Enhancing climate change adaptation and mitigation actions on land in Africa

Future Ecosystems for Africa (FEFA) | Oppenheimer Generations Research and Conservation (OGRC) | African Group of Negotiators Experts Support (AGNES) | African Union Development Agency – NEPAD (AUDA-NEPAD)

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Front cover image: Sally Archibald, Tundavala escarpment, Angola

Citation:

Armani, M., Asefa, M., Zakari, S. & Agyekum, E.O. 2022. Enhancing climate change adaptation and mitigation actions on land in Africa. Archibald, S.A., Pereira, L.M., Coetzer, K.L., editors. Future Ecosystems for Africa (FEFA), University of the Witwatersrand, Johannesburg, 92pp.

Acknowledgement

Future Ecosystems for Africa (FEFA) would like to thank the listed individuals for contributing to the preparation of this report. The authors have contributed to the report in their individual capacities. Their affiliations are mentioned only for identification purposes.

FEFA wishes to acknowledge the funding support for this report from Oppenheimer Generations Research and Conservation (OGRC).

FEFA would like to acknowledge the support from the African Group of Negotiators Expert Support (AGNES) and the African Union Development Agency-NEPAD (AUDA-NEPAD) for the coordination and organisation of the initial meetings that led to the development of this report.

Table of Contents

Table of Contents

List of Tables

List of Figures

Introduction

This working paper report was commissioned by the African Group of Negotiators Experts Support (AGNES) and partners (Oppenheimer Research and Conservation, University of the Witwatersrand, AUDA-NEPAD) with the overarching goal of enhancing climate actions on land in Africa. The report seeks to deepen understanding of the relationship between land and climate change adaptation in Africa. To achieve this goal, an extensive literature review was conducted to establish a framework for assessing climate actions in Africa (section 2). This review: 1) summarised climate trends in Africa, 2) identified key climate commitments made by African countries, and 3) highlighted the potential synergies and trade-offs between climate actions and sustainable development, including biodiversity conservation, rural development, land governance, climate securities and the concept of ecosystem degradation in the context of Africa.

Subsequently, a substantial number of case studies are reviewed (section 3) to evaluate available evidence for all the major land-based climate actions covering most of the proposed nature-based solutions (NbS). Adequate case studies were selected for all the major land-based biomes of Africa (mangroves, forests, grassy ecosystems and deserts) and land-use types (conservation, agriculture and urban). Climate change mitigation and adaptation actions considered include all emission reduction (ER) (ecosystem conservation and sustainable agriculture) and carbon dioxide removal (CDR) (ecosystem management, ecosystem restoration and agroforestry) pathways. The report particularly highlights and examines evidence across Africa's grassy ecosystems, identifying leading case studies on climate change adaptation and mitigation. In addition, non-ecosystem-based climate actions, such as urban- and desert-based climate interventions, were examined. A summary of the results of these analyses highlighting the carbon, biodiversity and livelihood benefits of proposed interventions are presented in Table 1 below.

Finally, the report also highlights the main data and knowledge gaps (section 4) that need to be addressed to enhance climate actions on land in Africa. The report is therefore expected to become an important source of information for African experts and negotiators to define a common African position on climate actions that can be promoted and operationalised across the agriculture-forestry-biodiversity-climate nexus.

1. Climate change, global warming and related impacts represent the most significant threat to sustainable development in Africa:

Currently, global warming is leading to, among others, increasing mean and extreme temperatures, increased heatwaves, frequent and intense drought, and flooding in many parts of Africa. Climate models predict that global warming will lead to declines in agricultural productivity, declines in net primary productivity in rangelands, a shift in species distribution, biodiversity loss and potential escalation of conflicts in many regions of Africa. These changes are already being felt in key sectors across Africa and are likely to affect a huge proportion of the African population, given the high dependence on natural resources and employment in climate-exposed sectors.

2. **Land-based climate mitigation and adaptation options are crucial to reducing global warming to within 1.5˚C or 2˚C of pre-industrial levels:**

   - In recent years, there has been renewed interest in and recognition of the importance of land-based ecosystems in climate change adaptation and mitigation. Actions targeting the protection, conservation and restoration of forests and other natural ecosystems are essential components of global efforts – such as the Paris Agreement – to reduce global warming to within either 1.5˚C or 2˚C of pre-industrial levels. In addition, climate actions targeting or dependent on natural ecosystems can also contribute to other global goals, such as the Sustainable Development Goals, through biodiversity conservation and social and environmental safeguards.

3. **Africa is uniquely positioned to become a major player in global climate actions:**

   - Africa is the world's second largest landmass, with a total land area of approximately 30.37 million square kilometres, and holds 60% of the world's arable land, although not all these lands can be put into productive use. Further, the continent possesses highly diverse and unique ecosystems – comprising mangroves, forests, woodlands, savannas and grasslands, rangelands, arid lands and deserts – as well as renewable energy potential. However, to realise its climate change mitigation and adaptation potential, Africa must advance a common position on and interest in climate change in global forums.

4. **Framework for assessing climate actions in Africa:**

   - Africa's response to global warming is to prioritise adaptation while supporting mitigation efforts, particularly if they provide opportunities for achieving the goals of Agenda 2063. Consistent with this position, there is clear prioritisation of adaptation actions in the NDCs of most African countries. The agriculture, water and disaster risk management sectors, which have high climate risks, receive most of the adaptation actions. In contrast, mitigation actions target mostly the energy, conservation, transport, waste management and agriculture sectors.

