 2002; Filipovic, 2020).

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 in these areas. 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. Active rainwater

UNDP implemented a project supported through the AF on soil and water conservation in Eritrea covering 232 km hill terracing, 7 307.23 m^3 capacity check dams, planting of 143 000 economical trees such as *Acacia senegal* (130 000) and sisal (13 000) (UNDP, 2018).

harvesting systems capture, redirect and store precipitation for later use. Rainwater harvesting includes a combination of techniques like water storage in cellars or tanks, terracing, plastic-film cover and micro-irrigation for increasing dryland-farming productivity. Rainwater harvesting system has 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. Resilience to climate change depends on increasing availability of water to boost agricultural productivity (Altieri et al., 2015).

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 are affected by increased concentration of sedimentation and agrochemicals (Kimaro, 2019).

In agriculture fields, several methods have been used to manage water use and these include: 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 WUE 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).

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. Water Plant and Soil Relation under Stress Situations | IntechOpen.

5.2.1.5 Soil and water conservation technologies and watershed management

Soil erosion together with forest degradation and land degradation is a major problem 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. Soil and water conservation are pillars in environmental conservation and food security. Soil erosion is a result of non-anthropogenic and anthropogenic activities such as poor land management, tree cutting, infrastructure development and natural events such as floods and strong winds.

Soil and water conservation measures are undertaken for the following reasons:

- To maintain or improve soil fertility;
- To control water runoff and prevent soil loss through soil erosion;
- To reduce soil compaction;
- To conserve or drain water; and
- To 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, are easily available and are 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).

Physical measures, which are 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, trenches, cut off drains, retention reservoirs, dams, grassed waterways and planting pits. In designing physical measures, the following principles should be considered (Tidemann, 1996):

- Increasing the time of run-off concentration to allow more water to infiltrate into the soil;
- Reducing the amount and velocity of surface runoff by dividing a long slope into several short ones;
- Reducing the velocity of surface runoff; and
- Protecting 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. 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 other NTFPs.

Agronomic measures applied for soil and water management include strip cropping, intercropping, mulching, mixed cropping, contour ploughing, grazing management and agroforestry (Misebo, 2018). Agroforestry was extensively discussed in section 5.2.2 above. These measures can easily be used together with the physical and/or vegetation measures. However, they need more technical knowhow than the other two. Implementation of these measures can be influenced by other socio- economic, political and institutional factors.

Conservation practices are important strategies for adapting to the impacts of climate change on the soil and water resources. Other key strategies include conservation farming, management of crop residues (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). To conserve soil and water in a changing climate, Delgado et al. (2013) added that adaptation policies and strategies should include conservation practices that contribute to increased soil water-holding capacity, improved drainage and the development of new crop varieties and cropping systems that are more resistant to drought.

UNDP implemented a project supported through the AF on soil and water conservation in Eritrea covering 232 km hill terracing, 7 307.23 m^3 capacity check dams, planting of 143 000 economical trees such as *Acacia senegal* (130 000) and sisal (13 000) (UNDP, 2018).

Activity 5.4 In text question (15 Minutes)
Describe at least two forest-based technological adaptations practices in your country.

5.2.1.6 Intensification of production systems

Sustainable intensification (SI) of production systems is the production of more output from the same area of land while decreasing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services (Pretty et al., 2011). SI can provide productivity, socio-economic and environmental benefits to smallholder farmers and 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, reductions in agriculture's GHG emissions and C footprint (FAO, 2011). SI of agriculture is required for increasing the productivity of land, given the urgency to cut GHG emissions. SI reduces and traps emissions whilst concurrently improving sustainable food security (Godfray and Garnett, 2014). 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 the production of future food. This is because the growing food demand should be met using existing agricultural land without opening up new land. The SI approach is an important climate change adapting option likely to lower emissions. However, it is important to consider the fact that having a more efficient agricultural system could lead to higher profits thus motivating 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). Protecting forested land, grasslands and wetlands requires governance mechanisms for protecting areas with large C 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.

SI 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), and the technologies have performed poorly because of their inadequacy to fit within local smallholder systems (e.g. Giller et al., 2011).

Furthermore, agricultural intensification can have benefits such as land preservation, food security, and reduction of GHG emissions without degrading soils and causing wider environmental degradation (Van Walleghem et al., 2017). For example, Tittonell and Giller (2013) showed that when soil degradation occurs, African small holder farmers will not be able to 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 positive feedback loops or vicious cycles characterised by the disturbance of soil physical properties, increased erosion, accelerated decomposition rates and gradually decreasing soil C inputs in the form of crop residues caused by declining crop yields (Tittonell and Giller, 2013). Tilman et al. (2002) 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 emphases 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.

Activity 5. 5 Revision (15 Minutes)

1. Give examples of ecosystem services under regulation, service and provisioning services;
2. Explain how agroforestry contributes to CCA;
3. Explain technological adaptation in the agricultural sector;
4. Explain the importance of urban forests and trees in CCA; and
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 services, provisioning services, cultural services and supporting services. Adaptation to climate change can be either technological or social and 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 systems. Agroforestry which can be in several forms depending on the objectives 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 included 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. Other options include manipulation of plant water relations including WUE and rainwater harvesting and usage. Plants are able to 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 clean energy source with less environmental impact. The resources are endless and they reduce dependence on fossil resources and provide energy security.

Further reading

Mugwe J, Ngetich F, Otieno EO. 2019. Integrated Soil Fertility Management in Sub-Saharan Africa: Evolving Paradigms Toward Integration. In: Leal Filho W, Azul A, Brandli L, Özuyar P, Wall T. (eds) Zero Hunger. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham.

Titonnel P, Giller KE. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. Field Crops Research. 143: 76-90. Available at: When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture – Science Direct.

5.3 Socio-economic adaptation

Socio-economic systems either amplify or moderate the impacts of climate change. Adaptation to climate change can vary depending on socio-economic indicators such as education, occupation or income. Velichko et al. (2009) traced the 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 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 the 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. In this session, we learn about social and economic adaptation linked to forest-based sustainable and diverse livelihoods.

Learning outcomes

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

i. Identify and implement forest-based sustainable livelihoods initiatives;
ii. Explain elements of social systems;
iii. Explain the meaning of gender and gender mainstreaming; and
iv. Explain some indigenous coping mechanisms.

Activity 5.6 (Brainstorming) (10 Minutes)

Share your views on how forest and tree resources are contributing to socio-economic adaptation to climate change and variability in your country.

Climatic change is not one of their greatest threats in most developing countries because their current priorities emphasise poverty reduction and economic growth. Measures of adapting such as bearing the losses, sharing the losses, changing use and changing location are related to socio-economic status of the individuals or community. The factors that push an individual or community to adapt in certain ways were described in chapter 2 and are linked to the socio- economic standing of the vulnerable groups and determines how coping and adaptation can be achieved.

5.3.1 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 are basis of life and are critically important for human and societal development (Arce, 2019), providing both wood and non-wood/NTFPs and buffering communities during periods of scarcity, being a source of nutrition for the poor (Agrawal et al., 2013).

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, while not undermining the natural resource base (Serrat, 2017). Diversification is a process (if planned) where the economic status of a household could improve through, for example growing new crop varieties, value crops, small enterprises and casual labour etc. 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. 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 to retain or modify their traditional livelihoods (Cannon, 2013; World Social Report, 2020).

> 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 impacts of unsustainable utilisation of biomass for charcoal/firewood through promotion of energy and resource use efficiency (Anyango et al., 2018).

When the 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, they 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). 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 in diverse activities which may be undertaken to meet short comings in 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, 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 are 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 activity-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; and
- Build complementarities through household diversification activities fostering on existing skills, experiences and information. For example, when home based part-time work is complemented with part-time domestic tasks. The changes depend on previous conditions and experiences.

> For Kenyan communities near east Mau forest, income from forests can be as much as 33% of the total household income, with highest contribution from fuel wood (50%), food (27%), construction material (18%) and fodder and thatching material 5% (Langat et al., 2016). Apart from the forest resource being destroyed by anthropogenic activities, the supply of forest resources can be disrupted by drought or other climate event affecting community livelihoods.

Throughout human history, forest products have been used for a variety of purposes including food, medicine, fibre, fodder, agricultural amenities and construction materials. These NTFPs can play an important role in rural livelihood strategies and can contribute to sustained forested landscapes (Ros-Tonen and Wiersum, 2005). World Bank (2016) stated that rural households who live near forests get as much as 22% of their income from timber and non-timber forest resources, 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.

Activity 5.7 In text question (5 minutes)
Describe the main forest products and services contributing to diversification and sustainability of livelihoods in your country.

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

Social systems are patterned networks of relationships that form 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 (Marten, 2001) including management of forest resources.

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 what they can adapt including sharing of the costs of adaptation. Negative impacts are chance occurrences that come as surprises whose 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 or bush fire (Schneider and Sarukhan, 2001).

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

A resource system was defined long back as comprising three (subsystems) of: biophysical, social and technological representing land, people and technology components of a resource system respectively. Biophysical/ecosystem includes soil, topography, climate, vegetation and other elements. Social system includes population, social, economic and political structures, etc., and technological system includes tools, implements, cropping patterns, resource practices, dissemination methods, etc. (Firey, 1960). 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 the movement of energy/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, social resources such as loyalties and resources from its environment.

Organisation of system expends, secures and conserves energy to preserve the system and promote its goals. Therefore, even if energy is available in and to a system, and there is no organisation, the system is also absent. This means a system has some form of organisation. Internal and external forces can disorganise a system. 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), or **purposeful** system that determines its own goals and the ways to achieve them (e.g. an animal, household or nation). In this context, the purpose of an organisation is to serve the purposes of its members while also serving the purposes of its environment (Gharajedaghi, 2012).

The five basic elements of any 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 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). 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, a consensus is essential to the alignment of multi-minded systems (Gharajedaghi, 2012);
- **Boundary/demarcation:** Boundaries or 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);
- **Legitimacy** relates to both power and authority which can be internal or external. Internal 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);
- **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); and
- **Hierarchy** shows interrelatedness and interdependence in a system. For example, a human being system is part of a household system, which is part of 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, cognizance of the influence of higher and lower-order systems must be taken.

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. Other networks are distributive as in the rumour mill existing in most organisations. Collaborative social networks make everyone accepted 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 (Barrow and Murphree, 2001).

5.3.3 Gender and forest-based adaptations

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

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). Gender is one of the cross-cutting issues that must not be ignored in CCA. In this regard, mainstreaming of gender is important for addressing concerns and experiences of women and men in designing, implementing, monitoring and evaluating all policies and programmes so that women, men and youths are treated fairly (United Nations, 2002).

Gender mainstreaming was adopted by the UN's Economic and Social Economic Council focusing on assessing how women and men are affected by any planned action, including policies, legislation and programmes at all levels, in all sectors. The UNFCCC (2014a) developed a gender-sensitive approach for mainstreaming climate change which can also be applied in forest-based adaptation initiatives.

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

5.3.4 Indigenous coping and adaptation mechanisms and strategies

Indigenous knowledge 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 indigenous knowledge to adapt to climate change and variability (Osbahr et al., 2010), including droughts (e.g. Ncube and Lagardien, 2015; Kihila, 2018), floods (e.g. Hooli, 2016), ocean warming (e.g. Belhabib et al., 2016).

Climate change impacts have affected livelihoods, but rural communities have developed their own coping and adapting strategies. The rural communities do not depend on modern scientific knowledge but have been growing crops using their local knowledge of ecological conditions. The adaptive actions are a product of their knowledge, priorities and capacities which permit them to plan and cope with local climate change and variability (Mugambiwa, 2018).

Communities have been using several strategies to cope and adapt depending on the type of livelihood venture. For example, communities in Tanzania used practices such as tree planting, terracing, crop diversification, water harvesting using locally-based water reservoirs and mixed cropping (Kihila, 2018). In Tanzania, farmers used strategies such as rain water harvesting in ditches, check dams and they also engaged in alternative economic activities. Farmers in South Africa used kitchen garbage and manure for improving soil fertility whilst others changed to more drought-resistant livestock systems from cropping system. In other cases, cotton farmers in Zimbabwe irrigated their crops and diversified into more drought-resistant crop varieties and 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 et al., 2019).

In southern Africa, people and communities have always adapted to climate variations through adaptive actions linked to their resources and their accumulated knowledge of experience of past weather patterns resulting in them being 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 in Mozambique), Namibia (e.g. The Mayuni Conservancy) and Zimbabwe (e.g. Masoka CAMPFIRE Programme) (Chishakwe et al., 2012).

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

Livestock farming has been considered the 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 other areas, sell their livestock early or destock without compromising the breeding herd. They also manipulate feeding strategies to sustain the herd. Farmers breed livestock for drought tolerance, change the 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 windmill to pump water from boreholes. Similarly, fishermen also adapted by changing fishing times, fishing in deep waters, scheduling particular times for fishing and also engaging in alternative economic activities (Kihila, 2018).

African farmers are known to have practiced the fallow system 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 certain areas. Forests have been recognised by traditional institutions for managing communal forest reserves. These well managed forests provided food and timber resources to the community (Ajani et al., 2013), although they did not know the role as C sinks. 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 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)

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 who reside close to forests, headed risk-averse older individuals who are less educated, depend more on forests to cope with climatic shocks than the others (Ludena and Yoon, 2015).

Activity 5.9 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? and
4. What is the importance of indigenous coping mechanisms in CCA? Give examples.

Summary

In this section, we learnt about social and economic adaptation. Sustainable drivers of 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 respectively. Social system includes population, social, economic and political structures etc., and technological system includes tools, implements, cropping patterns and 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 CCA because climate change affects women and men differently. We also discussed a gender based five step process for mainstreaming adaptation which was applied in one of the African countries. 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. These should be considered in designing adaptation strategies.

Chapter 6: National, Regional, and International Adaptation Strategies

6.1 Chapter overview

There are several national, regional and international CCA initiatives that are being implemented and funded in the African region. The initiatives include protection of current biodiversity patterns, NAPAs, NAPs, formulation of legislation and policies to support CCA and the barriers and challenges to adaptation. This chapter discusses these initiatives highlighting some of the examples from the African region.

Learning outcomes

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

i. Explain how current patterns of biodiversity can be conserved;
ii. Identify national, regional and international adaptation initiatives;
iii. Distinguish between NAPAs and NAPs and their processes;
iv. Analyse some of the legislation and policy instruments for supporting adaptation; and
v. Participate in national CCA initiatives.

Activity 6.1 Brainstorming (15 Minutes)

What are some of the strategies and approaches used in your country to protect current patterns of biodiversity?

6.2 Protecting current patterns of biodiversity

Climate change will have significant impacts on an array of ecosystem functions, causing a need for management options working both directly and indirectly to maintain ecosystems integrity in the face of climate change. Adaptation strategies and approaches for natural ecosystems to cope with projected climate change impacts have increased over time and vary from one country to another and from one place to another.

The approaches nested under each strategy further vary in management intensity and style, emphasis on form or function and reliance on traditional or experimental techniques. For SFM, more detailed adaptation responses with consideration of site conditions and management objectives may be needed. Selected approaches may promote existing species that are expected to be better adapted to future conditions or altered structure or composition to reduce risk or severity of a disaster e.g. fire. The strategies can vary in their emphasis on building resilience, resisting potential changes, or resistance to the changes (see Table 11). Approaches needed to achieve the strategies are outlined in Table 12.