Climate action	Carbon	Biodiversity	Livelihoods
Mangroves			
Avoided mangrove deforestation	+	+	+
Sustainable mangrove management	+	+	+
Restoration of degraded mangroves	+	+	+
Forests			
Avoided deforestation	+	+	+
Sustainable forest management	+	+	?
Reforestation	+	?	?
Fire prevention	+	+	+
Rangelands			
Practising of short-intense rotational grazing	?	?	?
Adoption of holistic management	?	?	?
Adoption of the wilder rangeland concept	+	+	?
Woodlands			
Avoided woodland conversion	+	+	?
Changed fire practice	+	–	?
Improvement of grazing management	+	+	+
Restoration of degraded woodlands	+	+	+
Savannas and grasslands			
Avoided conversion	+	+	+
Afforestation of savannas and grasslands	?	–	–
Change in fire practices	?	–	?
Use of fire and grazing to increase SOC	+	?	?
Allowing bush encroachment	?	–	–
Restoration of degraded savannas and grasslands	+	+	+

TABLE 1. Summary results of the analysis of evidence of proposed land-based climate actions across diverse ecosystems and land-use types in Africa

Results are presented for potential carbon, biodiversity and livelihood benefits associated with climate actions. Results are summarised, qualitatively, as "+" (i.e., positive benefit), "–" (i.e., negative impact) and "?" (i.e., when results are inclusive of the potential impacts of the climate action).

Climate action	Carbon	Biodiversity	Livelihoods
Arid zone, deserts and desertification			
Promotion of desert greening good	+	+	?
Reversal of desertification	+	+	+
Introduction of large-scale solar and wind farms	+	?	?
Agriculture			
Climate actions on cropland	+	?	+
Climate actions on pastures	?	?	+
Agroforestry	+	+	+
Cross-cutting themes			
Replacement of wood fuel use / Improved efficiency?	+	+	+

- Land-based climate actions – both adaptation and mitigation actions – are likely to affect sustainable development and the achievement of Agenda 2063. Climate actions could have positive (synergies) or negative (trade-offs) impacts on the society, economy and ecology of Africa. For instance, development of the renewable energy potential of Africa will trigger positive socio-economic growth. In contrast, some climate actions targeting natural ecosystems (e.g., large-scale afforestation in arid and grassy ecosystems) will have substantial negative impacts on both rural economy and rural ecology (see below).

- To reduce trade-offs and increase synergies, context-specific land-based climate actions are required in Africa. There is general acceptance that land-based climate actions, particularly those targeting natural ecosystems, must be implemented with caution to reduce trade-offs and maladaptation. In this respect, land-based climate actions in Africa should, at a minimum, meet the following criteria:
  - Reduce climate threats and risks to socio-ecological systems.
  - Address Sustainable Development Goals, particularly in places where decent liveli-hoods are possible, such as rural areas with highly productive soils and peri-urban are-as.
  - Improve natural resources governance.
  - Reduce land inequalities and tenure constraints.
  - Improve climate securities.
  - Be based on sound understanding of the ecology, structure and function of the targeted ecosystem.

5. How to enhance climate actions for mangroves:

- Mangroves store substantial quantities of carbon and are fundamental to the livelihoods of many coastal communities. Conservation, improved management and restoration of mangroves is crucial for coastal disaster risk management and preservation of fisheries-based livelihoods. Review of several case studies indicated that the avoided deforestation of mangroves can be achieved through financing mechanisms (REDD+ and blue carbon financing), local participation and stewardship, provision of alternative wood fuel sources, and improved regulatory frameworks. Several case studies also showed that mangrove restoration can be achieved using the community-based ecological restoration approach (CBERM). Importantly, case studies demonstrated that mangrove conservation, management and restoration lead to carbon storage, biodiversity conservation and improved livelihoods.

6. How to enhance climate actions for forests in Africa:

- **Conservation:** African forests are diverse in composition, structure and function. Forests in Africa store carbon, have high biodiversity and are the source of livelihood for many people. However, the continent is estimated to have one of the highest deforestation rates in the world, although this assertion is contested, with some experts asserting that both forest cover and deforestation rates in Africa are overestimated. The case studies examined revealed that avoided deforestation could contribute to climate change mitigation through avoided emission and provision of ecosystem services. Although several REDD+ initiatives have been implemented, funding gaps constrain their success. Participatory and community-based forest management initiatives have proven successful. Political will and interest, adequate funding, provision of alternative livelihood activities, and adoption of technology are critical to forest conservation in Africa.

- **Sustainable forest management (SFM):** SFM could contribute substantially to adaptation and mitigation efforts in Africa. However, disparities in benefits-sharing and responsibilities could lead to significant trade-offs between livelihood and environmental goals, especially in the absence of democratic decentralisation. Trade-offs between carbon, biodiversity and livelihood benefits of SFM can be reduced through provision of alternative livelihood interventions. However, financial incentives for carbon offset from concession-based SFM is relatively low in Africa.

- **Restoration:** Three distinct reforestation approaches exist in Africa. Generally, natural regeneration and mixed species plantations seem to perform better (in terms of biodiversity and carbon storage) than single species monocultures. However, quantitative assessment of the performance of the different approaches is constrained by lack of data. Reforestation in Africa is also constrained by agricultural expansion, such that successful reforestation often leads to deforestation leakages. Here, novel forest landscape-level sustainability initiatives may be the best choice for integrating livelihood, biodiversity and carbon goals.

- **Forest fires:** Fires have particularly damaging effects on forest composition, structure and function. Reducing fire incidence in forests could contribute significantly to carbon storage, biodiversity conservation and rural livelihoods. Several examples showed that participatory fire management schemes involving relevant stakeholders can reduce fire incidence and impact on forests in Africa. However, to be successful, forest fire management must consider regional differences in vegetation types, climate and local practices. In some regions of Africa (e.g., South Africa), fire control uses helicopters and organised teams for protecting urban areas and flammable crops, and requires large, organised bodies. Further, fire protection in commercial forestry, including large-scale commercial plantations, involves well-organised and equipped fire teams, which involves millions of dollars in operation costs. As Africa rapidly urbanises, such fire problems and large-scale fire control will likely grow.