Table 11. Climate change adaptation strategies and options for biodiversity conservation

Strategy		Resistance	Resilience	Response
1.	Sustaining critical ecological functions	X	X	X
2.	Reducing the impact of prevailing biological stressors	X	X	X
3.	Protecting forests from severe fire and wind disturbance	X	X	
4.	Maintaining or creating refugia	X		
5	. Maintaining and enhancing species and structural diversity	X	X	
6.	Increasing ecosystem redundancy across the landscape		X	X
7.	Promoting landscape connectivity		X	X
8.	Enhance genetic diversity		X	X
9.	Facilitating community adjustments through species transitions			X
10.	Planning for and responding to disturbance			X

Source: Butler et al. (2012)

Table 12. Adaptation strategies and approaches for forest ecosystems

Strategy	Approaches
Sustain fundamental ecological functions	• Maintain or restore soil quality and nutrient cycling; • Maintain or restore hydrological systems; and • Maintain or restore riparian areas.
Reduce the impact of existing biological stressors	• Maintain or improve the ability of forests to resist insect pests and pathogens; • Prevent the introduction and establishment of invasive plant species and remove existing invasive species; and • Manage herbivory to protect or promote regeneration.
Protect forests from severe fire and wind disturbance	• Alter forest structure or composition to reduce risk or severity of fire; • Establish fuel breaks to slow the spread of catastrophic fire; and • Alter forest structure to reduce severity or extent of wind and ice damage.
Maintain or create refugia	• Prioritise and protect existing populations on unique sites; • Prioritise and protect sensitive or at-risk species or communities; and • Establish artificial reserves for species at-risk and displaced species.
Maintain and enhance species and structural diversity	• Promote diverse age classes; • Maintain and restore diversity of native tree species; • Retain biological legacies; • Restore fire to fire-adapted ecosystem; and • Establish reserves to protect ecosystem diversity.
Increase ecosystem redundancy across the landscape	• Manage habitats over a range of sites and conditions; and • Expand the boundaries of reserves to increase diversity.
Promote landscape connectivity	• Use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity; • Establish and expand reserves and reserve networks to link habitats and protect key communities; and • Maintain and create habitat corridors through reforestation or restoration.
Enhance genetic diversity	• Use seeds, germplasm and other genetic material from across a greater geographic range; • Increase diversity of nursery stock for species or genotypes likely to succeed; and • Favour existing genotypes that are better adapted to future conditions.
Facilitate community adjustments through species transitions	• Anticipate and respond to species decline; • Favour or restore native species expected to adapt to future conditions; • Manage for species and genotypes with wide moisture and temperature tolerances; • Emphasise drought-and heat-tolerant species and populations; • Protect future-adapted regeneration from herbivory; and • Establish or encourage new mixes of native species.
Plan for and respond to disturbance	• Prepare for more frequent and more severe disturbances; • Prepare to realign management of significantly altered ecosystems to meet expected future environmental conditions; • Promptly revegetate sites after disturbance; • Allow for areas of natural regeneration after disturbance; and • Remove or prevent establishment of invasive and other competitors after disturbance.

Adapted from Butler et al. (2012)

Climate refugia are specific areas where climate and associated biophysical circumstances are likely to remain stable, with small impact on biodiversity, as other places suffer from climate change impacts. They can also be areas hosting climates that are suitable for species in the surrounding areas affected by climate change, but they are suitable. Examples of these latter types of refugia include high plateaus, mountain ranges and cold-air drainages.

Activity 6.2 Brainstorming (15 Minutes)
Identify different strategies that can build resilience, resist potential changes, or cause them to respond to the changes.

6.3 National Adaptation Programmes of Action (NAPAs), National Adaptation Plans (NAPs)

Adaptation to climate change is becoming an international issue required by all countries to cope with the impacts of climate change. The seventeenth session, the COP to the UNFCCC acknowledged the importance of NAPs so that all developing and LDC parties can assess their vulnerabilities, mainstream climate change risks and address adaptation. NAPAs were initially created to act as channels through which LDCs could quickly access support to manage new and heightened levels of vulnerability to floods, drought and other adverse effects of climate change and had to take advantage of win-win measures that would avoid increased damages and be more expensive to implement in the future. This section discusses NAPAs and NAPs.

Learning outcomes

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

i. Identify national, regional and international adaptation initiatives;
ii. Distinguish between NAPAs and NAPs and their processes;
iii. Analyse some of the legislation and policy instruments for supporting adaptation; and
iv. Participate in national CCA initiatives.

Activity 6.3 Brainstorming (15 Minutes)

What are some of the domesticated international climate CCA initiatives you are familiar with?

6.3.1 NAPAs

Countries are expected to monitor, review, update and periodically report their progress to the UNFCCC through their National Communications (NCs). LDCs are more vulnerable to climate impacts and are assisted through their NAPAs as submitted to the UNFCCC. NAPAs were initiated by UNFCCC in 2001 to assist LDCs identify their most critical and priority actions in the absence of which vulnerability and/or costs are increased. Parties in LDCs prepared the documents (NAPAs) outlining urgent or priority activities, responding to their specific needs for coping with climate change. Progress has been made and substantial efforts and progress have been made by developing nations in preparing their NCs to create NAPAs, following UNFCCC reporting guidelines. The NAPAs are then presented to the global donors for funding. Figure 19 shows the nine steps for developing NAPAs.

The NAPA process involved the establishment of multidisciplinary NAPA teams of national experts, from government agencies, civil society and local communities to prepare the NAPA and coordinate its implementation. Engagement of national experts ensured a successful NAPA preparation process and equally contributed to enhancing the experience and capacity for adaptation. The NAPAs are developed to help national planning as an APF to assess vulnerability and develop adaptation strategies (Adger et al., 2007).

Important information and procedures for climate change mainstreaming are provided in the NAPAs, recognising the importance of community-level involvement as a key information source and that communities are the key stakeholders. Existing information is used by considering existing grassroots coping strategies and building on the information to identify important strategies instead of focusing on scenario-based models for evaluating long-term vulnerability and national policies. The focus of NAPAs is generally not to mainstream CCA into development planning but can help to incline and often suggest mainstreaming as a significant intervention.

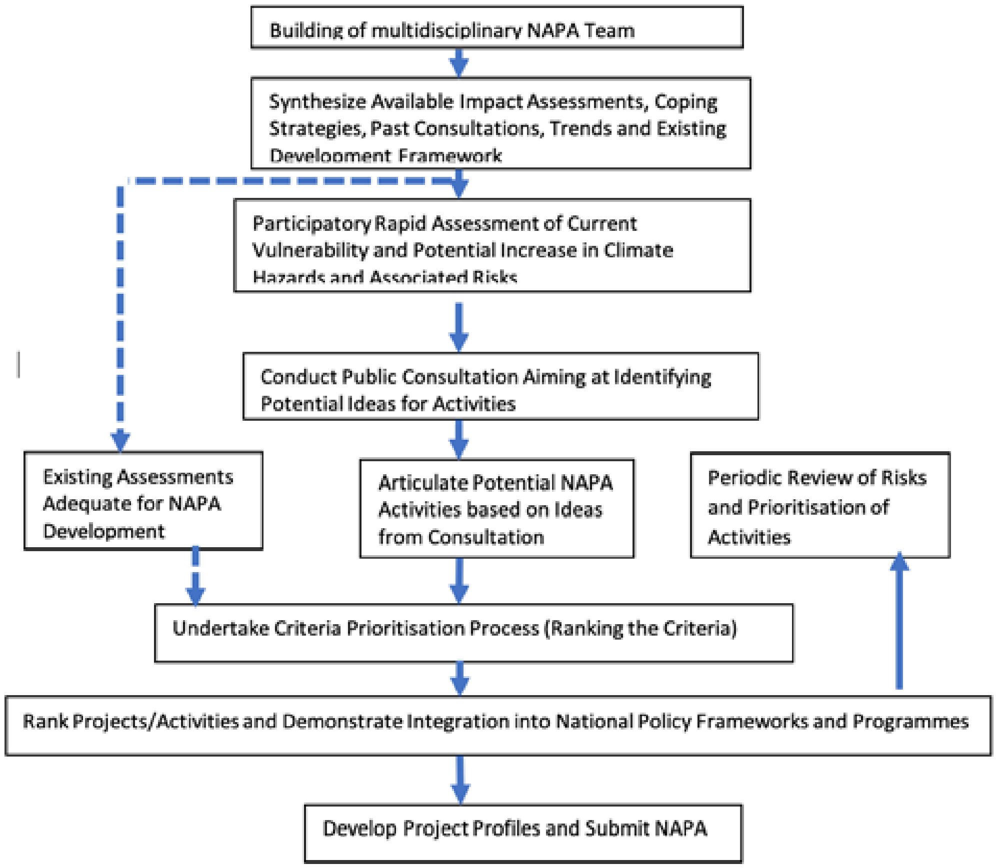

Figure 19. Steps in developing NAPAs. Details at: https://www.uncclearn.org/sites/default/files/inventory/unfccc65.pdf

Climate change mainstreaming issues related to vulnerability and adaptation were put on the agenda at the COP 7 in Marrakech, Morocco in 2001, where it was decided that special support should be given to a group of LDCs to the development of NAPAs (Burton and Lim, 2005). COP 7 also further supported adaptation activities by a strong recognition of the special needs of developing countries (Adger et al., 2003). Examples of African countries with NAPAs that have a forestry component are shown in Box 6.1.

Box 6.1 Forests for climate change adaptation in African NAPAs

In Africa, inclusion of adaptation in forestry is not well defined and mainstreaming into policy is lacking. However, some NAPAs proposed adaptation actions that are related to forestry. Forestry strategies in NAPAs aim at SFM instead of CCA and these include:

- Afforestation/reforestation and forest restoration using species suitable for future climate and fast-growing tree species resistant to possible disturbances, such as insect pests, pathogens and fire (e.g. Burundi, Eritrea, Samoa and Tanzania);
- CBFM and forestation (e.g. Ethiopia, Tanzania and Zambia); and
- SFM and protected areas to promote forest conservation (e.g. Djibouti, Democratic Republic of Congo (DRC), Guinea, Guinea-Bissau, Senegal and Tanzania) (https://www.cirad.fr/en).

It is difficult to extrapolate from current ecological knowledge how ecosystems will adapt to a changing climate and how cumulative ecosystem vulnerability might evolve although models show that climate change will very likely affect the distribution of ecosystems and species, with consequences for the flow of ecosystem services. Maladaptation and short-term coping strategies may create additional pressures on ecosystems, for example if forest products used as safety nets come from unsustainably managed forests. There is need to increase cross-scale and cross-sectoral linkages in adaptation planning as ecosystem benefits and management costs generally occur in different locations and in different sectors of society.

6.3.2 National Adaptation Plans

The NAPA process was designed to produce one national adaptation programme of action whilst the NAP process creates a comprehensive system through which countries can integrate CCA into national planning and produce NAPs on an ongoing basis. In this regard, the NAP process builds upon the achievements and lessons learned from the NAPA process to make medium and long-term plans for adaptation (LDCEG, 2012). NAPs have emerged as important mechanism for bringing together several adaptation efforts into logical and sustainable national approaches. The UNFCCC process helps countries to address climate risks through NAPs, which detail measures to help make nations and communities resilient to climate change impacts. Through expert bodies and committees, the UNFCCC supports governments across the whole adaptation cycle-science and observation, planning and implementation, reporting, monitoring and review.

The procedures for formulating and implementing NAPs aim at reducing vulnerability, mainstreaming adaptation and providing an opportunity to address synergies between adaptation and development. Given their success as planning instruments, the resources available for their support and their iterative nature and flexible nationally driven formats, NAPs are an excellent option to support the implementation of enhanced adaptation action.

The UNFCCC guidelines show the NAP process with four elements and 17 steps (Figure 20) supported by guiding principles (Box 6.2). The objectives of the NAP process are to:

- Develop adaptation capacities and increase resilience in order to reduce vulnerability to climate change; and
- Facilitate the coherent integration of CCA into appropriate new and existing policies, programmes and activities, in particular, development planning processes and strategies, within all sectors and at different levels, as applicable (decision 5/CP.17, paragraph 1).

Box 6.2 Guiding principles for NAPs

In decision 5/CP.17, paragraph 3, the COP agreed that enhanced action on adaptation should:

- Be assumed in agreement with the Convention;
- Follow a country-driven, participatory, gender-sensitive, and fully transparent approach, considering vulnerable groups, communities and ecosystems;
- Be based and guided by the best existing science and, as suitable, traditional and local knowledge, and by gender-sensitive approaches, with a view to integrating adaptation into relevant social, economic and environmental policies and actions, where appropriate; and
- Not be prescriptive, nor result in the repetition of efforts implemented in-country, but facilitate country-owned, country-driven actions.

Figure 20. Elements and steps in technical guidelines for NAP process under UNFCCC

There are several challenges for developing countries to the development and implementation of NAPs and these include: capacity-building, finance, technology development and technology transfer. Establishment of institutional structures and coordination for CCA remains a key challenge for most developed and developing nations. The process of formulating and implementing NAPs can successfully support the enhanced adaptation action and the development of integrated approaches to adaptation, sustainable development and DRR. NAPs have the potential to become a key instrument for facilitating the integration of adaptation into sustainable development. NAPs give exceptional opportunities for supporting implementation of improved adaptation activities because they are successful planning instruments, they are supported by funding, are flexible and nationally driven.

6.3.3 Legislation and policies on adaptation to climate change

The Paris Agreement requires all countries to execute their NDCs. To keep the rise in mean temperature below 2^{0}C, countries need to introduce new laws and policies, revisit, revise and intensify their operational policies and laws to keep up with ambitions of the Paris Agreement together with issues of monitoring, reporting, and verification (MRV). The success of the Paris Agreement depends on the ability of countries to import the internationally approved targets into legitimate national policies and laws and to translate the targets into action. However, all Parties to Paris Agreement have at least one law focusing on climate change or some transition to a low-C development. As of March 2018, over 1,500 climate laws and policies were produced globally, with 106 more legislative frameworks introduced since the Paris Agreement. About 139 countries have framework laws that address climate mitigation or adaptation holistically (Nachmany and Setzer, 2018).

Most climate change laws are either framed as climate change mitigation or adaptation. The Climate Change Laws of the World database (Climate Change Laws of the World) shows that about 99 countries uploaded policies/laws related to mitigation and adaptation. About 65 of the countries submitted policies/laws related to CCA up to 2018 but only nine are from sub- Sahara Africa. The focus of the African adaptation policies/laws is mainly disaster and risk management (Kenya, Mali, Ghana and Tanzania), national climate change response strategy (Zambia), national adaptation strategy and disaster management organisation Act (Ghana) and NAP from Burkina Faso. Clare et al. (2017), showed that about 139 countries made attempts to address climate change through framework laws, that set the agenda, created institutional infrastructures for action and caused momentum that increased the adoption of subsequent legislation.

APF studies can be in the form of:

- **Vulnerability-based approach**: Determine how future climate hazards are likely to affect current or desired vulnerability;
- **Hazards (natural)-based approach**: Analysis of probable outcomes from a particular climate hazard;
- **Adaptive-capacity approach**: Analysis of adaptation barriers and proposals of how to overcome them; and
- **Policy-based approach**: Investigation of the efficacy of an existing or proposed policy given a fluctuating exposure or sensitivity.

Activity 6.4 Revision (10 Minutes)

1. Distinguish between NAPA and NAP;
2. Explain the importance of NAPs; and
3. Describe forms of adaptation policy frameworks.

Summary

In this session, we looked at international arrangements through UNFCCC for facilitation adaptation in developing countries. The NAPA process was designed to produce national adaptation programmes of action and the NAP process builds upon the achievements and lessons learned from the NAPA process to make medium and long-term plans for adaptation. The NAP process is expected to create a comprehensive system through which countries can integrate CCA into national planning and continuously produce and update NAPs. In this regard, the processes have clear guidelines for implementation under UNFCCC. The success of the Paris Agreement depends on the ability of countries to import the internationally approved targets into legitimate national policies and laws and to translate the targets into action. There are several forms of adaptation policy frameworks that can be applied.

6.4 Challenges to adaptation

Changes in one system on the 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 risk, 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 and these will be discussed in this section.

Learning outcomes

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

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

i. Identify technical challenges to CCA;
ii. Explain social challenges to CCA;
iii. Explain financial and economic challenges to adaptation; and
iv. Explain political and institutional challenges to CCA.

Activity 6.5 (Brainstorming) (10 Minutes)

What do you think are the major barriers and challenges of CCA?

6.4.1 Adaptation gaps and barriers

Despite the benefits that adaptation practices can provide, the barriers that could make individuals reluctant are many. Many factors complicate and impede public understanding, initiation, implementation and support of actions to reduce GHG emissions and encourage adaptation. Climate change is now adding new challenges related to the many uncertainties involved, 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 for 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.

Moser and Ekstrom (2010) 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 is not '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. Furthermore, 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. Box 6.3 shows some of the major CCA barriers.

Box 6. 3 Barriers to adaptation

- **Poor policy environment:** Policy environment has no conditions to support to 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 infrastructure 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, historical track records weak, 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 chain);
- **Uncertain or unknown value-added:** Users are not aware of the value or benefit of the technology or its uncertainty; 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:** Includes 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; and
- **Informational barriers:** Lack of information on climate change predictions and weather, agroforestry and/or afforestation, different crop varieties and adaptation strategies (Niang et al., 2014; Hallmeyer and Tonkonogy, 2018).

6.4.2 Policy/ institutional 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). In some cases, absence of practical implementation strategies, 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.

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 CCA initiatives in Southern Africa is blocked by other issues such as mitigation, disaster and risk (Chevallier, 2012; Nciizah et al., 2021).

Furthermore, forest governance issues can be a barrier to successful forest-based climate change action and Atyi (2017) identified five barriers related to forest governance:

- Poor enforcement of forestry laws and regulations;
- Invasive political influence on forestry policy and decision making;
- Lack of land-use planning;

- Lack of coordination between government ministries; and
- A substantial but poorly monitored informal sector.

6.4.3 Technical/ 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 a need to understand the behaviour and how it affects the flow of ecosystem services. Maladaptation and short-term coping strategies create a challenge by generating additional pressures on ecosystems. For example, when NTFPs used as safety nets are collected from forests that are not sustainably managed (Apeaning, 2019).

To overcome some of these challenges, adaptation planning should be linked across sectors and scales. Poor seed quality and no inputs ascribed to lack of quality controls by government and corrupt business practices by traders, poor market access and insecure tenure are some of the challenges (Onyango et al., 2020). Technical knowledge or capacities are often lower in the developing world than 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 of the existing policies do not apply the landscape approach frameworks for implementing climate and development objectives (Aronson et al., 2019).

Implementation of NDCs and NAPAs lack the capacity to use the specific policy tools and actions for forestry projects. There is an inability to carefully consider and factor in the potential of trees to provide ecosystem services under changing climate (Chambwera et al., 2014). There are also 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 (e.g. 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. 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 (Fazey et al., 2010; Schirmer and Yabsley, 2018).

There is high variability of adaptation needs, risks and decisions about potential climate risk depending on economic/resource sectors and regions. The level and speed of adaptation in developing countries are affected by their technological progress. Also, there is poor 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 are difficult to model because of the sparse coverage and short and fragmented digitised records available (Boko et al., 2007). There are also poorly resourced meteorological agencies with no in-country expertise to interpret and use climate information for planning and decision making (Dinku et al., 2011).

6.4.4 Financial and economic challenges

There are several factors linked to economic challenges for adapting to climate change including lack of finances, adequate preparation and quick response to climate change disasters. Adoption of some adaptation strategies can be hampered by discouraging results e.g. possible reduction in short-term crop yields. Savvidou et al. (2021) showed 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. High costs of adaptation actions may require external inputs for the poor communities. Intangible advantages of taking specific actions (adapting or limiting emissions) are usually not clear to the laymen. There is a lack of ready markets for ecosystem goods and services, complicated and lengthy processes to get global environmental funds. There is uncertainty around investment returns. Lack of consideration of climate risk in investment decisions and high upfront costs of technology.

There is some discouragement resulting from possible short-term crop yield reductions for some of the 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.

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.

6.4.5 Socio economic challenges

Socio economic challenges are linked to the financial challenges stated above including lack of finances and discouragement resulting from possible short-term crop yield reductions for some adaptation strategies. The costs and benefits of different courses of action 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. In Africa, poverty limits the means to cope with and adapt to climate change effects (Dungumaro and Hyden, 2010; Adhikari and Baral, 2018).

Farmers can become reluctant due to their own perceptions, views and beliefs about climate change exacerbated by inadequate economic capacity to adapt for most of the rural poor (IPCC, 2014). Public understanding on climate change is disturbed by inadequate support for initiation and implementation of adaptation measures.

Activity 6. 6 Revision

1. Give an outline of political or institutional challenges to adaptation;
2. What are technological and social challenges? and
3. Give examples of socio-economic challenges for adaptation to climate change.

6.5 Case studies on forest-based climate change adaptation strategies

The following two case studies from Ethiopia and Guinea document forest-based climate change adaptation strategies.

Livelihood resilience and ecosystem protection in Ethiopia

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 was rehabilitated. Furthermore, six nurseries were established with 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 oil extracted create savings and also 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.

Adaptation in coastal zones of Guinea

The coastal management project focused on strengthening the protection of vulnerable coastal communities and areas against the harmful effects of climate change. About 94,169 people (56% women and 44% men) in 35 districts of Guinea are working on integrated approach for coastal protection measures and land restoration. Coastal protection activities included clearing silt and sedimentation along 4 200 metres of the 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 879 ha of agricultural land which was abandoned due to salt water invasion was restored. Furthermore, 1,356 ha of rice fields were protected against salt water intrusion, salt water flooding and erosion of channels. This is expected to increase rice yields from 600 kilograms per ha to 2 500 kg/ha, thus improving food security in those communities. The protection dykes and the use of seeds that are tolerant to salt water and soil acidity have resulted in improved rice yields.

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

- A community association managing 200 beehives;
- Efficient charcoal production kiln used with a local name “the meule casamançaise”. About eight ha were planted for extraction of charcoal wood in managed areas. A SFM plan will be used to define logging zones, regulate access and determine the sustainable harvesting yield;
- Improved cook stoves, with enhanced efficiency of 35%;
- Cultivation of oysters to diversify income; and
- 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.

Summary

In this section, we learnt that there are challenges to CCA 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 CCA are linked to social characteristics of communities that expose them to the impacts of a changing climate.

6.6 Initiatives for adaptation in Africa

In the previous section, we learnt about the barriers and challenges faced when planning and implementing CCA initiatives. In this section, we discuss NDCs, adaptation benefit mechanisms and other African initiatives. Adaptation initiatives are based on submissions submitted in the NDCs.

Learning outcomes:
By the end of this section, learners should be able to:
i. Give an outline of some of the African adaptation initiatives;
ii. Explain INDCs; and
iii. Explain adaptation benefits mechanism.

Activity 6. 7 (Brainstorming) (10 Minutes)
Share your experiences about African adaptation initiatives.

6.6.1 Nationally Determined Contributions (NDCs) adaptation

Decisions 1/CP.19 and 1/CP.20 of the COP, expected all Parties to communicate their INDCs before COP 21 clearly displaying transparency, understanding and clarity of their INDCs. 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. When countries adhere to the INDCs, the global success of the ambitious 2015 agreement for a low-C, climate-resilient future is guaranteed.

The INDC is scaled into NDC after formally joining the Paris Agreement by submitting an instrument of ratification, acceptance, approval or accession. The Paris Agreement of 2015 (Article 4, paragraph 2) requires every Party to formulate, communicate and sustain consecutive NDCs for reducing national emissions and adapting to climate change impacts. Parties should monitor domestic mitigation and adaptation actions, aiming to achieve the 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 are required by 2020 and every five years thereafter for all Parties, irrespective of their implementation stages. In this regard, beginning of 2023 and every subsequent five years. Governments are required to assess the implementation towards the achievement of the purpose of the Paris Agreement and its long-term objectives.

The Paris Agreement adopted at COP21 of UNFCCC encouraged Parties to programmes that include implementing REDD+ and joint mitigation/adaptation activities, taking into consideration the non-C 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. INDCs 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 level, increasing temperatures and drought. Fobbisie 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.

6.6.2 Adaptation benefits mechanisms

The AfDB developed a new funding mechanism called the Adaptation Benefit Mechanism (ABM), which draws from earlier experience with market mechanisms and aims to provide an incentive for investment in activities that contribute to adaptation. The ABM was launched in March 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 CIF.

Project outputs include any outcome that makes households, communities or economies less vulnerable to climate change and improves them economically. The pilot phases in Côte d'Ivoire, Rwanda and Uganda are being implemented by the World Agroforestry Centre and the Center for Governance and Human Security Studies respectively. The projects covered obtain Adaptation Benefit Units that are measured according to the approved methodologies. The ABM is a non-market mechanism and Adaptation Benefit Units cannot be transferred.

6.6.3 Other African adaptation initiatives

Although environmental management problems have always been associated with varying levels of uncertainty, limited information and risk, there is need for rethinking and reforming of management and conservation approaches in the face of climate change. In Africa, adaptation initiatives have mainly focused on building resilience 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. Adaptations reported from Africa are mostly from countries receiving adaptation funds for reducing vulnerability and building resilience, 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). Some of the adaptation initiatives are shown in Box 6.4.

Box 6.4 Case studies

Solving land degradation in Ethiopia

International Fund for Agricultural Development supported a project addressing land degradation in Ethiopia using Community-based Natural Resource Management (CBNRM) 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 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 the livestock

(http://africasd.iisd.org/news/ifad-project-combats-land-degradation-in-ethiopia/).

Zimbabwe fruit orchard land use system (UNDP, 2018)

A community in Ward 7 of Chiredzi District in Zimbabwe with 624 members planted 5 ha of mango tree orchard integrated with cassava and vegetable production to adapt to climate change. A farming group was initiated after members contribute 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 a contribution of a monthly or quarterly membership fee of US$ 1 to improve the group's cash flow. The CBA for mango production was favourable with participants generating US$ 27,500 (corresponding to US$ 352 per household per year). Initial costs were US$ 32,440 reducing to US$ 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.

Livelihood resilience and ecosystem protection, Rwanda

In Rwanda, 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 has a memorandum of understanding with the Rwanda Agricultural Board. The Rwanda Agricultural Board 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 are showing sustainability of the project by continuously providing tree seedlings and generating income to the people who work in these nurseries. The project has raised up to 5 million seedlings, 3 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. The 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 the 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 fodder trees support livestock whilst indigenous tree species are planted for medicinal value and help the conservation of biodiversity. Further, there will be 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 6. 8 Revision

1. Distinguish INDC and NDC;
2. Discuss the relevance of ABM to the African continent; and
3. Explain some of the forest based CCA initiatives in Africa.

Summary

In this section, we learnt that INDC set out the steps that governments proposed to undertake to tackle climate change post 2020. The INDC is then scaled into NDC after formally joining the Paris Agreement by submitting an instrument of ratification, acceptance, approval or accession. The AfDB developed ABM 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.

PART III:
NON-FOREST BASED CLIMATE CHANGE ADAPTATION

Chapter 7: Other Sectors Impacted by Climate Change

7.1 Chapter Overview

Understanding strategies used in adaptation to climate change in other sectors is fundamental in providing a holistic approach to learners on how to relate them to forestry. This will enhance the knowledge and understanding of learners because forestry is inexorably linked to other sectors, because it also plays a significant role to other sectors like water, health, agriculture, fisheries and coastal ecosystems, among others. This chapter will introduce learners to adaptation strategies and related mechanisms from outside the forest sector.

Learning Outcomes

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

i. Explain the effects of climate change on sectors outside forestry; and
ii. Describe the technological adaptation outside forestry sector.

Activity 7.1 (Brainstorming) (10 Minutes)

Explain the relationship between forestry and other sectors relative to CCA.

7.2 Development sectors affected by climate change

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, learners are exposed to climate change impacts in the following sectors: agriculture, water, marine and coastal, energy, transport and tourism sectors. Options to improve CCA such as effective use of EWS are cross-cutting for all sectors.

7.2.1 Agricultural sector

Agriculture is one of the key sectors sustaining human life and is also critical for adaptation to climate change together with mitigation initiatives because it addresses climate change and is important for food security. Climate change impacts on agriculture have negative consequences on food supply. Box 7.1 shows a summary of climate change impacts on agriculture.

Box 7.1 Climate impacts on agriculture (Prutsh et al. 2014)

- 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 during 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 pathogens;
- 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 dangerous to plant development; and
- Higher summer temperatures reduce food intake and productivity in animal husbandry.

Smallholder farmers and agriculture are threatened by rainfall and temperature variability. Agriculture impacts are more severe for those who depend on rain-fed activities. Several adaptive actions have however been implemented in different circumstances. Adaptation strategies in agriculture include: changing planting strategies, crop rotation, minimum tillage, switching crops, rain water harvesting, using irrigation, improving agricultural methods, planting drought-resistant crops, shifts from rain-fed to irrigated agriculture and small and drought-resistant livestock (Akinnagbe and Orohibe, 2014; Myers et al., 2017). Box 7.2 shows examples of adaptation in cropping and livestock practices.

Activity 7.2 In text question
What are the two most important variables for crop growth that are impacted by a changing climate?

Box 7.2 Examples of cropland and livestock adaptation initiatives in Africa

Cropland adaptation

- Adaptation in cropping systems include planting of drought resistant crop varieties in the practices by smallholder farmers as adaptation methods to climate change in Burkina Faso, Nigeria, Ghana and Senegal (Ngigi, 2009; Thierfelder et al., 2017);
- Crop diversification can be used as insurance against rainfall variability to promote food security in Africa (Akinnagbe and Irohibe, 2014; Waha et al., 2018). In western Sudan, food crops were replaced with cash crops and more resilient crop varieties (DFID, 2004), whilst in Uganda, farmers diversified crop varieties to spread risks on the farm (Orindi and Eriksen, 2005; Atlin et al., 2017);
- Improved irrigation efficiency through increased use of irrigation. In Gambia, South Africa and Sudan, farmers used adaptation measures as irrigation water transfer, water harvesting and storage to cushion the effects of rainfall variability (Osman et al., 2005; Nkomo and Gomez, 2006). In Kenya, they use soil moisture retention practices such as terracing and sand dams (Kalungu et al., 2015); and
- Change in cropping pattern and calendar of planting-In Tanzania, crop production risks due to rainfall variability and drought were averted by staggered planting dates in order to distribute risk (Liwenga, 2003).

Livestock adaptation

- Nomadic pastoralists living in the desert margins of Kenya adopted drought tolerant strategies to sustain their livestock (Langill and Ndathi, 1998); and
- Pastoralists in Ethiopia traditionally regulate the mating periods of their goats and sheep to avoid loss of new borne and the mother during possible harsh drought conditions (Menghistu et al., 2020).

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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 also protect crops against climate extremes through microclimate amelioration (Chavan et al., 2014). With their deep root systems, trees are able to explore larger soil depths for water and nutrients, which will be beneficial to crops in times of drought. Their contribution to increased soil porosity, reduced runoff and increased soil cover leads to increased water infiltration and retention and reduction of moisture-stress during low rainfall. On the other hand, excess water is pumped out of the soil more rapidly in agroforestry plots due to their higher evapotranspiration rates. Furthermore, Nitrogen-fixing trees make agriculture more drought-resilient due to improvements in soil nutrients and water infiltration, especially in degraded land. Adaptation strategies however, vary depending on area and type of crop because different crops are affected differently by climatic events (IPCC, 2001).

In Malawi and Zambia, maize production yields were greater in areas where conservation farming was practiced with *Faidherbia albida*, a tree shedding its foliage during the early rainy season when crops are established and re-growing its leaves at the end of the wet season, thus limiting competition for light, and minimising competition for nutrients, or water with growing crops. 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, FMNR programme with *F. albida* improved their sorghum and millet yields, partly due to reduced wind speed and increased soil moisture (FAO, 2016d). 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).

7.2.2 Coastal, marine systems and fisheries

Communities living on 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 defense against rising water, floods and lagoon siltation. In Guinea, communities engaged in coastal protection focus on clearing silt and sedimentation from 4,200 metres of the drainage channels in Kaback and building 13,000 metres of stone dykes (UNDP, 2018).

In 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 western shores of lake Turkana. The communities were able to show attitude change and also realise income from an area that was previously filled with negative attitude towards the invasive *Prosopis juliflora* (Owino et al., 2020).

The rising sea-levels threaten a large number of 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). Many 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 the changing of the 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 coral, eelgrass and abalone (Dutta et al., 2020).

7.2.3 Health and sanitation

Africa is vulnerable to a number of 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). Furthermore, UNFCCC (2017) stated that extreme temperatures can aggravate cardiovascular and respiratory diseases and increase mortality. Future climate variability will also interact with other stresses and vulnerabilities such as HIV/AIDS (which is already reducing life expectancy in many African countries) and conflict and war (Harrus and Baneth, 2005), resulting in increased susceptibility and risk to infectious diseases (e.g. cholera and diarrhea) 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 is associated with a 0.3% increase in economic growth. A summary of the impacts of climate change on health is given in Box 7.3.

Activity 7. 8 Brainstorming (10 minutes)
Give examples of climate related health issues that are linked to forests.

Box 7.3 Impacts of climate change on human health

- 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 (especially, 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 island;
- Expansion of distribution areas and establishment of new disease vectors (insects, ticks, rodents) and pathogens (e.g. lyme disease);
- Climate change can cause the 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 irritate mucus membranes and respiratory reactions; and
- Increased Ultraviolet radiation increases the risk of skin tumours and cancer (Prutsch et al., 2014).

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 the 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.

7.2.4 Built environment and infrastructure

Besides social conflicts and pollution, the 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 Africa, population in urban areas is relatively low but is likely to rise and pose more problems. Climate change destroys built environment and infrastructure (Box 7.4).