7. How to enhance climate actions for open and grassy ecosystems in Africa:

Rangelands

- **Grazing impact on SOC:** Most of the grassy ecosystems of Africa are grazed by wildlife and livestock. Africa is home to over 40 million pastoralists, whose livelihood depends on healthy rangelands. Climate actions proposed for rangelands seek either to reduce emissions or to increase SOC in range soils. There are several lines of evidence that grazing affects SOC. However, the relationship between grazing and SOC is contingent on rainfall variability, with grazing causing reduction in SOC only when annual rainfall is >600 mm. Current pastoral practice in Africa, which involves high seasonal mobility, is likely to have minimal impact on SOC, except when resource constraints lead to overgrazing.

- **Grazing systems:** Short-intense rotational grazing is promoted as a superior grazing system for climate change adaptation and mitigation, compared with continuous grazing. Some experimental evidence lends support to this claim. However, under other conditions, continuous grazing performs as well as or better than short rotational grazing. These contrasting results suggest that context is critical when advocating grazing systems in Africa.

- **Holistic management (HM):** HM seeks to integrate ecology, economy and society in grazing management. It advocates grazing management that mimics native wildlife dynamics using short-intense grazing rotations. Although most of the predictions or central tenets of HM are contested, several case studies suggest that when properly practised, HM does lead to positive ecological, social and economic outcomes. However, the claim that HM, if practised on 50% of the world's grasslands, could reduce atmospheric CO_2 to pre-industrial levels, is currently unsubstantiated. Most controversies over HM stem from miscommunication and inconsistent use of terminologies by both proponents and opposers. Therefore, clarifying the key concepts of HM may help reconcile some of the controversies associated with its approach and practices.

- **The wilder rangeland concept (WRC):** WRC seeks either to replace managed livestock with harvestable communities of native wild herbivores, or to "rewild" livestock grazing practices. Climate change mitigation benefits of the WRC approach are linked to reduction in methane emission (through changes in size-class distribution), improvement in SOC and changes in fire regime. Adaptation benefits from the WRC approach may accrue from increased and diversified revenue streams and improved resilience to economic and climatic shocks. Some case studies have demonstrated both mitigation and adaptation benefits of the WRC approach. However, only a few case studies currently exist. Importantly, large-scale adoption of the WRC approach in Africa is likely constrained, given the existing land tenure system and the potential for human-wildlife conflicts. Further, keeping cattle/livestock has significant cultural importance in Africa and is unlikely to be replaced by wildlife/game farming, which rarely benefits the average person in Africa.

Woodlands

- **Conservation:** Several woodland types exist in Africa, including the *Isoberlinia* woodlands of the Sudanian region, the *Acacia* woodlands of the Sahel and East Africa, and the Miombo woodlands of the Zambezian region. A substantial area of Africa's woodlands has been converted to agricultural lands, with negative impacts on soil organic carbon, biodiversity and provision of ecosystem services. Therefore, conserving existing and restoring degraded woodlands is of critical importance to climate change adaptation and mitigation.

- **Fire regime:** Regulating fire regime through changes in fire frequency or season has been proposed as climate action that can enhance carbon storage in woodlands. However, in these systems, which can often burn in the dry season, the degree to which human fire management can alter fire regime at the scale required for climate mitigation is unclear. Moreover, unlike in forests, there are potentially negative biodiversity consequences to changing fire regime. Substantial data exists on this, but needs to be integrated into clear policy guidelines. Importantly, significant changes in fire regime in woodlands is likely to have significant negative impacts on the diversity of the herbaceous layer.

- **Restoration:** Several case studies have shown that degraded woodlands can be restored either through natural regeneration or by adding indigenous tree species to farmlands. Species richness, AGB and soil carbon recover remarkably quickly in agricultural land left to natural regeneration, highlighting the importance of conserving and managing areas that have been harvested or tilled, as they hold great potential for biodiversity conservation and carbon storage.

Savannas and grasslands

- **Conservation:** Most of Africa's savannas and grasslands have been converted to croplands, with associated biodiversity and carbon loss. Cropland expansion has resulted in significant changes in fire frequency and intensity. Wildlife biomass has also declined and been replaced by livestock, driving changes in herbivory regime. In addition, bush encroachment of savannas and grasslands is widespread across the continent. Despite these trends, there is no global financing mechanism (e.g., REDD+-type initiatives) for conservation of grasslands and savannas.

- **Afforestation:** There is a major push for afforestation in Africa's grasslands and savannas. Major large-scale afforestation projects, such as the Great Green Wall and AFR100, are currently being implemented. Afforestation is touted to have high carbon sequestration and livelihood benefits. The case studies examined provided inconclusive evidence for soil organic carbon (SOC) benefits of large-scale afforestation in grasslands and savannas. In contrast, the evidence clearly pointed to the negative impact of afforestation on hydrology, groundwater and biodiversity across Africa. Once afforested, grasslands and savannas are particularly difficult to restore. Importantly, fire risk in savannas and grasslands implies that robust fire protection measures are required to safeguard the carbon sequestration potential of such tree planting programmes. This requirement massively increases the cost of tree planting programmes in savannas and grasslands. Despite this, there are several examples of successful community-based tree planting initiatives targeting livelihood improvement and C-storage which, by using appropriate trees and ecological principles, could also be deemed good for biodiversity.

- **Fire regime:** Proposals for large-scale fire abatement or changes in fire seasons may be impractical and unlikely to deliver significant emission reduction benefits. Fire frequency and season affect emission characteristics. Recently, proposals have been made to alter fire frequency and season to reduce fire-based emissions. However, available evidence suggests that such fire-based climate actions are unlikely to deliver the projected emission reductions. This is due to several reasons, including: 1) current trend of steady decline in annual burned area, 2) difficulty in influencing some aspects of fire (e.g., fire-return interval), 3) little evidence that early dry season burning yields significant emission reduction across different types of savannas and grasslands, and 4) early dry season fire being already extensively practised across Africa.

- **Soil organic carbon (SOC):** Maintaining and enhancing soil organic carbon (SOC) in grasslands and savannas is an important climate change mitigation option. More than half of total ecosystem carbon (TEC) in grasslands and savannas is stored belowground as SOC. The case studies examined indicated that biome-appropriate levels of fire and grazing have little impact on SOC, whereas extremes (e.g., high-frequency fire or fire exclusion, and grazing exclusion or overgrazing) reduce SOC. Many papers tout livestock management, or rewilding with indigenous grazers, as mechanisms to increase soil carbon, but the evidence for this is so far insufficient. As these interventions can potentially be practised at scale, it is important to clarify whether grazing management has potential as a climate mitigation option.

- **Biodiversity conservation:** Climate actions in savannas and grasslands must consider the impact of proposed interventions on biodiversity. For instance, proposals for changes in fire regime or increasing TEC and SOC have rarely considered the biodiversity implications. The evidence is clear that disturbance (fire and herbivory) is critical to maintaining open canopies, which, in turn, is crucial for conserving the diversity and biomass of the herbaceous layer, upon which a variety of life forms and ecosystem services depend.

- **Bush encroachment:** The impact of bush encroachment on TEC and SOC in grasslands and savannas is dependent on climate and topo-edaphic factors. Therefore, bush encroachment may increase TEC and SOC under some conditions, while driving reduction under other conditions. However, the impact of bush encroachment on biodiversity is well established, with several studies reporting negative impacts on ecosystem services, mammalian and herpetofaunal assemblage, termite activity and mesocarnivore scavenging activity.

8. How to enhance climate actions for arid zones, deserts and desertification:

- **Contributions of deserts:** About one third of the land area in Africa is desert. Two major desert formations exist, namely the Sahara and Namib Deserts. Some deserts in Africa (e.g., the succulent Karoo) have rich biodiversity and provide important ecosystem services such as fertilisation of the Amazon and equatorial Atlantic Ocean. Deserts also have high albedo, which play important roles in land-atmosphere feedback systems.

- **Desert greening:** Currently, most deserts are getting greener and contributing to climate change mitigation naturally. Some climate actions in deserts in Africa also target increasing contribution to mitigation through increase in plant cover. However, existing evidence suggests that greening of deserts (naturally or through afforestation) may have a negative effect on provision of other ecosystem services (e.g., reduced dust transport to the oceans and decreased albedo). For instance, limited evidence suggests that greening of Africa's deserts may even worsen local climatic conditions. Importantly, afforestation in deserts is likely ineffective due to high plant mortality.

- **Desert-based solar and wind farms:** Proposals have been made to deploy large-scale photovoltaic solar and wind farms to generate renewable energy for Europe and Africa. Proponents of such climate actions argue that such an initiative would reduce fossil fuel consumption and generate local climate benefits. However, few studies exist that provide empirical evidence to support these claims. For instance, one study concluded that large-scale solar farms in the Sahara Desert may cause an increase in local rainfall in the neighbouring Sahel region. However, another study indicated that such large-scale solar farms would have several negative impacts, including drought in the Amazon, increased surface temperature, sea-ice loss and enhanced tropical cyclones. Importantly, large-scale renewable energy projects often displace people from their ancestral lands and largely exclude local people from job opportunities. Engagement and active participation of local people in such project designs and management are key to enhancing their resilience to climate change.

- **Desertification:** Many countries in Africa are experiencing desertification. Therefore, climate actions seek to reduce or reverse desertification. There is substantial scientific evidence that land degradation is a major problem in Africa, and actions to halt this trend are essential for climate change adaptation. Indeed, Africa's flagship programme, the Great Green Wall initiative, is geared towards halting the southward expansion of the Sahara Desert. However, several case studies argued that conflating land degradation and desertification leads to promotion of climate actions (e.g., large-scale afforestation) that are decoupled from the root cause of the problem. Indeed, several case studies have shown that land degradation in Africa is driven mainly by poor soils, which forces poor communities to clear and degrade land every few years as well as over-exploit natural resources.

Thus, land degradation is best addressed through local restoration efforts that maximize livelihood opportunities.

9. How to enhance climate actions for agriculture:

- **Climate change and agriculture:** Agriculture is a critical component – together with the informal sectors – of Africa's economy. Agriculture, fisheries and forestry account for 14% of GDP and employ over 53% of Africans. However, agriculture in Africa is largely subsistence and rainfed. Therefore, the agricultural sector in Africa is highly exposed to climatic risks, and climate change impacts are already being experienced. Climate actions in agriculture in Africa focus mostly on adaptation, but several examples of mitigation interventions exist.

- **Climate actions in cropland:** In croplands, climate actions were mostly local in scale, involving indigenous adaptation practices and other interventions such as climate-smart agriculture (CSA), conservation agriculture (CA) and land intensification practices. Most of these interventions were geared towards maintaining soil fertility, improving yields, increasing resilience (e.g., to drought, flood, windstorm, etc.) and reducing GHG emissions. Substantial evidence exists suggesting that indigenous and climate actions, such as CSA and CA, results in improvement in productivity, carbon storage and livelihoods. However, empirical evidence of cost-effectiveness of indigenous crop-based climate interventions is lacking and may constrain upscaling of innovative practices.