Box 7.4 Impacts of climate change on infrastructure development

- Heat stress can increase and indoor conditions become bad;
- Sealing/insulation measures can increase the 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.); and
- Buildings and infrastructure can also be damaged by storm (Prutsch et al., 2014).

Figure 21 shows a flooded residential are in Harare, Zimbabwe.

Infrastructure adaptation can be categorized into two:

Structural adaptation measures: e.g. changing the composition of road surfaces so that they do not deform in high temperatures, building seawalls or using permeable paving surfaces to reduce run-off during heavy rainfalls. Ecosystem-based approaches using natural infrastructure to design adaptation measures are also key alternatives to be considered alongside structural adaptation measures.

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 changes (EUFIWACC, 2016).

Figure 21. Floods affected residential areas in Harare in 2020

7.2.5 Energy resources

Most African countries have substantial deposits of fossil fuel resources but their extraction is becoming less appealing owing to their contribution to GHG emissions. Depletion of the reserves may also cause a gradual shift to new technologies and renewable energy (ACPC, 2013). Countries have opportunities to exploit their potential by investing in infrastructure and the 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 likely to be threatened by international fossil fuel regulations likely to threaten oil, gas and coal industries (Caldecott et al., 2013). However, most of the countries in Africa have rural areas that depend on biomass as the primary source of energy (Bildiricia and Özaksoy, 2016; Gabisa and Gheewala, 2018) but can maximise the use of solar energy.

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 temperature has increased or decreased, with the extent varying with geographic, technological and socioeconomic conditions (van Ruijven et al., 2019).

There is also room to minimise emissions by improving the efficiency of existing power plants. The volume of thermal power generation will decrease in many regions of the world whilst use of water 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). Box 7.5 shows climate impacts on the energy sector.

Box 7.5 Impacts of climate change on the energy sector

- High or low water levels disrupting power 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; and

Climate change events can affect the success of biomass production (Prutsch et al., 2014).

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). Furthermore, energy saving stoves reduce forest destruction. For example, in Kenya, energy saving stoves reduced the amount deforestation by consuming less wood with savings of 12.7%-33.3% of wood fuel with less pollution (Manoa et al., 2017).

Further reading:

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. Available from: https://www.intechopen.com/chapters/73230.

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

7.2.6 Water resources

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

Water scarcity especially freshwater has become a global problem, with its intensity aggravated by climate change and human activities. Freshwater is basically water from precipitation and can be divided into green and blue water resources. Green water is site-specific precipitation that does not run off but more or less temporarily contributes to soil water storage and eventually consumed by ecosystems through evapotranspiration, while blue water is surface and groundwater that is stored in rivers, lakes, aquifers and dams and can be extracted for human use. Green water consists of productive green water i.e. transpiration from biomass production in terrestrial ecosystems and the non-productive green water i.e. interception and soil evaporation (Rockström and Falkenmark, 2000; Falkenmark and Rockström, 2006).

Water shortages can also affect the industrial sectors such as soft drinks and bottled-water (Duva, 2014). Other impacts are:

Melting of glaciers affecting water quality;
- Increase in the intensity of precipitation will affect 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 (exception: glacier-fed rivers) in 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; and
- Reduction in spring discharge (water yield) of near-surface springs.

> 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).

7.2.7 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 damage transport infrastructure (Chinowsky et al., 2015) (Figure 22). 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 as virtually all models show that weather extremes will put considerable pressure on the system.

The 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 pavements 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 network;
- 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; and
- Destruction of infrastructure including roads and bridges during storms.

Figure 22. Road destruction caused by Cyclone Idai (2019) in eastern highlands of Zimbabwe (a) road damaged (b) softened road surface causing busses to sink and (c) Bridge washed away

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. On the other hand, the transport sector presents particular challenges for GHG emission mitigation due to inadequate data on transport policies and the complexity of the transport sector as a system. The transport sector in

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

many countries 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 (2020b)'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 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 7.3 (Group discussion) (20 minutes)
Discuss role of biofuels in responding to climate change in the transport and energy sectors.

7.2.8 Tourism sector

Tourism is affected by climate change in that holidays are planned to be during favourable weather conditions. 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 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 7.6 shows some of the impacts of climate change on the tourism sector.

Activity 7.4 (Brainstorming) (10 Minutes)
Identify forms of tourism in your country and how they are affected by climate change.

Box 7.6 Impacts of climate change on tourism

- 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 summers;
- Reduced precipitation in summer months affects vegetative tourist areas;
- Increased water temperatures promote swimming, but there can also decrease in water quality;
- Landscape changes due to glacial retreat;
- Melting of the permafrost increases the possibility of rockslides, rock falls and mudslides, signifying a possible danger for mountaineers and the strength of tourism infrastructure; and
- Variations in the demand for and availability of energy and water for the tourism sector (Prutsch et al. 2014; Pandey and Rogerson, 2018; Dube and Nhamo, 2020).

Activity 7. 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; and
   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 and these include agriculture, water, energy, transport, marine and coastal resources including fisheries and tourism sectors. Water resources and their relationship with climate change and climate 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.

7.3 Sectoral adaptation measures

Generally, all sectors manage risks to reduce vulnerability using different measures including technological, ecological and socioeconomic measures. Adaptation techniques need technical support and backup. The AF is one of the major sponsors for adaptation activities with a total of 27 projects in 29 African countries funded since June 2010 (Adaptation Fund, 2019). The 27 projects have a total grant of US$ 204.5 million with some US$ 45.5 million allocated to the food security sector, US$ 39.9 million to water management projects and US$ 36.3 million for agriculture projects. Some of the projects funded by the Adaptation Fund were discussed under funding mechanisms. Although adaptation options can be categorised by sector, the Intergovernmental Panel on Climate Change (IPCC) developed three categories based on the diversity of adaptation options for different sectors and stakeholders (Noble et al., 2014). These are: structural/physical, social and institutional adaption options. These will be outlined.

Learning outcomes

By the end of this chapter, the learner should be able to:
Identify suitable technological options for adaptation; and
Identify suitable socio-economic options for adaptation.

Activity 7.5 (Brainstorming) (15 Minutes)

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

7.3.1 Structural and physical adaptation

This includes application of discrete technologies and the use of ecosystems and their services to serve adaptation needs and delivering specific services at the national, regional and local levels. Options encompass actions related to engineering and built environments, technological options, EbA and services. IPCC showed four categories of structural and physical options as follows (Noble et al., 2014): **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; EWS; 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: 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;

Ecosystem based: 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, CBNRM and adaptive land use management; and

Services: Social safety nets and social protection, food banks and distribution of food surplus, municipal services including water and sanitation, vaccination programmes, essential public health services, including reproductive health services, enhanced emergency medical services and international trade.

Other options include building settlements in safe zones, improving building designs and EbA. These will be discussed in detail in the following sections.

7.3.1.1 Technological options

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

Adaptation technologies can be regarded in terms of technological maturity, with differences between traditional, modern, high and future technologies (Klein et al., 2006). Traditional technologies are those developed and applied through history for adjusting to weather-related risks. These have been in the form of agricultural management practices, construction of dykes for protection against floods or building houses on stilts. Modern technologies use improved designs, new materials and chemicals. High technologies are designed using recent scientific developments for example, information and communication technologies, geographical information systems, earth observation systems supplying more precise weather forecasts and use of genetically modified organisms. Future technologies are technologies that are yet to be developed, for example, a malaria vaccine or crops that require little or no water (UNEP, 2014).

There are three categories of adaptation technologies: software, hardware and orgware (Boldt et al., 2012; Thorne et al., 2007). **Software** refers to capacities and processes for using technology, and includes knowledge and skills and components of training, awareness-raising and education. **Hardware** comprises of the hard technologies such as equipment and capital goods including irrigation systems and drought-tolerant crops. Hardware technologies are frequently capital-intensive, expert driven, large-scale and highly complex (Sovacool, 2011). They can also include simpler technologies that are easily available, encompassing traditional and local knowledge, not yet used by a larger number of users. The **Orgware** is concerned with ownership and institutional arrangements of a community or organisation where the technology will be applied.

Some of the technologies have been integrated in some existing adaptation approaches such as the EbA where a wide range of ecosystem management activities have been applied to reduce the vulnerability of people and the environment and increase their resilience to climate change. The adaptation technologies used in EbA include the restoration of key habitats to reduce vulnerability to storm damage, protected area systems design and water reservoirs established through forests and watersheds restoration (UNEP, 2014). The stages of adaptation are associated with some form of adaptation with each of the four stages of adaptation linked to some technology (Klein et al., 2006) for example:

- **Information development and awareness:** Uses mapping and surveying, airborne laser scanning (LiDAR-light detection and ranging), satellite remote sensing, coastal vulnerability index or computerised simulation models;
- **Planning and design:** Spatial planning using Geographical Information Systems;
- **Implementation:** Dykes, floodwalls, levees, saltwater-intrusion barriers, early-warning systems and dune restoration and creation; and
- **M&E:** Use of the same technologies used in the first stage. Reliable data or indicators enable effective evaluation and the data should be collected at regular intervals using the correct monitoring system.

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 strengthening the ability to make informed climate change decisions through building an environmental information system, 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 Tanzania's Lindi, Mtwara and Pwani 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).

Technology mechanism that was acknowledged under the UNFCCC is meant to help in addressing technological needs. There are two components to this effect, the Technology Executive Committee and the Climate Technology Centre and Network (CTCN), are expected to respond to needs of different countries for technology development and transfer at both the policy and the implementation level (UNFCCC, 2014a). The CTCN is the implementation arm of the mechanism, offering technical assistance to developing countries. When adopting a technology, there is need to consider the technological requirements for overcoming the impact of climate change in different sectors (CTCN, 2019). IPCC (2007a) 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.

The CTCN services focus on: technical assistance, knowledge sharing, collaboration and networking. Most of the African countries' technical assistance from CTCN in 2019 show the need for supportive policy frameworks and including 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 assistance and 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).

The CTCN technical assistance portfolio has six categories of support:

- Awareness raising, training and sharing experience (15%);
- Technology identification and selection (11.7%);
- Research and development (28.3%);
- Project readiness and facilitating financing (25%);
- Technology feasibility, piloting and deployment (5%); and
- Policy, planning and law (14.2%)

The list of possible technologies is long and includes the following:

- Alternative eco-friendly energy;
- Flood safeguards;
- Agroforestry and integrated agricultural systems;
- Climate-smart agricultural production e.g. conservation tillage;
- EWS and climate information systems;
- Diversification of livelihood strategies/alternatives;
- Improved infrastructure design;
- Local governance of resources and resource decentralisation;
- Insurance schemes;

- Effective use of genetic materials;
- Analysis and dissemination of suitable crop varieties adapted to local areas;
- Food storage and preservation facilities;
- Use of local knowledge systems and considerations for gender;
- Improve infrastructure for small scale irrigation;
- Water harvesting, water storage, improving soil and water management; and
- Adjusting farming systems and livelihood options and changing planting dates and plant varieties (e.g. switching to those resistant to drought or pests).

Clements et al. (2011) outlined seven key criteria for prioritising adaptation technologies:

- **Environmental:** The technology should promote sustainable use of local resources;
- **Productivity:** The technology should be able to support natural life cycles; enable farmers to produce enough for self-consumption, improve quality of crop and productivity; easily disseminated and replicated;
- **Economic:** The technology should increase productivity without promoting inequalities or causing environmental degradation. It should improve livelihoods and reduce transaction costs;
- **Cultural:** The technology should respect cultural diversity, allow intercultural dialogues and local knowledge, and be easily understood and applied by all farmers;
- **Political:** The technology should be coherently integrated into policies at regional and national levels and disseminated for wider application;
- **Institutional:** Technologies should support and strengthen formal and informal institutions, including civil society; and
- **Awareness and Information:** Technology should facilitate access, integration and dissemination of information.

Activity 7.6 (Brainstorming) (10 Minutes)
Identify technological options in forest-based sectors and compare with non-forest-based technological options.

7.3.1.2 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).

> 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.

Irrigation and other means of agricultural water management are essential in building resilience to climate change and variability. In West Africa, the FAO implemented a project funded by the International Fund for Agricultural Development 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), as well as irrigation sprinkler schemes and surface irrigation (pump irrigation and river diversion). 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 irrigated. In 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. The use of canals and groundwater can improve the flexibility and dependability of water resource provision for both small- and large-scale farmers (FAO, 2019).

7.3.1.3 Soil and water conservation

Land degradation affects the productivity of ecosystems. To adapt the land resource to climate impacts, responses can give immediate results (short term or long-term effects). Examples of coping strategies with immediate impacts include the conservation of high-C ecosystems such as peatlands, wetlands, rangelands, mangroves and forests whilst in the long term they provide multiple ecosystem services and functions, achieved through afforestation and reforestation as well as the restoration of high-C ecosystems, agroforestry and the reclamation of degraded soils. Therefore, reducing, avoiding and reversing desertification enhances soil fertility, increases biomass and C 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. IWRM improves the water 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.

In Ethiopia, a livelihood resilience and ecosystem protection project was implemented by communities and activities included integrated soil and water conservation activities in order to increase agricultural productivity and to protect the resource base. Six micro watersheds covering 3,049 ha were rehabilitated as the communities enforced restrictions on open livestock grazing in designated areas and tree planting, which led to the regeneration of hillside vegetation through area closure. The farmers enjoyed greater productivity of crops due to greater conservation of soil moisture and less erosion (UNDP, 2018).

More efficient irrigation systems are required to improve the lives of affected farmers. However, there is a 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 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 adapted conservation tillage (Clements et al., 2011).

7.3.1.4 Integrated water resources management

IWRM is a practice that supports development of water resource 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, Ireland 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 policy-makers at all levels to develop water management options;
- Women play a significant role in providing, managing and safeguarding water resources; and
- 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 23) emphasising 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 environmental/ecological sustainability.

The IWRM approach is based on three pillars:

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

International collaboration on water issues is managed through the Global Water Partnership Organisation, comprising the Global Secretariat, a Steering Committee and a Technical Committee.

Box 7.7 Examples of adaptation in 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 rain water 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, for example in Pakistan, farmers changed from traditional cotton varieties to growing genetically modified cotton varieties. By doing this, they escaped losses arising from pest attacks that were common in traditional cotton varieties. Furthermore, they planted wheat varieties tolerant to high heat stress in response to increasing frequency of extreme maximum temperature events.

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, 2017b; Katengeza, 2019).

Figure 23. General framework for IWRM (source: https://www.gwp.org)

7.3.1.5 Adaptation in agricultural sector

The agricultural sector is more threatened by variability in rainfall and temperature. The agricultural sector has already applied several practices and techniques to adapt to impacts of climate change and 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) used tied ridges with better cotton varieties to cope with the impacts of a changing climate in Zimbabwe. Furthermore, crop changes and/or diversification depend on rainfall and temperature trends, anticipated seasonal shifts of rainfall 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 food crops to traded non-food crops (e.g. tobacco, cotton and biofuel); and
- Switching from subsistence or marketed staple foods to traded non-staple foodstuff crops (e.g. to 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. Examples of adaptation in agriculture are shown in Box 7.7.

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). Climate information services and information related to planting dates, pest and disease control and water availability are crucial.

7.4 Adaptation in other sectors

The transport sector needs to be climate-resilient, effective and efficient in order to lower the operational costs and improve on competitiveness. The energy sector is important because it needs to improve its efficiency by using improved technologies that reduce energy costs. Renewable energy technologies and second-generation biofuels are important technological options for adaptation. Adaptation in the insurance sector can be improved using risk-commensurate insurance premiums. Financial resilience is improved through risk management. Tourists adapt to climate change by adjusting timing, regions to visit and selection of holiday activities. Those dealing with recreation also adjust the timing of their activities. Seasons for tourist activities may be shifted in other regions of the world depending on the type of climate impact. Fishermen can vary fishing times, catch fish in deep waters, schedule their fishing times and engage in other income-generating activities.

Activity 7.7 Revision (10 minutes)

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

Summary

This session covered non-forest-based adaptation and included sectors of agriculture, fisheries, health and sanitation, built environment, energy, transport, water and tourism. Sectorial adaptation initiatives were also highlighted including technological options. In the agricultural sector, adaptation strategies include crop diversification, agroforestry, crop rotation, minimum tillage, switching crops, rainwater harvesting, using drip irrigation etc., IWRM,and and soil and water conservation. IWRM shows how water resources management is linked to economic efficiency, equity and environmental/ ecological sustainability.