- **Climate actions in livestock (pasture):** Climate actions in livestock production under pasture focused on emission reduction through improved feeding practices and pasture management practices. Adaptation measures included cattle watering, fodder and pasture management, and livestock management. Further, drought prediction and planning and opportunities for livestock mobility were identified as the most important aspects of livestock adaptation. In contrast, mitigation interventions were limited to improved fodder, manure management and SOC. Both adaptation and mitigation measures had positive impacts on livestock productivity and GHG emissions. However, production of improved forage in Africa is likely to increase GHG emissions either due to land conversion or due to increased fertiliser inputs.

- **Agroforestry:** Agroforestry was highlighted as a particularly promising climate action across all ecological zones. Substantial evidence exists in Africa demonstrating the utility of agroforestry in delivering carbon, biodiversity and livelihood gains. Indeed, several case studies showed that local agroforestry-based interventions could be a particularly powerful tool for improving biodiversity and enhancing livelihoods across diverse biomes, including in arid environments.

10. How to enhance climate actions for urban areas:

- Africa is rapidly urbanising. However, climate change is expected to have a particularly high impact on urban centres in Africa. Most African urban areas have high exposure to climate change risks but have low adaptive capacities.

Improving climate resilience in Af-rica's urban centres is fundamental to mitigating the negative impacts of climate change. Despite this, there is a dearth of case studies on successful climate change adaptation and mitigation approaches in urban centres in Africa. The existing case studies are mostly exploratory in nature and deal with issues such as drainage and flood management, urban green infrastructure, natural resource use, water and watershed management, spatial planning and resource use. Importantly, examples of urban-based climate actions in Africa are mostly from South Africa, emphasising a large regional disparity.

11. How to enhance climate actions for wood fuels:

- Wood harvest and wood fuel use is a major socio-economic activity for over 60% of Africans. Both commercial (which feeds urban markets with affordable charcoal) and domestic (i.e., fuel for rural areas) are thought to have important CCMA implications. The climate mitigation impacts of interventions to reduce wood fuel use depend on what energy source is proposed as an alternative. Case studies show that more efficient cooking stoves are an effective intervention – hav-ing no negative livelihood or GHG consequences – but the degree to which these can be scaled to achieve real climate mitigation impacts is unclear. Case studies on sustainable harvesting of woodlands demonstrate that wood fuel can be a climate-neutral energy source, but again, whether sustainable harvesting practices are feasible at scale. More research is required.

12. There are significant knowledge, information and data gaps that need to be addressed to enhance climate actions on land in Africa:

Concerted efforts must be directed to addressing the following knowledge, information and data gaps to enhance climate actions on land in Africa:

General and cross-cutting themes:

- Estimate the mitigation potential across climate actions, ecosystems, land-use types and the five sub-regions.
- Determine the limit of climate change adaptation in Africa for various socio-ecological systems.
- Understand the cost-benefit of large vs local-scale climate actions in Africa.
- Accumulate empirical evidence of the effectiveness of nature-based solutions (NbS) under different contexts in Africa.
- Understand gender and social gaps in climate change mitigation and adaptation in Africa.
- Evaluate the effectiveness of existing frameworks for genetic resources and biodiversity conservation in Africa.

Mangroves and forests

- Understand the response of distinct forests and mangrove types to climate change in Africa.
- Examine variations in trade-offs between carbon, biodiversity and livelihood goals across distinct forest and mangrove types and land-use types.

- Evaluate the benefits and trade-offs associated with different forest restoration options (natural regeneration, mixed species plantation, and monoculture) across land-use types.
- Assess the potential of novel forest landscape sustainability initiatives across distinct climatic zones in Africa.

Grassy ecosystems

- Map and quantify the extent of various grassy ecosystems in Africa to serve as a baseline for ap-praising, monitoring and evaluating climate actions.
- Quantify the total ecosystem value (TEV) of grassy ecosystems in Africa to enhance evaluation of the opportunity and trade-off cost associated with climate actions.
- Explore the potential benefits of "avoided grassland tillage" as a carbon offset activity and de-rive mechanisms to reward people for "avoided grassland tillage" and grassland conservation.
- Assess the effectiveness of existing international financing mechanisms for conservation, management and restoration of grassy ecosystems.
- Develop improved and easy-to-use protocols and tools for carbon accounting in grassy ecosystems.
- Conduct more research to tease out the impact of grazing and fire on SOC stocks and dynamics across the various grassy ecosystem types in Africa.
- Document and assess the effectiveness of indigenous and traditional practices in supporting con-servation, management and restoration of grassy ecosystems in Africa.

Agriculture

- Identify and promote low-cost and best practices for tree regeneration on farmlands under arid conditions.
- Establish benchmarks for sustainable agricultural, traditional and indigenous practices.
- Evaluate impacts of farm-based climate actions on biodiversity conservation.
- Evaluate the cost-effectiveness of local and indigenous adaptation practices across agro-ecological zones.

Urban areas

- Generate empirical evidence of cost-effectiveness of proposed urban climate action across Africa.
- Close the regional data and knowledge disparity on urban-based climate actions in Africa.
- Promote transfer, wherever appropriate, of low-energy solutions to rapidly growing urban centres in Africa.

Abbreviations

AUDA-NEPAD	African Union Development Agency – New Partnership for Africa's Development
AFR100	African Forest Landscape Restoration Initiative
ACCS	African Climate Change Strategy
AGNES	African Group of Negotiators Expert Support
AU	African Union
AUMS	African Union Member States
AFOLU	Agriculture, Forestry and Other Land Use
AUC	African Union Commission
CH4	Methane
CO_2	Carbon dioxide
CBFM	Community-based forest management
CBEMR	Community-based ecological mangrove restoration
CCMA	Climate change mitigation and adaptation
COP	Conference of Parties
CBA	Community-based adaptation
CBNRM	Community-based natural resources management
CSE	Catchment systems engineering
CDR	Carbon dioxide removal
CBD	Convention on biological diversity
EbA	Ecosystem-based adaptation
EE	Ecological engineering
ER	Ecological restoration
ERA	Ecosystem restoration approach
GCP	Glasgow Climate Pact
GHG	Greenhouse gas
GGW	Great Green Wall
GI	Green infrastructure
GDP	Gross domestic product
LSS	Land systems studies
LULUCF	Land use, land-use change and forestry
MAP	Mean annual precipitation
SDGs	Sustainable Development Goals
SFDRR	The Sendai Framework for Disaster Risk Reduction
NbS	Nature-based solutions
NCS	Natural Climate Solutions
NDCs	Nationally Determined Contributions
NWFPs	Non-wood forest products
TOR	Terms of Reference
TEV	Total ecosystem value
REDD+	Reducing emission from deforestation and forest degradation
SFM	Sustainable forest management
SSNM	Savanna Science Network Meeting
SOC	Soil organic carbon
PA	Paris Agreement
IPCC	Intergovernmental Panel on Climate Change
UNEP	United Nations Environment Programme

Chapter 1

Introduction

Credit: Sally Archibald, Grumeti landscape, Tanzania

This working paper report has been prepared with the goal of enhancing climate actions on land in Africa. The report seeks to address two recent calls made in relation to improving climate actions on land. Firstly, paragraph 21 of the cover decision of the Glasgow Climate Pact (GCP) emphasises the importance of protecting, conserving and restoring nature and ecosystems, including forest and other terrestrial and marine ecosystems, to achieve the long-term global goal of the Convention by acting as sinks and reservoirs of greenhouse gases and protecting biodiversity, while ensuring social and environmental safeguards [1]. Paragraph 59 of the cover decision of the GCP further invites parties to submit views on how to enhance climate action on land and, under the existing UNFCCC programmes and activities in paragraph 75 of the report, on the dialogue on the relationship between land and climate change adaptation related matters. The Chair of the Subsidiary Body for Scientific and Technological Advice (SBSTA) is requested to prepare an informal summary report and make same available to the Conference of the Parties at its 27th session (COP27) [1].

Secondly, the African Union (AU) Agenda 2063 envisions African participation in global efforts for climate change mitigation that support and broaden the policy space for sustainable development on the continent, and specifically calls for "Africa speaking with one voice and unity of purpose in advancing its position and interest on climate change" in global forums [2]. Importantly, the draft African Climate Change Strategy (ACCS) document identifies the lack of a coordinated and common African position as one of the key challenges affecting the continent's response to climate change [3]. The ACCS further indicates that "identifying, documenting and disseminating best practices and success stories" is fundamental to facilitating exchange of knowledge and experiences between regions, countries and communities for climate change adaptation and mitigation [3].

Objectives

The main aim of this working paper report is to deepen understanding of the relationship between land and climate change mitigation and adaptation in Africa. Africa is highly vulnerable to climate change, because of high exposure (e.g., continental warming greater than the global average) and low capacity to adapt to climate change and related impacts [4,5]. In spite of this, the continent can play a crucial role in addressing global climate change, given its low historical contribution to GHG emissions, vast landmass, high renewable resources potential (e.g., huge potential for solar energy) and unique ecosystems (including forests, mangroves, wetlands, savannas, grasslands and deserts) [3]. However, climate actions designed to harness Africa's climate change mitigation and adaptation potential require careful consideration of co-benefits and trade-offs, particularly those linked to livelihood opportunities, biodiversity conservation, adaptation and conflicts [3,6,7]. This calls for context-specific climate actions that are fit for purpose and consistent with both the working of nature and society across all levels [3].

The report has been prepared considering the current state of knowledge of climate actions across Africa's diverse ecosystems and land-use practices. Leading examples of climate actions on lands in Africa have been extensively reviewed to evaluate their climate objectives and other environmental and social co-benefits and trade-offs. The analyses took into consideration the different ecosystems and land-use/management types across the five sub-regions of Africa (i.e., North, West, Central, East and Southern Africa). The report is therefore expected to become an important source of information for African experts and negotiators to define a common African position on climate actions that can be promoted and operationalised across the agriculture-forestry-biodiversity-climate nexus.

"...climate actions designed to harness Africa's climate change mitigation and adaptation potential require careful consideration of co-benefits and trade-offs, particularly those linked to livelihood opportunities, biodiversity conservation, adaptation and conflicts."

The report particularly highlights the role of Africa's open and grassy ecosystems in the context of climate change mitigation and adaptation options, identifying case studies of potential interest. Africa is predominantly a continent of open and grassy ecosystems. Approximately 55% of Africa's land mass is covered by grassy biomes (i.e., rangelands, woodlands, savannas and grasslands) [8] that are fundamental to livelihoods. These grassy ecosystems contribute significantly to Africa's biodiversity and serve as important net CO_2 sinks. However, the structure and functions of these grassy ecosystems are currently threatened by over-exploitation (e.g., overgrazing), land-use changes (leading to changes in fire and herbivory regimes) and climate change [6]. Inappropriate climate actions in Africa's grassy ecosystems (e.g., large-scale afforestation targeting carbon sequestration) are likely to worsen current threats on these systems and reduce their adaptation and mitigation potentials [9,10].