Chapter 8: Other Adaptation Options

8.1 Overview

Several sectors of social economic development are affected by climate change and some of them have also developed coping and adaptive strategies to ensure their survival. There are several adaptive measures that are beneficial to all sectors such as EWS which can improve the vigilance for climate-related hazards by both individuals and decision-makers and their willingness to optimise positive weather conditions. The chapter discusses structural and physical adaptation, EbA and socio-economic options such as livelihood diversification, improved access to markets, use of indigenous knowledge and options and social safety nets. The chapter concludes by highlighting the importance of countries to prepare for migration which can be a result of climate change impacts.

Learning outcomes

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

- Explain adaptive measures that are beneficial to all sectors;
- Describe structural and physical adaptation options;
- Explain importance of EbA;
- Apply traditional coping strategies to local climate change challenges; and
- Prepare and apply risk assessment protocol.

Activity 8.1 Brainstorming (10 minutes)

Explain the importance of EWS in CCA.

8.2 Early warning systems

EWS is one of the CCA actions integrating communication systems to assist community preparation for dangerous climate-linked events. The EWS improves the vigilance for climate-related hazards by both individuals and decision-makers and improve their willingness to optimise positive weather conditions. These can be complemented by hazard mapping and monitoring technologies. The EWS for natural risks requires a 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 EWS. The elements of EWS follow a logical sequence having direct mutual linkages and interactions with each other. There are four interacting elements for effective and complete EWS and these include: information about the risk, provision for monitoring and warning services, communication and dissemination protocols and capacity to respond (UNISDR, 2016).

EWS 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, and risking human health. Given these consequences, timely notification using EWS to vulnerable people can be an adaptive option for reducing human health disasters. The correct use of an EWS 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. in a few cases, message alerts to target groups using mobile phones can be used. Promotion of the development and operationalisation of people-centred, multi-hazard EWS has been prioritised at global level (UNISDR, 2015). Examples of EWS applied globally are shown in Box 8.1.

Box 8.1: Examples of EWS

- The UNDP's programme on "Strengthening Climate Information and 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, the programme was implemented by equipping the 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 the Uganda population depending on subsistence agriculture (http://ews-undp.blogspot.com/);
- The UNEP's Climate Risk and EWS, is an initiative that was launched at the UN Climate Change Conference in Paris in 2015 to increase the capacity of Multi-Hazard EWS. The initiative operates in areas most susceptible to tropical cyclones and floods in 19 countries of Africa and the Pacific, including LDCs and SIDS. 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 DRR and CCA programme (UNDP-UNEP, 2015);

- The Climate Information for Resilient Development in Africa 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 communications toolkit for communicating EWS (http://undp-cirda.blogspot.com/); and
- Outside Africa, climate change stimulated the early rehabilitation and advanced improvement of EWSs. In Europe, they have had considerable experience with EWS, 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" 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 (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 8.2 (Brainstorming) (10 Minutes)

1. Identify some of the activities facilitating EWS in your country; and
2. What are the challenges associated with effectiveness of EWS 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 affecting effectiveness of EWS in Africa:

Absence of reliable data: Most National Hydro Metrological System (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, preventative response actions of most African nations are limited to a few who are able to 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 and crop reports, including how people should react when there is bad weather. Other packages could be tailored towards private sectors. The creation of interesting packages, allows NHMS to overcome credibility problems and also create new effective relationships with consumers of their products;

Limited relationships between NHMS and traditional media or 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 residing in remote areas. Information that is well packaged and good is likely to be more trusted as users are enlightened on possible actions in the event of bad weather and this saves lives;

Inadequate business-development capacity and frameworks: Skills required for developing 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 revenue streams and link with new groups of potential partners, that are currently not existing in some countries;

Cultural challenges: One of the biggest problems associated with the use and/or understanding early warnings is linked to cultural beliefs, gender, age, language, education and literacy levels. There should be ways of reaching the diverse group that speaks various 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 with the active involvement of relevant actors at the policy and public level;

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

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 presents new challenges for NHMS and their advancement.

EWSs can be strengthened when administrative commitments are complemented by strong institutional capacities that are constantly influenced by public appreciation. In most cases, community responsiveness and support are generally higher soon after a big catastrophic incident than at other times. This awareness and support can be utilised to strengthen and secure sustainable EWS. Some of the major challenges of EWS have been highlighted to include the absence of well-defined institutional structures and inadequate capacities at national and local levels to support public and institutional capacity development. Users who are knowledgeable and fully aware of the system are convinced and will trust in the system.

Activity 8.3 In text question
Identify and describe three case studies in your country or region on the application of various technological non-forest-based options applied in different sectors of socio-economic development.

8.3 Structural and physical options

Structural and engineering options include the application of discrete technologies to minimise impacts of disasters and use of ecosystems and their services to serve adaptation needs. These include the following categories: building settlements in safe zones and improving building designs. This can even mean considering climate change when building roads or railway lines. 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). Examples of 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.

Other options include: building settlements in safe zones, improving building designs and EbA. These will be discussed in detail in the following sections.

Activity 8.4 (Brainstorming) (10 Minutes)
Critically analyse the relationship between forest and structural and physical adaptation options.

8.3.1 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 of the engineering options are extensions and improvements of existing practices, plans, and structures. Newer projects are now considering the risk of climate change in initial designs, including management of storm and waste water 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).

In coastal areas, sea walls and coastal protection structures can be built. 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 and adjusting power plants and electricity grids are some of the adaptation actions that can be taken to reduce vulnerability (IPCC, 2014).

8.3.2 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 the built area requires the adoption of climate-compatible infrastructure. Technological options to improve building designs include the 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 buildings to the climate impacts and these are summarised in Table 13.

Table 13: 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; and • 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 development 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; and • 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; and • Specifications for materials that can survive flood and hurricane damage.
Wild fire	• 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; and • 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; and • Plan and zone communities to maintain functionality without power.

There is a 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 moving away (relocation). Other activities can include the construction of cyclone-resistant houses.

8.4 Ecosystem based adaptation approach

EbA entails the use of biodiversity and ecosystem services to help people to adapt to the 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; 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 similar to the definition adopted by the 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; and
- As part of (the 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; and
- Support equitable governance and enhance capacities.

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

In South Africa, they promote the use of EbA using biodiversity and ecosystem services to help people adapt and build resilience to the 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, andnodes 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 the protection of trees on farms and in forests. Indigenous trees are being planted because of their drought tolerance. The 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).

8.4 Socio-economic options

Social adaptation options are categorised by IPCC (2012) into: educational, informational and behavioural options. Examples of educational 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. Others include the sharing of local and traditional knowledge including their integration into adaptation planning and 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 EWS, systematic monitoring and remote sensing, climate services including improved forecasts, downscaling climate scenarios, longitudinal data sets, integrating indigenous climate observations, CoBA plans including community-driven slum upgrading and participatory scenario development. Finally, behavioural include: accommodation, household preparation and evacuation planning, retreat and migration (has own implications for human health and human security), soil and water conservation, livelihood diversification, changing livestock and aquaculture practices, crop-switching, changing cropping practices, patterns, and planting dates, silvicultural options and reliance on social networks (IPCC, 2012; 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, PES, 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 8.5 (Brainstorming) (10 Minutes)
Share your views on connection between forest and socio-economic adaptation options.

8.4.1 Livelihoods diversification

All forms of livelihoods, whether subsistence farming, fishing, full-time labour employment or seasonal work are threatened as climate change impacts cause 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 level 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, the inclusion of women and the inclusiveness of NAPs can assist economic growth and increase the income of vulnerable people (UNFCC, 2019b).

The ability to diversify can be affected by wealth status: poor farmers in the Sahel region of West Africa were limited to expand their land resources, intensify farming to stabilise food production, or diversify to non-agricultural production (Dietz et al., 2004) although the others sold animals and embarked on-farm diversification or specialisation (Sissoko et al., 2011). During drought periods in Uganda, it was more difficult for lower-income farmers to change their crop patterns and access water-saving technology and water storage sources (Hill and Mejia-Mantilla, 2014).

Engagement in off-farm activities largely depends on the pattern of assets held by individuals or households and their capacity to increase livelihood opportunities and reduce their vulnerability. Off-farm activities are heterogeneous and complex, varying in space and time. Engagement in off-farm activities is normally a response to external factors (such as market, policy or extreme weather events) 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 *opportunity-driven* (chosen preferentially over existing activities including farming and involves earning income and/or investments that shift the dependence of the person or household away from 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, 2016a).

8.4.2 Improved access to markets

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. Improved access to markets is mostly beneficial to women as lack of access prevents them from benefitting from the opportunities associated with nonfarm activities (Assan et al., 2018). Furthermore, Belay et al. (2017) and Gessesse and Zerihun (2017) showed that access to input and output markets can have a positive and significant effect on farmers' input intensity and crop diversification.

8.4.3 Use of indigenous knowledge and practices

Changes in climate affect rural livelihoods prompting them to develop various means for coping and adapting to climate change effects (Musarandega et al., 2018). 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.

> 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).

Unique methods are used by communities that 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, Democratic Republic of Congo 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. They also adjusted the periods of planting to match with the beginning of the rain season (Mdungela et al., 2017). 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.

8.5.4 Social and safety nets

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). 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 programmes, 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 (Shackleton, 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 (e.g. NTFPs) whilst outsiders exploit the most valuable chuck (Bergen, 2001; Nelson, 2010).

The NTFPs are important safety nets in times of food insecurity as they provide income opportunities for otherwise marginalised people (African Union Commission, 2020). For example, Department of Agriculture, Forestry and Fisheries (DAFF,2015) reported that about 27 million people in South Africa benefit from medicinal plants, wild fruit and other forest-based foods, and an estimated 20 million tonnes of medicinal plants are harvested and traded annually in natural forests. The Shea fruit benefits 20 000 women farmers in West Africa (African Union Commission, 2020).

8.5.5 Migrations including internal 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. One of the greatest impacts of climate change is that human migration where millions of people are often displaced by climate hazards. Climate change impacts driving human migration can either be related to 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 disasters 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. 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).

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 e sending remittances, and could potentially serve to alleviate pressure on already degraded lands (Laczko and Aghazarm, 2009).

However, migration is usually considered a failure to adapt. To reduce the risk of creating migration refugees, countries should adequately be prepared, with effective EWS 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 8.6 Revision questions (5 minutes)

1. Using examples, explain socio economic adaptation options; and
2. Explain the meaning of safety nets and how they can be strengthened.

All sectors are adapting to climate change through technological interventions such as EWS. Other adaptive options include building settlements in safe zones, better building designs and ecosystem-based approach. 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. Migration can result in refugees and to reduce the risk of creating migration refugees, countries should adequately be prepared, with effective EWS and widespread climate change education.

Chapter 9: Policy, Institutional and Regulatory Options

9.1 Overview

Most African countries are recognising the need to shift from policies with a pure environmental focus to policies that address threats to sustainable development. Therefore, the management of current and future climate risks should be an integral part of development processes at all levels and should encompass a cross-sectoral approach even reflected in national budgets. Fröhlich and Knieling (2013) stated that when dealing with climate change, governance encompasses a broad range of forms of coordination of adaptation and mitigation characterised by cross-boundary, multilevel, multi-sector and multiagency settings as well as long-term challenges and uncertainty. Several African countries including Botswana, South Africa, Uganda and Kenya have national policies for disaster management addressing the prevention, mitigation, preparedness, response, recovery and development (Mosha, 2011). For example, the Ugandan government created a climate change unit within the Ministry of Water and Environment for coordinating all issues on climate change and spearheading national policy formulation. In Zimbabwe, a similar unit is under the Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement. For effective mainstreaming of adaptation to occur, national and regional policies should be formulated to guide implementation at a local level. This chapter discusses policy, institutional and regulatory options for adapting to climate change.

Learning Outcomes

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

i. Describe international, regional and national regulatory options supporting CCA;
ii. Explain the importance of gender mainstreaming in adaptation planning and actions;
iii. Describe tools used for mainstreaming gender into adaptation planning;
iv. Explain types of disasters;
v. Describe approaches to hazard management; and
vi. Describe importance of nexus approach to adaptation planning.

Activity 9.1 (Brainstorming) (10 Minutes)

What is the extent of mainstreaming CCA in your country?

9.2 Importance of institutional and regulatory options to support climate change adaptation

In CCA, institutions can have a blended definition with cross-disciplinary relevance. Institutions are rules, procedures, conventions, protocols, moral templates or cognitive scripts (O'Riordan and Jordan, 1999). In this regard, institutions become the generally accepted and acknowledged rules, social structures and organisations formed based on shared belief systems that transform individual acts and expectations into collective actions, convert personal values into social norms and shared beliefs and define the formal and informal behavioural systems of human existence. Hence, rules, social structures and organisations represent institutions that shape self-enforcing expectations, which subsequently motivate individual actions and affect behaviour (Greif and Kingston, 2011). The rules, structure and organisations can be formal or informal. The success of adaptation initiatives depends on particular institutional arrangements, including well-defined property rights which determine resource access and risk exposure (Agrawal et al., 2008). The development of appropriate adaptation responses requires institutional arrangements that enable the measures to be implemented.

Institutions are important in adaptation because of their ability to:

- Reduce uncertainty from individual and group expectations and constant arrangement of social relations;
- Provide stability and predictability through established power and authority systems;
- Identify exclusions and inclusions by determining permissible actions and the conditions for certain activities to be undertaken;
- Connect individuals to society by giving everyone a shared identity;
- Foster adaptive capacity; and
- Mobilise resource utilisation.

Successful adaptation requires coordination across multiple levels of governance, including the local, subnational, national and regional levels. National government engagement with subnational and local authorities can help to facilitate transformational change. Some of the good practices identified by UNFCCC (2015a) include:

- Providing funds or access to funds for linking local and national adaptation planning;
- Integrating CCA considerations into sectoral and development planning processes of local government institutions; and
- Promoting the sharing of knowledge through inclusive, multidisciplinary processes for harmonising top-down and bottom-up approaches considering the multi-sectoral dimension of CCA actions.

Regional cooperation is also important in contributing to the enhancement of national adaptation efforts and has the potential to improve the effectiveness and longer-term impacts of adaptation initiatives. This can be achieved through several activities such as:

- Focusing on the need to enhance capacity for adaptation planning and implementation;
- Broadening of adaptation knowledge base by connecting a regional pool of experts and maximising their experiences, sharing best practices and lessons learned within the region;
- Providing opportunities for sharing costs and gathering resources for processes that can be jointly implemented;
- Solving any discrepancies between political and ecosystem/landscapes boundaries; and
- Evading negative transboundary impacts, especially on shared river basins or other ecosystems.

Activity 9.2 In text question (5 minutes)

Explain the importance of regional cooperation in CCA.

9.3 Mainstreaming gender into adaptation planning and actions

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, thus 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 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).

The exposure of women to climate change hazards and their capacity to cope or adapt is significantly different from men. Gender inequalities can successfully be addressed only if the responsibilities, rights and opportunities of both men and women are recognised and their needs and priorities are considered. Women are said to be vulnerable to climate change not because of natural weakness but because of the socially and culturally constructed roles ascribed to them as women. However, given the severity of gender inequality, particularly in the developing world, climate change is not only likely to magnify but also to affect women more than men. Gender mainstreaming considers women and men as equal actors in the development process and involves the assessment of the various implications for men and women for any planned action including legislation, policies or programmes in any area and at all levels. It also includes the participation of women and men in project design, implementation and M&E. Benefits of gender mainstreaming are shown in Box 9.1.

Box 9.1 Benefits of gender mainstreaming for climate adaptation

Advantages of gender mainstreaming in development initiatives:

- Use of available resources to guarantee the maximum benefit for all (men, women, boys and girls);
- Identification and use of opportunities to improve gender equality in projects;
- Policies that would not have otherwise been considered gender issues; and
- Gender mainstreaming can encompass real initiatives for women in strategic areas such as decision making and legislation, but can also address the hidden biases that cause inequitable conditions for men and women in all sectors of policy-making.

Moreover, unlike earlier approaches to addressing gender inequalities in development policy, gender mainstreaming:

- Allows policy makers and practitioners to identify and address the processes and circumstances that cause inequality;
- Is able to identify and maximise opportunities to improve gender equality in situations that would not have otherwise considered gender issues; and
- Maintain interest on gender equality throughout the project or policy cycle, ensuring the establishment and appropriate M&E for complementary systems. This means that attention to gender can move from being a mere 'token' sentence in a project document and to bringing real and sustained benefits to men and women (UNDP, 2007).

Gender mainstreaming targets the transformation of unequal social and institutional structures to make them significantly responsive to gender. When gender is mainstreamed, both women and men will equally benefit from the development activities. In this regard, mainstreaming gender is more than simply adding women's participation to existing strategies and programmes.