The report also highlights data, information and research gaps that need to be addressed for more Africa-appropriate climate change mitigation and adaptation solutions to be operationalised. These highlights include: 1) data and research gaps on climate solutions and country-level policies and processes (e.g., the Nationally Determined Contributions (NDCs)), 2) impact of proposed climate solutions on aboveground and belowground carbon storage and emissions across the different ecosystems, 3) land-use/management types and CO_2 emissions, and 4) transboundary climate risk and impacts.

Report preparation

The African Group of Negotiators Experts Support (AGNES) and partners (Oppenheimer Research and Conservation, University of the Witwatersrand, AUDA-NEPAD) commissioned a working paper on climate actions on land in Africa in February 2022 with the aim of deepening understanding of the relationship between land and climate change mitigation and adaptation in Africa. The terms of reference (TOR) and concept notes were then sent to the lead author on 2 February 2022. On 10 February 2022, a first TOR meeting was conducted between the lead author, AGNES and partners to provide detailed guidelines for the working paper report. Subsequently, the lead author submitted an inception report on 21 February 2022 and commenced developing a framework for gathering the relevant case studies for the report (see chapter 2 for details).

Four [4] main activities were undertaken to gather the relevant case studies and information for the preparation of the report. Firstly, the lead author attended the Savanna Science Network Meeting (SSNM) and post-network meeting workshop on nature-based solutions in the Kruger National Park, South Africa, from 5 to 16 March 2022. The SSNM is an annual conference where scientists working on open ecosystems across the world meet to share their latest research findings. The 2022 SSNM conference, therefore, provided the lead author the opportunity to discuss the goal of the working paper report with several African grassy ecosystem scientists to solicit their views on the different land-based CCMA options for different ecosystems, and to seek their recommendations on critical case studies to be included in the review.

Secondly, the authors conducted extensive literature review to 1) identify the main land-based CCMA options proposed for the different ecosystems and land uses, 2) summarise current trends of climate change and impacts across Africa, 3) identify the key climate commitments made by African nations, 4) identify and characterise Africa's framework for climate change mitigation and adaptation, 5) identify critical and topical issues of importance to CCMA, and 6) gather evidence for land-based CCMA actions across the diverse ecosystems, land uses and sub-regions (North, West, Central, East and Southern Africa) across Africa. For this exercise, and in addition to case studies gathered during the SSNM conference, the authors conducted

“Inappropriate climate actions in Africa's grassy ecosystems (e.g., large-scale afforestation targeting carbon sequestration) are likely to worsen current threats on these systems and reduce their adaptation and mitigation potentials”

a search for specific land-based CCMA options in Africa on Scopus (https://www.scopus.com/) and Google Scholar (https://scholar.google.com/). Outputs generated from these searches (e.g., {Agroforestry} AND {Africa}) were reviewed individually, and those providing evidence of land-based CCMA options (either quantitative or qualitative) were selected for more detailed examination. In addition to these searches, all NbS case studies provided by the Nature-based Solutions Evidence Platform Policy (https://www.naturebasedsolutionsevidence.info/) were included in the list of case studies.

Thirdly, the lead author attended a working session meeting to develop common a African position on how to enhance climate action on land, held in Livingstone, Zambia, from 30 March to 1 April 2022. The meeting brought together scientists, practitioners, policy makers and negotiators across Africa, working on diverse ecosystems and land use to deliberate on existing land-based CCMA options and identify new and innovative approaches for enhancing climate actions for Africa. The output of this meeting (draft submission by the Republic of Zambia on behalf of the Africa Group on how to enhance climate action on land) greatly influenced the final structure of this report.

Finally, for land-based CCMA options lacking adequate case studies or with relatively few empirical studies in Africa, the lead author reached out to experts in the field through emails and Zoom calls to obtain input.

Terminologies and scope of climate actions considered

Several concepts are used to frame Climate Change Mitigation and Adaptation (CCMA) on land. Of these, the concept of "nature-based solutions" (NbS) has gained popularity in recent years [11-14]. Nature-based solutions are defined as "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" [15]. NbS interventions are generally geared towards 1) protecting and enhancing biodiversity, 2) mitigating and adapting to climate change, and 3) ensuring human well-being. The NbS concept builds on other earlier concepts – such as ecosystem approach and ecosystem-based adaptation/mitigation [16,17].

1

In spite of its popularity and operating as a unifying concept, the use of the term "NbS" is still strongly contested in global climate change forums. Opponents of the NbS concept argue that:

1. Framing of some climate actions as "natural" and others as "unnatural" limits the range of effective options available to policy makers [18].
2. There is the likelihood of misunderstanding that NbS can provide a global solution to climate change [19].
3. "Nature" being expressed as "solution" to climate change is inappropriate and detracts attention from the need for urgent reduction of greenhouse gas emissions[1].
4. Pledges for NbS often translate into targets for afforestation, often with monocultures and non-native species [20].
5. There is limited proof that NbS actions are more desirable, given existing technical limitations, risks and uncertainties, particularly in relation to actual carbon sequestration potential, land requirements and potential trade-offs (e.g., with biodiversity) [18].

> "In spite of its popularity and operating as a unifying concept, the use of the term "NbS" is still strongly contested in global climate change forums."

1 See here for detailed discussions on this during the approval of the Summary for Policymakers (SPM) of the assessment report of the Intergovernmental Panel on Climate Change (IPCC) Working Group 2 (WGII) on "Climate Change: 2022: Impacts, Adaptation and Vulnerability".

In this working paper report, we use the term "land-based CCMA options" to encompass diverse CCMA concepts and actions that involve the use of ecosystems, biodiversity and nature in climate change mitigation and adaptation [21,22]. Land-based CCMA options include diverse concepts and actions covering ecosystems-, agriculture-, urban- and community-based interventions (FIGURE 1.1).