Gender analysis is the tool used to address the gender dimensions of any given issue or intervention to mainstream gender. Tools used include: Gender Analysis Matrix Framework; Moser Framework; Social Relations Approach Framework; Capacities and Vulnerabilities Analysis Framework; and Harvard Analytical Framework and People-Oriented Planning (UNDP, 2007). During the process of mainstreaming gender, it is important to remember that gender-sensitive language should be used, data should be collected and analysed by gender, there should be equal access to and utilisation of resources or services, women and men should be equally involved in decision making and there should be equal treatment integrated throughout the steering processes. Precise consideration of gender is important starting from the initiation of the project cycle, where the choice of adaptation interventions can have unintended gender implications.

The UNFCCC (2014b) developed a gender-sensitive approach for mainstreaming climate change into development plans based on good practice to address climate risk, climate proof current plans, and ensure adaptive development. Figure 24 shows 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 the people have minimal training for assessing climate risk, facilitating adaptation and climate-resilient development.

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).

Disaster linked social protection

- Kenya's Hunger Safety Net Programme is investing in poverty mapping to understand levels of household vulnerability;
- In Morocco, there is a crop insurance programme by the government and the agricultural mutual insurance company;
- In Ethiopia, the Productive Safety Net Programme helps the rural poor facing chronic food insecurity to resist shocks and become food self-sufficient (GFDRR and World Bank, 2014).
- In 2018, around US$ 1.5 million of insurance payouts were distributed through the WFP AR4 initiative in Ethiopia, Kenya, Malawi, Senegal and Zambia to compensate for weather-related losses (WFP, 2019).

	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 devalopment 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 24. Five step process for gender sensitive mainstreaming of climate change into development planning (Source: UNFCCC, 2014b)

9.4 Insurance cover, subsidies and risks

In the face of uncertain future, there is need for governments or individuals to provide incentives for communities to take adaptation measures, for example, innovative mechanisms such as insurance. Insurance solutions have been recognised as a way to facilitate adaptation to climate change as they ease the creation of social and economic structures and become examples of cooperation between the public and private sectors (Global Facility for Disaster Reduction and Recovery (GFDRR)(GFDRR and World Bank, 2014). The insurance industry should develop and facilitate implementation of climate insurance solutions by providing expertise, risk models, risk capital and best practices from other regions. When properly structured, insurance solutions represent an effective tool to finance burdens of proof and for creating incentives to take preventive measures (by way of knowledge transfer and/or deductibles).

Insurance schemes can directly target beneficiaries by focussing on risk awareness and household resilience, with the premise that households have a general understanding of insurance. This approach can lead to high transaction costs and thus comparatively high premium loading. As such, even with substantial premium subsidies, most pilot projects with voluntary insurance for climate risks failed. Alternatively, micro insurance schemes can overcome this challenge on account of their low premiums although it is limited in scope. The schemes have become increasingly more popular in most developing countries as local or regional group insurance schemes with funding built on mutual solidarity. The climate-related micro-insurance initiative led by GIZ on behalf of the Federal Ministry for Economic Cooperation and Development (Germany), developed micro- insurance products for communities in Zambia and Peru based on country studies that provided information on the main risks, at-risk groups and needs for risk management strategies (GIZ, 2020). The Group of Seven summit of 2015, saw the launch of a climate insurance initiative (InsuResilience), highlighting the importance of financial risk transfer concepts, particularly for emerging and developing countries. InsuResilience's objective is to give insurance access to an additional 400 million people in emerging and developing countries by 2020 so that they will be protected against weather-related catastrophes. The insurance will either be on a macro level (covering whole countries, indirectly covering the population) or on a micro-level (directly covering individuals) (GIZ and BMZ, 2015). Furthermore, insurance can focus on governments and public institutions instead of direct beneficiaries and providing pay out and early efforts to fix critical infrastructure to reduce economic costs of climate-induced natural disasters.

9.5 Mainstreaming climate adaptation into sectorial policy, planning and actions

Climate change is a threat to the development process, affecting human and natural systems and the achievement of the SDGs. Mainstreaming climate change is the incorporation of climate change vulnerabilities or adaptation into several aspects of related government policy (IPCC, 2007b) and includes integration of adaptation considerations into policy-making, budgeting and implementation processes at the national, sector and subnational levels (UNDP, 2004; UNDP-UNEP, 2011). Climate change's cross-cutting nature results in economic, geographic, administrative and temporal scales effects. In this regard, adaptation programmes or strategies need to be prepared as a component of the wider development plans. Successful CCA should be planned to ensure that the long-term effects of a changing climate are not ignored. This requires engagement and harmonisation of activities across various levels of authority (regional, national, sub-national and local levels) to improve adaptation actions and provide opportunities to catalyse development (UNFCCC, 2016a).

Although all societies are to some extent adapting or have adapted to climate change impacts, the ability to adapt to different variabilities and accelerated alterations varies significantly posing a need for policy support. Emerging international policy responses and funding mechanisms of the UNFCCC and Kyoto Protocol were a product of the recognition of the inabilities and vulnerability of the developing world to adapt.

Mainstreaming CCA requires three levels of intervention with the first level being development efforts consciously aiming at reducing vulnerability (not necessarily to climate change) while avoiding maladaptation. This strengthens the adaptation base by addressing the adaptation deficit and increasing the overall resilience of the country and population. The second level is about considering climate change in the decision-making in appropriate government departments so that mainstreaming is done through the development of policy measures encompassing climate change. Not only climate-proofing policies but also addressing emerging needs for adaptation within the different sectors or geographical areas. The third level requires specific adaptation policy measures targeting issues that the first two levels did not tackle. Each of these levels requires changes in the way government deals with policy-making, budgeting, implementation and monitoring at national, sector and subnational levels (UNDP-UNEP, 2011).

Efforts of mainstreaming adaptation in development planning processes should be initiated early in the process so that adaptation is aligned with development priorities. This means mainstreaming should be considered at every stage of the adaptation process. The four main stages of the adaptation process are: (i) assessment of climate change impacts, vulnerabilities, risks and resilience options, (ii) adaptation planning, (iii) implementation of adaptation actions, and (iv) M&E (UNFCCC, 2011).

Activity 9.3 In text question (5 minutes)
What are the possible criteria that you can use to define priority adaptation actions?

The national adaptation responses should be included as components of development policies, together with activities that are indirectly connected to climate change. Mainstreaming CCA is an iterative multi-stakeholder and multi-year process for integrating CCA into all processes of development at national, sectorial and sub-national levels. This involves coordinating with both governmental and NGOs to define the impact of adapting to climate change on livelihoods and development (UNDP-UNEP, 2011).

9.6 Cross-sectoral coordination in adaptation planning

Effective CCA requires policy coherence and mainstreaming across multiple sectors. Although sectoral approaches to adaptation planning exists in many countries, the nexus approach integrating interlinked sectors, recognising sectoral interdependencies and policy entry points is appropriate. For example, the nexus approach that links water, energy, agriculture and environment sectors appreciates the complex and dynamic interdependencies between sectors although this is often lacking in Africa. For example, England et al. (2018) analysed CCA and cross-sectoral policy coherence in Malawi, Tanzania and Zambia and found that sectoral policies differed in their coherence on CCA, being strongest in Zambia and weakest in Tanzania. Furthermore, sectoral policies were more coherent in addressing short-term disaster management issues of droughts and floods ignoring longer-term strategies of climate adaptation. Stringer et al. (2014) showed that policy activities focusing on cross-sector dialogue and actions have been established in southern Africa through inter-ministerial climate change committees and task forces in some countries including Malawi, Zambia and Zimbabwe. They further proposed that approaches for promoting institutional support for cross-cutting policies, practices and partnerships can include:

- Strengthening national coordination and clearly defining roles across sectors;
- Partnerships are based on competencies of different stakeholders across sectors;
- Defining stages for facilitating learning and information sharing; and
- Developing mechanisms for allowing a more equitable and transparent distribution of costs and benefits.

Informed planning for future development requires an understanding of the many links between the energy, water, food and environment sectors. Cross-sectoral and thematic integration can also include DRR and sustainable development goals to successfully implement adaptation and avoid maladaptation (OECD, 2009).

9.7 Legal frameworks

Although mitigation was initially more prioritised than adaptation, the climate change community, international and domestic communities, now recognise the urgency and importance of adaptation and formulating policies aligned to adaptation. The Paris Agreement (Art 7) showed the importance of adaptation by committing Parties to serious adaptation planning, financing and implementation (UNFCCC, 2016b).

Governments should intervene through deliberate adaptation policies and laws to create a legal framework in which the benefits and losses arising from climate change are distributed across society, provision of relief and showing ways of managing conflicts arising from adaptation (McDonald, 2010). Legal frameworks for adaptation can strengthen institutional rules, shape processes of policy formulation, regulate behaviours, determine access to decision-making processes and define liabilities and responsibilities. Therefore, these facilitate effective implementation of adaptation policies, allowing flexibility of the adaptation measures and enabling fast responses to emerging knowledge and information (Adger et al. 2007). Some countries in Africa have formulated special climate change laws covering legal framework for climate change mitigation and adaptation. These are in the form of climate change policy or strategy or disaster and risk management frameworks. For example, Ethiopia formulated a climate-resilient green economy strategy (CRGE, 2011). Outside Africa, the United Kingdom (UK) has a Climate Change Act (United Kingdom, 2008) that shows the responsibility of the government for assessing and reporting climate change risks and designing the plans to address them.

9.8 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).

Learning outcomes

By the end of this section, 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: and
iv. Explain approaches to hazard management.

Activity 9.4 (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.

9.8.1 Aims and objectives

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.

Climate-related risk is the result of the interaction of physically defined hazards with the properties of the exposed systems i.e. their 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, 2007b; Amuzu et al., 2017). DRR is a systematic approach to identify, assess and reduce the risks of disaster. It aims at reducing socio-economic vulnerabilities to disaster as well as dealing with the environmental and other hazards that trigger the disasters.

The Sendai Framework for DRR 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 the 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 is a state of having limited knowledge where it is impossible to precisely describe the existing state or future outcomes. It applies to predictions of future events, to physical measurements already made, or to the unknown.

Risk categories used to guide decision-making are:
- Acceptable risks;
- Bearable risks; and
- Intolerable risks (which exceed a socially negotiated norm).

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 system(s) to threaten adequate levels of societal welfare (ECONADAPT toolkit).

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

Adaptation measure used by parties to the UNFCCC for disaster management include the following:
- Early warning systems;
- Risk management institutions;
- Hazard mapping;
- Resilience standards for buildings and infrastructure; and
- Emergency operation plans

(United Nations Climate Change Secretariat, 2019).

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

9.8.2 Types of disasters and disaster management

Disasters can either be natural, technical/human-induced or emerging complex (Table 14). Natural disasters are categorised by Centre for Research on the Epidemiology of Disasters (CRED, 2009) as:
- Biological (e.g. insect/animal outbreaks and disease epidemics);
- Climatological (e.g. drought, extreme temperatures and wildfires);
- Geophysical (e.g. earthquakes, tsunamis, landslides, and volcanic activity);
- Hydrological (e.g. floods and avalanches); and
- Meteorological (e.g. storms/wave surges and cyclones).

Table 14. Types of disasters

Natural Disasters	Technological/Human Induced	Complex Emergencies
• Earthquakes; • Extreme heat; • Floods; • Drought; • Tropical cyclones; • Landslides; • Tornadoes; • Tsunamis; • Volcanoes; • Wildfires; • Winter weather; • Outbreaks of infectious disease; and • 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; and • Pollution.	• War; • Conflict; • Displaced populations; • Food insecurity; and • Epidemics.

Source: Khan (2008)

In managing climate change risks, it is important to understand linkages between adaptation to climate change, DRR and development (Figure 25). Proper planning can build resilience and enable 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).

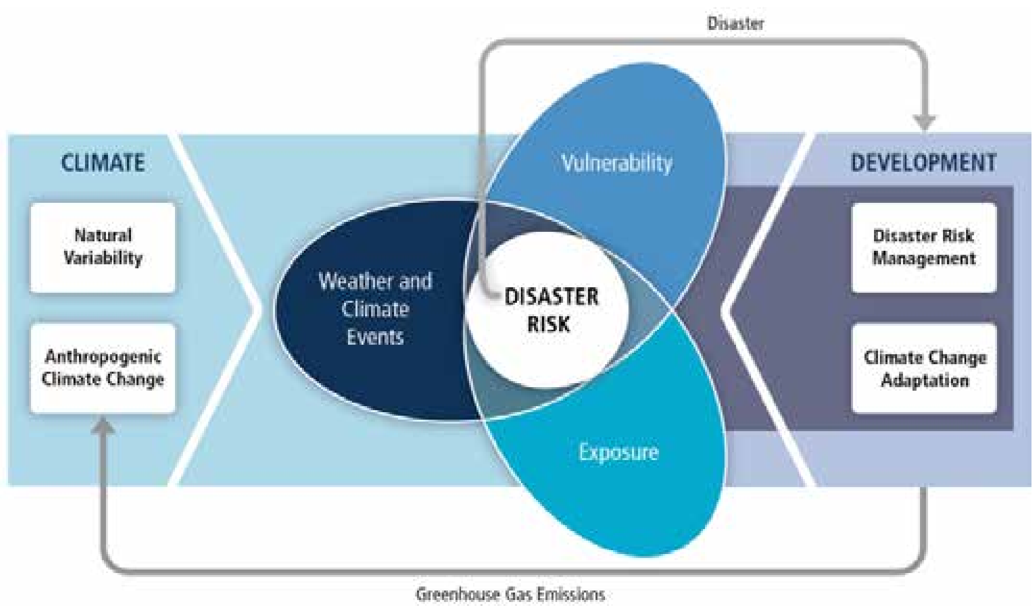


Figure 25. Linkages between climate, disaster risk and development (Source: IPCC, 2012) https://goo.gl/1gNpEs

Adaptation measure used by parties to the UNFCCC for disaster management include the following:

- Early warning systems;
- Risk management institutions;
- Hazard mapping;
- Resilience standards for buildings and infrastructure; and
- Emergency operation plans

(United Nations Climate Change Secretariat, 2019).

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: Hazard management 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 hazard, area and people involved. The natural hazard management process can be divided into three:

- Pre-event measures - Include 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 – include rescue and relief measures; and
- Post-disaster measures – rehabilitation and reconstruction.

A project on "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.org).

Economic diversification: This is one 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).

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: 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.

9.8.3 Disaster management cycle

The disaster management cycle follows steps from mitigation to recovery and the steps of the cycle overlap with the length of each step determined by the severity of the disaster (Khan, 2008) (Figure 26). **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.

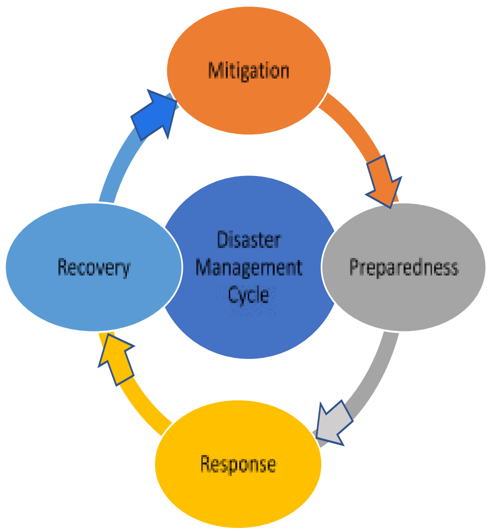


Figure 26. Disaster management cycle (Source: Warfield, 2008)

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 the occurrence of a national or local catastrophe. 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.

Response encompasses the 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 the 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 is able to 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 programmes and economic impact studies.

Activity 9.5 In text question (5 minutes)

Which part of the disaster management cycle do you think is most important? Support your answer.

9.9 Case studies on climate change adaptation strategies in the non-forest sector

The following are case studies on CCA in various countries of Africa.

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

The project on "Strengthening Capacity for CCA in Land and Water Management" targeted at CCA interventions to strength community and individuals. It uses different institutional training mechanisms starting with the 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

The US Agency for International Development is promoting the feed the future initiative by the US government. The programme supports multi-stakeholder research projects in SI under "Africa Research in SI 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; and
- Maize-legume-livestock integrated farming in eastern 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, the 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 country of Namibia. 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 9.6 Revision (15 Minutes)

1. Describe international, regional and national regulatory options supportingCCA;
2. Explain the importance of gender mainstreaming into adaptation plans and actions;
3. List some of the tools used for mainstreaming gender into adaptation planning;
4. What are some of the approaches that can be used to promote institutional support for cross-cutting policies, practices and partnerships?
5. Explain types of disasters; and
6. Describe approaches to hazard management.

We learnt that climate change mainstreaming occurs at all levels: national, regional or international. At national levels, countries prepare NAPs for implementation at sectoral levels. Governments coordinate with other development agencies to promote adaptation at all levels with supportive legal frameworks. Approaches that can promote institutional support for cross-cutting issues were also discussed. Furthermore, importance and role of insurance and mainstreaming adaptation into development processes were discussed. We also learnt about types of disasters, disaster management cycle, hazard management and concluded the section with some case studies on non- forest adaptation options.

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: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: Field CB, Barros VR, Dokken DJ, et al. (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 833-868. Available at: 14 — Adaptation Needs and Options (ipcc.ch).

PART IV: MONITORING, REPORTING AND EVALUATION OF ADAPTATION PRACTICES TO CLIMATE CHANGE

Chapter 10 Monitoring, Reporting and Evaluation Of Adaptation Practices to Climate Change

10.1 Chapter Overview

Monitoring, reporting and evaluation of adaptation practices and projects is important for CCA 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.

Learning Outcomes

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

i. Describe concepts of M&E in the context of CCA in forestry;
ii. Apply appropriate methods for M&E of CCA in forestry projects;
iii. Describe the different methods used for M&E of non-forest-based adaptation options/projects to climate change and climate variability; and
iv. Assess different types of adaptation measures to climate change in forestry and other development projects.

Activity 10.1 (Brainstorming)

Explain importance of M&E in CCA.

10.2 Concepts and purpose of 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 make adjustments 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 programmes 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 programmes and enable programmes to be delivered (Frankel and Gage, 2007).

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

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

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

Indicators: Quantitative or qualitative measures of programme performance that are used to demonstrate change and that detail the extent to which programme 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 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 programme design, management and evaluation tool that describes the main elements of a programme and how these elements work together to reach a particular goal. The basic elements in describing the implementation of a programme 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 outcomes (Frankel and Gage, 2007; USAID, 2018).

M&E is critical for ensuring the long-term success of CCA 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; and
- Determining whether planned outputs and outcomes from adaptation actions have been achieved.

Monitoring can be defined as a systematic and continuous critical assessment of actions in order to measure their evolution and adjust them according to circumstances and the project's objectives. Data collected can be quantitative and/or qualitative. It is a basic and universal management tool for identifying project/programme strengths and weaknesses (UNDP, 2009). Results of monitoring help all the concerned actors in making appropriate and timeous 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 show whether the programme implementation is on track and whether the planned activities are taking place as scheduled; and
- Check whether the intended impact is on track to be achieved.

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

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 methodologies on ongoing or completed project, programme, 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-summative evaluations to show programme's overall effectiveness e.g. audit, renewal, quality control and accreditation;
- Enabling programme improvements using formative evaluation e.g. showing programme strengths/ weaknesses and progress; and
- 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 evaluation/outcome, impact or results evaluation, process-based evaluation, behavioural change evaluation or economic 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 mission statement, 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 whether the project or programme achieved its objectives using the most economical resources;

Effectiveness: Assessing whether the activity achieved satisfactory results compared to the 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?;

Equity: Equity and justice are important factors to consider when evaluating adaptation interventions because they deal with the effects of the project on different social groups and their ability to engage in the project and benefit from the intervention. This indicates whether the intervention targeted the "right" people or exposure of certain groups to disproportionate risks, additional costs or become negatively affected by the intervention. If the gender issues discussed above are given consideration they can be evaluated here; and

Accountability: Can overlap with effectiveness and efficiency. It can be a procedural or contractual requirement for an evaluation to be conducted to check if expectations, commitments and standards are met against the baseline (PROVIA, 2013).

Evaluation differs from monitoring in terms of focus, timing and level of detail (Table 15).

Table 15. Differences between monitoring and evaluation

Monitoring	Evaluation
A **continuous** process;	A **specific** activity or moment;
To provide information for day-to-day decision making (adjustments);	To provide recommendations for strategic decision-making processes;
It is carried out by the project team; For 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; and	It focuses on outcomes, impacts and overall goal; and
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).

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; and
  - Identifying actors and mapping of roles of each in the adaptation project.

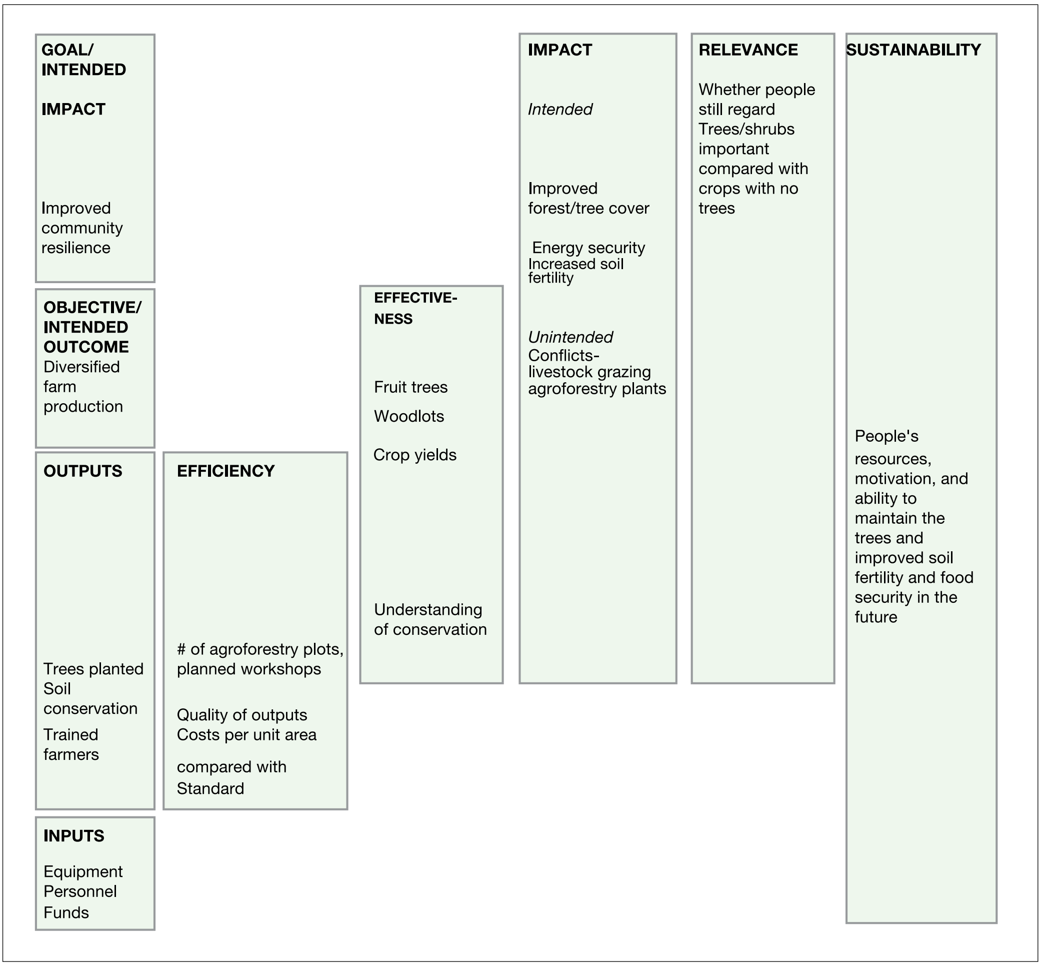
Other components of M&E were given by Turner et al. (2014) and STAP (2017):

Indicators: Pointers of progress toward the proposed results can reveal the status of an activity, project or programme. Indicators can be either performance, process, output or outcome indicators;

> An 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.

- **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; and
- **Data and information management systems** through the collection and sharing reliable and robust data for use in making informed decisions. Includes infrastructure (e.g. computers) and processes.

A results framework is often depicted as a theory of change, 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 results. A results-based approach focuses on ensuring that all project (or organisational) processes, products, and services promote the realisation of the desired results. However, a theory of change framework is increasingly being favoured for CCA 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. Table 16 shows an evaluation criteria and how its related to project logic using some forestry related examples for each component/element.



Source: Modified after UNICEF 2003.

Activity 10.2 (Brainstorming) (10 Minutes)

Identify a forest-based adaptation project in your country or region and discuss the methods used for M&E.

10.3 Types of monitoring and evaluation of climate change adaptation practices

Approaches for M&E differ depending on the purpose e.g. whether the primary focus is on accountability, management or learning/awareness. The approaches for M&E also vary with the level of application such as project level, national level or across the levels. Evaluation of CCA options should consider more than just effectiveness and economic efficiency in assessing usefulness to farmers and other interested parties. When using multi-criteria evaluation, a framework for evaluation gives decision-making criteria that are examined simultaneously. M&E systems are basically of two types: community-based; and programme, project and policy-based (Spearman and McGray, 2011). However, both M&E can be carried out using methods and approaches given by OECD (2014) (Table 17).

Table 17. Categories of relevant monitoring and evaluation approaches

Monitoring and evaluation approaches	Examples from OECD review (2014)
General monitoring and evaluation approaches	Developmental evaluation, longitudinal evaluation, impact evaluation, institutionalised learning.
Official social science approaches	Surveys, focus groups and interviews.
Econometrics/statistics	Modelling, statistical analyses, stochastic baseline, deterministic baselines and normalisation.
Experiment-related approaches	Case studies, experimental design, quasi-experimental design, propensity score matching, phased pipeline, purposeful sampling and regression analysis.
Participatory approaches	Most significant change analysis, beneficiary monitoring, limiting factor analysis, outcome mapping and recall techniques.
Iterative approaches	Sequential targeting, results-based monitoring, theories of change, stepwise approach, contribution analysis, scenario building, rolling baselines and reconstructing baselines.

10.3.1 Community based M&E systems

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

The Participatory M&E methods are variable and include: Participatory Monitoring, Evaluation, Reflection and Learning for community-based adaptation 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 also assist stakeholders to reflect on the factors that influence adaptation and its value for different actions (Krause et al., 2015).

Community based monitoring can be applied to any project where locals take part in the monitoring process. Forest based monitoring initiatives include:

- Monitoring Matters-in Ghana, Namibia and Tanzania among other countries, where local monitors were trained to monitor forest disturbance (Danielsen et al., 2011); and
- The Think Global, Act Local project that supported locally based monitoring of forest and C stocks in Mali, Senegal, Guinea Bissau and Tanzania (Verplanke and Zahabu, 2011). Furthermore, many of the REDD+ pilot projects being implemented in Tanzania are building on locally managed monitoring systems and verified using more technologically-focused methods, such as satellite imagery and aerial photography.

The UNDP piloted the use of the Vulnerability Reduction Assessment (VRA) tool in Guatamela demonstrating that it can be used as an indicator system suitable for community-based adaptation (CoBA) projects (Biesbroek et al., 2018). The VRA assessment is built upon four questions that capture context-specific problems identified during community level meetings (3-4) in the course of the CoBA 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).

10.3.2 Programme, project and policy-based M&E systems

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.

The WRI National Adaptive Capacity framework is another approach that gives an understanding of institutional aspects of national adaptive capacity. Furthermore, a consolidated monitoring, reporting and evaluation system was also developed in Europe to work at the national level (EEA, 2015). The monitoring, evaluation and reporting system 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 27). Track 1 assesses institutional climate risk management while track 2 measures adaptation and development performance across scales (Brooks and Fisher, 2014).

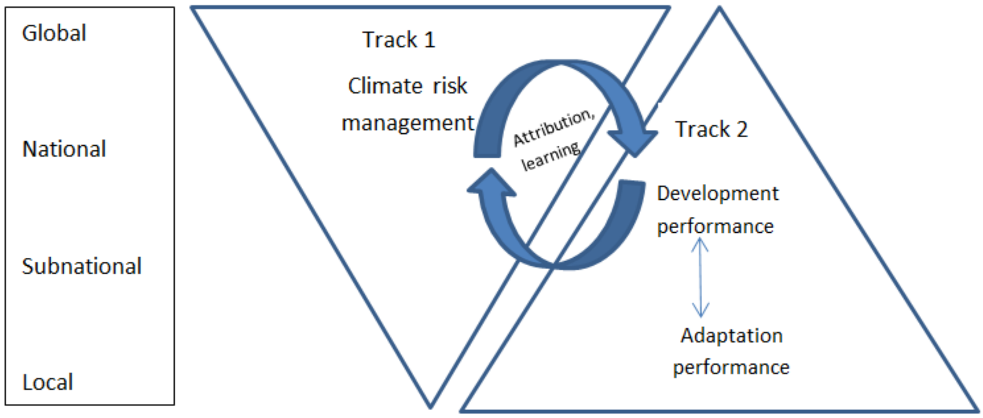


Figure 27. The relationship between Track 1 and Track 2 in TAMD

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).

10.4 Monitoring and evaluation parameters

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

10.4.1 Monitoring and evaluation of vulnerability

The IPCC (2007b) 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 and to cope with the impacts. These were adequately explained in chapter 1. Adaptive capacity includes modifications of both behaviour, resources and technologies (Adger et al., 2007; Vittal et al., 2020). The climate change vulnerability impact monitor provides national information on key climate vulnerabilities and an assessment of the social and economic costs of climate impacts (DARA, 2011). 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; GIZ, 2014; Vestby, 2018).

10.4.2 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 global programmes such as PPCR, GFDRR programme logic, GFDRR - results-based framework and 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-Evaluation of Community of Practice, Organisation for Economic Co-operation and Development (OECD) Studies on Climate, Change Adaptation M&E, and SEA Change Community of Practice (Williams, 2016).

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

- Wicked problems require creative and adaptive solutions-climate change is complex;
- Climate and disaster resilience M&E poses a number of 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; and
- The field of climate and disaster resilience M&E is young and learning (quickly) from experience-therefore stakeholder engagement is critical and plan to learn from experience and adapt accordingly.

10.4.3 M&E for adaptive capacity

M&E for adaptive capacity can be done at local or national levels. For example, the CIF Project Cycle includes a M&E of adaptive capacity using adaptive capacity assessments which identifies the links between climate and development and promotes the inclusion of climate adaptation activities in development programmes. 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.

10.4.4 Indicators

Indicators show aspects 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. Good indicators should be specific, measurable, available at acceptable costs, relevant and time-bound. Adaptation indicators could reflect the following aspects (Schwan, nd; Vallejo, 2017):

Climate parameters: Information on climatic conditions being observed e.g. rainfall, temperature and extreme events.

Climate indicators include:

- Global surface temperature;
- CO_2 concentration;
- Land ice; and
- Sea level.

Climate impacts: Information about the impacts being observed relative to climate change and variability on socio-ecological systems such as number of people displaced due to floods.

Adaptation action (implementation): Information to help track the implementation of adaptation strategies e.g. number of people who received training, number of awareness-raising workshops organised, proportion 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, percent increase in crop yield per ha during the dry season, proportion of household income used to treat water-borne diseases.

Social adaptation: Indicators for adaptive capacity designed on basis of determinants of adaptive capacity (Smit and Pilifosova, 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-till or zero-tillage etc.

Donatti et al. (2020) reviewed the intended adaptation outcomes and indicators used in 58 EbA projects implemented globally using three major donor databases (UNFCCC, 2015b; UNEP: http://ebaflagship.unep.org/; and GEF: https://www.thegef.org/projects?search_api_views_fulltext=ecosystem-based+adaptation). Results showed that 13 adaptation outcomes could be achieved through EbA and seven indicators monitor the success of EbA in achieving adaptation outcomes. The most common indicators for assessing outcomes were change in income and change in agriculture productivity. Common indicators for assessing outputs included number of ha restored, number of ha protected and number of people trained. Their review suggested the need for a set of common indicators that could be used by adaptation projects to monitor outcomes.

Activity 10.3 Brain Storming (10 minutes)
Based on any forest-based adaptation project, define relevant indicators that can be used for monitoring the projects to achieve the intended outcome.

10.5 Methodologies in monitoring, evaluation and reporting

10.5.1 Methods and frameworks for monitoring and evaluation

10.5.1.1 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 assessment of the results of GCF investments in developing economic, social and environmental co-benefits and gender-sensitivity (Fayolle et al., 2017) (Box 10.1).

10.5.1.2 Global stock take mechanism

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 on the basis of equity and the best science available. The GS is expected to inform Parties so that they can progressively update and improve their pledges for climate action to keep within 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 takes place in three phases of:

- Gathering of inputs - including data from latest IPCC reports, UNFCCC, UNEP and NC;
- Considering the inputs through a technical process; and
- 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 maximising opportunities emerging from societal, economic and technological changes, and lessons learned and integrating the new information and best practices (Nothrop et al., 2018).

10.5.1.3 GEF 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 LDCF/SCCF Fund (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 CCA projects.

The M&E framework developed by the OECD is mostly relevant for use by policymakers and M&E practitioners. This was based on an evaluation of several M&E approaches. They discovered challenges related to M&E 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., 2014).

Box 10.1 The GCF indicators

- 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 forest–pastoral systems, agroforestry projects or EbA 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 EWS;
- 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; and
- Number of indirect and direct recipients, disaggregated by sex and income levels (Fayolle et al., 2017.

10.5.1.4 Climate Vulnerability and Capacity Analysis (CVCA) framework

The Climate Vulnerability and Capacity Analysis (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 M&E 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 role of local and national institutions and policies in facilitating adaptation is 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 CCA 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.

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 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 DRR, and focusing on hazards. It examines both hazards and conditions, and analyses 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); and
- 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 of local resources to support adaptation among communities (Dazé et al. 2009).

Further reading:

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

10.5.1.5 Climate ADAPT

CCA M&E frameworks should follow the ADAPT principles, i.e. ones that are Adaptive, Dynamic, Active, Participatory and Thorough (Villanueva, 2011). The ADAPT principles are:

- **Adaptive learning and management**: Recognise experience-based learning and needs to deal with uncertainty;
- **Dynamic baselines**: Recognises 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; and
- **Thorough**: Reduces chances of maladaptation by evaluating trade-offs and recognising multiple stressors and processes across scales.

10.5.2 Tools for monitoring

10.5.2.1 CRiSTAL tool

Community-based Risk Screening Tool – Adaptation and Livelihoods (CRiSTAL) is a project planning and management tool designed to help users to integrate risk reduction and CCA 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 the following (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; and
- Adjustments that can be made to a project to increase access to or availability of these critical livelihood resources.

The process follows a logical 4 step process (Figure 28) and can help users to analyse the data on excel sheet. Steps 1 and 2 give climate and livelihood information whilst steps 3 and 4 give information useful for planning and managing adaptation.

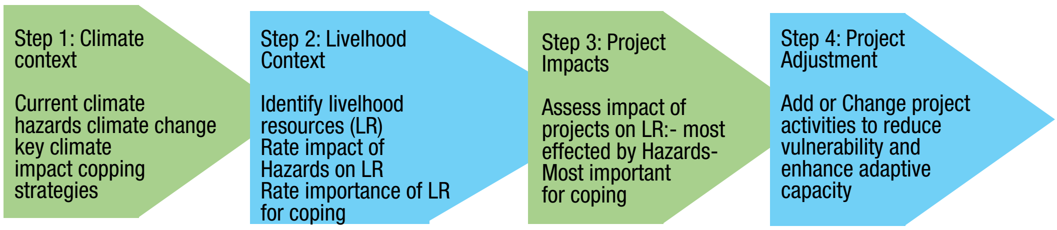


Figure 28. The CRiSTAL process (Source: IISD, 2011)

10.5.2.2 Adaptation, Monitoring and Assessment Tool (AMAT)

CCA monitoring and assessment tool (AMAT) 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. 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 RBM of CCA under the LDCF and the SCCF.

In AMAT CCA 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. 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 RBM 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. 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); and

Objective 3: Promote transfer and adoption of adaptation technology (3 indicators).

10.5.2.3 AdaptME toolkit

AdaptME toolkit is a practical tool for providing practitioners with critical information and guidance for devising a CCA M&E framework that suits their programmes, contexts 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 10. 4 Revision activity (10 minutes)

Choose the correct answer

1. Which one of the following statements is not true for indicators?
   - i. Specific, simple and have clear meaning;
   - ii. Comparable across the target population and over time;
   - iii. Agreeable with key stakeholders; and
   - iv. Specifies the direction of change.

2. Evaluation entails assessment of the following:
   - i. Efficiency, relevance, accountability, impact and sustainability;
   - ii. Efficiency, relevance, effectiveness, impact and sustainability;
   - iii. Efficiency, impact, effectiveness, transparency; and sustainability; and
   - iv. Transparency, impact, sustainability, relevance and effectiveness.

3. Explain the interlinkages and dependencies between planning, M&E.

10.6 Reporting and feedback processes

10.6.1 Utilisation of monitoring and evaluation feedback

M&E reports can be made for use by internal or external audiences. Internal audience use the reports to support project or programme management while external reports are for stakeholders outside the project or programme teams. External reports demonstrate accountability, create opportunities for raising funds, promote wider learning and provide evidence for policy influencing work and many other different purposes (INTRAC, 2018).

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 2021).

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 on 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 SIDS can submit their BURs when convenient. Information on domestic climate-related finance is also supplied through limited sources, including NCs, BURs from the UNFCCC, Climate Public Expenditure and Institutional Reviews, NDCs and other independent studies (UNFCCC.int, 2021; UNDP-UNEP-GEF, nd).

Kenya: Proposed National Performance and Benefits Measurement Framework 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 has Regional Environmental Information System 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 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).

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 are based on country-specific data 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.

The Adaptation Communication Drafting Assistance Tool 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, 2019b).

Some reports from non- Annex I countries can be accessed at: National Reports from non-Annex I Parties | UNFCCC. Some African countries with recent submissions include:

- Gambia: https://unfccc.int/sites/default/files/resource/The%20Gambia%20Third%20National%20Communication.pdf.
- Ghana: https://unfccc.int/sites/default/files/resource/Gh_NC4.pdf.
- Liberia: https://unfccc.int/sites/default/files/resource/SNC.pdf.
- Malawi: https://unfccc.int/sites/default/files/resource/TNC%20report%20submitted%20to%20UNFCCC.pdf.
- Namibia: https://unfccc.int/sites/default/files/resource/Namibia%20-%20NC4%20-%20Final%20signed.pdf.
- Nigeria: https://unfccc.int/sites/default/files/resource/NIGERIA_NC3_18Apr2020_FINAL.pdf.
- Zambia: ttps://unfccc.int/sites/default/files/resource/Third%20National%20Communication%20-%20Zambia.pdf.

Box 10.2 shows some case studies on monitoring and evaluation.

2 FCCC/PA/CMA/2018/3/Add.1 (unfccc.int)

Box 10.2 Case studies

1. *Framework for tracing effects of extrinsic and intrinsic factors on decision to participate in an intervention and its outcomes*

Framework traced how extrinsic (personal and external environment characteristics) and intrinsic factors (knowledge and attitudes) influence the decision to participate in an intervention and its outcomes. This framework was used in a tree planting intervention in the Kintampo Forest District, located in the Bono East region of Ghana. Data were collected on the adaptation profiles (entrepreneurial adaptation profile, environmentalist adaptation profile, sustainable charcoal production profile); extrinsic factors (personal characteristics, external environment characteristics, intervention characteristics); intrinsic factors (knowledge, attitudes); decision to participate (outcomes of participation, confirmation of participation). Results suggested that these factors influenced tree planting outcomes. The framework allowed a more inclusive planning, M&E of CCA interventions which would ensure that participants' knowledge and preferences are reflected in the intervention (Wojewska et al., 2021).

2. Kenya's Monitoring adaptation framework

Kenya adopted use of the MRV+ system for measuring progress in climate change action. The MRV+ system is an integrated framework for measuring, monitoring, evaluating, verifying and reporting results of mitigation and adaptation actions and the synergies between them. Although the adaptation M&E system is under development, it builds on the requirements of the Climate Change Act (2016), the guidance provided in the national climate change action plan (2018–2022), learning generated through the development of Kenya's NAP, input from stakeholder consultations and a validation workshop (Mutimba et al., 2019).

Activity 10. 5 Revision (15 Minutes)

1. Distinguish between the following:
   i. M&E; and
   ii. Output and outcome;
2. Explain the main components of evaluation;
   i. What are the parameters considered in monitoring and evaluation of adaptation initiatives? and
   ii. Identify and describe any two methods of monitoring and evaluating adaptation initiatives.

Summary

In this section, we looked at issues of MRV 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 tool. 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 to build the structure of adaptation reports.

Chapter 11. Future Trends in Climate Change Adaptation in African Forestry

11.1 Overview

In previous chapters, we learnt that climate change is a result of global environmental changes manifested through rising average global temperatures, extreme events including droughts and floods, changes in day, night and seasonal temperatures, changes in the frequency, duration and intensities of heat waves, wind and storm patterns, frost, snow and ice cover, rising sea levels and changes in precipitation regimes (IPCC, 2007b). These changes can affect all development sectors and the distribution and dynamics of all types of terrestrial ecosystems, including forests, woodlands and savannas, deserts, grasslands and shrub lands. The people, societies and forest ecosystems are likely to respond sensitively to the changes in climate, as well as economic activities that are dependent on forests. In this chapter, we emphasise the impacts of climate change on forests, policy options and assess future trends in CCA for African forestry.

Learning outcomes

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

i. Describe current and future climate change impacts on forest ecosystems;
ii. Identify appropriate methods for adapting forests to future climate change;
iii. Describe relationship between forests, food security and sustainable development; and
iv. Assess linkages of adaptation measures to climate change in forestry projects.

Activity 11.1 Brain Storming (10 minutes)

Considering the forest-based adaptation measures you have learnt, what do you think are the best options in the future?

11.2 Introduction

Although Africa contributes small amounts of global GHG emissions, the continent is most vulnerable to climate change impacts because of low adaptive capacity compounded by a shrinking ecological base, land degradation and increased population pressure (Mburia, 2015). This is exacerbated by low levels of economic development which makes the continent highly vulnerable to the impacts of climate change.

A changing climate also threatens human health and affects access to water for people and ecosystems. In this regard, most efforts to increase food security and broad-based economic growth and development are hindered (UNEP, 2012). The effects of climate change on forest ecosystems however varies with vegetation type and species composition. Efforts to improve forest and land management can reduce GHG emissions by up to 20% to meet the 2°C Paris Agreement goals, at the same time increasing community and ecosystem resilience (Ahmed et al., 2020). The long-term land management should be applied at landscape level, with supportive policies that are locally driven, engaging all relevant actors and industry sectors, including agricultural sector (Ahmed et al., 2020).

11.3 Predicted climate impacts

Climate change impacts are expected to increase the risk of droughts and floods in Africa. Alterations of temperature and precipitation will affect a range of ecosystem functions and processes, including physiological and reproductive processes such as photosynthesis, water use, flowering, fruiting and regeneration, growth and mortality and litter decomposition (Keenan, 2015). Along coastal areas, sea level rise causes mangrove forests in sub-tropical coastal areas to expand landward into freshwater marshes and forest zones (Di Nitto et al., 2014).

Climate change is expected to worsen the current threats to forests and their ecosystem services by increasing the frequency and intensity of fires, insect pests and pathogens, extreme events (flooding and storms) and changing precipitation regimes (Louman et al., 2019) and will alter competitive relationships within and between species. However, species that suffer high mortality rates or whose populations are subjected to regular disturbances such as storms or fires are expected to be the quickest to adapt to a warming climate whilst those with a wide geographic range, large populations and high fecundity may suffer local population extinction but are likely to persist and adapt whilst suffering adaptational gap for a few generations (Keenan, 2015).

Bernier and Schoene (2009) showed that arid and semi-arid lands will experience drought which can increase tree mortality and result in degradation and alteration of species distribution in forest ecosystems. Forests such as those dominated by Atlas cedar (*Cedrus atlantica*) in Algeria and Morocco are likely to be more affected. They added that drought also affects productivity of adjacent agricultural land, forcing communities with limited livelihood alternatives to turn to the forests for timber and NTFPs, causing more deforestation and forest degradation. Niang et al. (2014) added that climate change will affect water-stressed catchments, amplify existing stress on water availability in Africa.

There will be shifts on ranges of some species and ecosystems caused by elevated CO_2 and climate change, compounded by effects of land use change and other non-climate stressors (Niang et al., 2014). Ocean ecosystems, in particular coral reefs will be affected by ocean acidification and warming as well as changes in ocean upwelling, thus negatively affecting economic sectors such as fisheries and tourism. Given the projected impacts of climate change, strategies that integrate land and water management and DRR within a framework of emerging climate change risks would bolster resilient development (Niang et al., 2014).

Activity 11.2 Brain Storming (10 minutes)
What can you do to safeguard a future of forests under a changing climate?

11.4. The future of climate related policies

In terms of climate change, most African countries signed the UNFCCC and ratified subsequent protocols and agreements increase the need for African governments to align existing policies and institutions to promote climate action. Unfortunately, most of the African countries do not have appropriate institutions, policies and legal frameworks to support global initiatives for the benefit of their people. Forest policy and management activities should focus on reducing vulnerability to future climatic conditions, avoiding or reducing the impact of climate-related events, managing a broader suite of climate ‘risks’ or increasing resilience and capacity in forest ecological and production systems to recover from climate ‘shocks’ (Keenan, 2015). Niang et al. (2014) analysed progress of adaptation policies in Africa and showed that most countries initiated national and subnational policies and strategies for mainstreaming adaptation into sectoral planning but most of them were incomplete, under-resourced and had fragmented institutional frameworks. They concluded that there were generally low levels of adaptive capacity, especially competency at local government levels to manage complex socio-ecological change resulting in mostly ad hoc and project-level approach, often driven by donors.

Policy reforms in African countries should provide clear, enforceable and secure tenure rights over trees and forests, supported by simple, low-cost and verifiable procedures for legalising community forest agreements and management planning. Above all, they should include all legitimate stakeholders in the future forest management activities (i.e. disadvantaged/invisible groups such as women, poor households, youths etc (Blomley, 2013). FAO (2018) stressed the need for better coordination of land use policies to promote sustainable agriculture that can benefit from healthy, sustainable and productive forest and tree ecosystems in the general context of attaining the 2030 Agenda for Sustainable Development.

It is important for countries to mainstream ecosystem services, biodiversity and gender across development sectors. Despite their importance, these issues are not integrated into national planning, development and local poverty reduction strategies. The Committee on World Food Security, at its 44th Session recommended the use of an integrated approach that includes the nexus among forestry, agriculture, water and food security and nutrition to support policy coherence across sectors, at different scales, by reinforcing cross-sectoral coordination through a participatory and inclusive process (FAO, 2018).

11.5 The Future of forests adaptation

Forests and trees are key for meeting objectives of the Paris Agreement, SDGs and food and nutrition security. Forests have an important role in CCA especially with good management. They are able to reduce flood or landslide risks and provide valuable safety nets for local people, providing supplemental food sources in times of stress when crops or pastures fail due to droughts, fires or pests or other extreme weather events (Louman et al., 2019). In this regard, forests should benefit all including indigenous peoples, local communities and smallholders particularly those who are forest dependent because they get spiritual, social, cultural, political and economic benefits from forests.

SFM should focus on gender responsive implementation, gender equality and women's and girls' empowerment, respecting their rights and access to forest land and tenure, agriculture and forestry support services, capacity building and fostering women's equal participation in decision making. This will also help to achieve food security and nutrition and should therefore be mainstreamed across all policy recommendations (FAO, 2018).

Future CCA should focus on gender responsive initiatives that reduce vulnerability and most of these have been discussed in this compendium. The initiatives include the following:

- DRR;
- Social protection, social services and safety nets;
- Technological and infrastructural adaptation;
- Ecosystem-based approaches;
- Livelihood diversification;
- Better water and land governance;
- Tenure security for land and vital assets;
- Enhanced water storage, water harvesting and post-harvest services;
- Strengthening civil society and greater involvement in planning;
- Paying more attention to urban and peri-urban areas;
- Ensuring equity in all development initiatives;
- Adoption of sustainable land use options and intensification; and
- Promote transformation through elimination of the underlying causes of deforestation and forest degradation and promote afforestation/reforestation, biodiversity conservation and agroforestry.

Locatelli et al. (2008) stressed the importance of management activities that reduce the impacts of climate change on forests and their ecosystem services and management of forests to help local people and society to adapt to expected climatic changes. They added that more than one measure is advisable in each case and implementation must be flexible to the changing situation because the extent of future climate change is uncertain. Furthermore, promotion of traditional beliefs, values and systems has potential to succeed because the rules and norms are crafted within a local context for specific internally identified needs, having greater local legitimacy although sometimes undemocratic and unrepresentative (USAID, 2010). However, without formal legal protection, such efforts could suffer from external threats (Blomley et al., 2005).

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