Land-based CCMA options are generally "supply-side measures" that seek to reduce emission, increase carbon sequestration of natural ecosystems and improve community resilience [21]. Land-based supply-side measures include interventions to protect, manage and restore forests and other ecosystems; reduce emission and enhance carbon sequestration in agriculture; and enhance carbon sequestration using bioenergy. In contrast, "demand-side" measures for climate change mitigation encompass strategies targeting consumption-based or lifestyle-based approaches, such as interventions targeting food waste, dietary changes towards less energy-intensive diets, and efficient resource use in production of consumable products [23,24].

Land-based CCMA pathways can further be categorised into emission reduction (ER) and carbon dioxide removal (CDR) pathways (FIGURE 1.2) [25]. Land-based emission reduction interventions seek to reduce GHG emissions from forest and other ecosystems – by conserving carbon-rich ecosystems, as well as adoption of sustainable agricultural practices. Land-based CDR pathways include improved management of ecosystems, restoration of degraded ecosystems and agroforestry [26]. Although both ER and CDR interventions can target any given ecosystem or land use, subtle variations exist with respect to where the different sub-pathways can be deployed. For instance, conservation, improved management and restoration interventions can be deployed for all terrestrial ecosystems (e.g., forest, mangrove and savanna/grassland). However, agroforestry and sustainable agriculture interventions are specifically designed for croplands and pastures.

Afforestation Eco-disaster risk management Ecosystem-based adaptation Ecosystem restoration approach (ERA) Natural climate solutions (NCS) Reforestation Rewilding Partoralism **Ecosystem**	Agroecology Agroforestry Conservation agriculture (CA) Climate-smart agriculture (CSA) Livestock – Pasture **Agriculture**
Community-based adaptation (CBA) Community-based natural resources management (CBNRM) **Community**	Catchmeny systems engineering (CSE) Ecology engineering (EE) Green Infrastructure (GI) **Urban**

FIGURE 1. 1: Examples of land-based CCMA options across ecosystem-, agriculture-, urban- and community-based interventions. These interventions are also commonly referred to as nature-based solutions (NbS) or natural climate solutions (NCS).

Several components can be identified under each sub-pathway, as follows: 1) ecosystem conservation includes avoided deforestation and avoided conversion of non-forest ecosystems such as grassy ecosystems; 2) sustainable agriculture encompasses farm energy consumption, manure and fertiliser management and enteric fermentation, 3) ecosystem management includes interventions such as sustainable forest management, changed burning practices in grassy ecosystems and managing soil carbon in grasslands, 4) ecosystem restoration includes reforestation and ecosystem restoration (for non-forest ecosystems), and 5) agroforestry covers integration of variable tree cover in croplands and agropastoral systems [13].

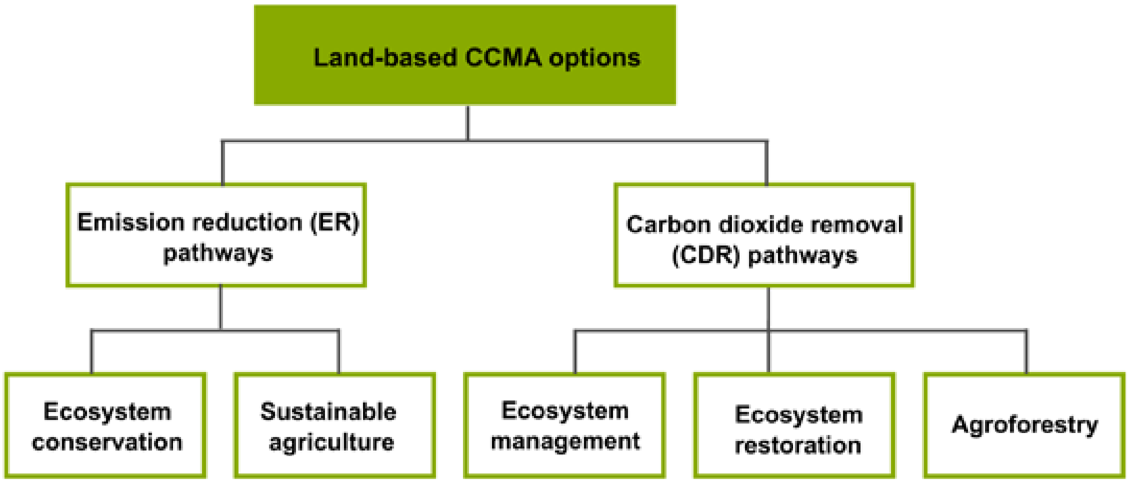

FIGURE 1.2: Overview of land-based CCMA options emphasising different sub-pathways under emission reduction and carbon dioxide removal pathways

Chapter 2

Climate change adaptation and mitigation in Africa

Credit: Sally Archibald, Kasanka National Park, Zambia

We performed extensive literature review to establish a framework for assessing climate actions in Africa. The review below first provides an overview of global actions and the role of land-based CCMA options for reducing global warming to within 1.5°C or 2°C of pre-industrial levels in this century. Subsequently, we summarise climate trends in Africa and identify the key climate commitments made by African countries. Given that Africa's focus is on climate change adaptation and sustainable development, the review highlights potential synergies and trade-offs between climate actions and sustainable development. The review shows that trade-offs and synergies between climate actions and sustainable development go beyond biodiversity conservation and rural development, and include topical issues such as land governance, climate securities as well as the concept of ecosystem degradation.

Global climate actions – From Paris to Glasgow and beyond

There is consensus among scientists that global warming above 2°C of pre-industrial levels will lead to significant societal, economic and ecological damage [27]. Global warming above 2°C is predicted to usher in extreme climate risks, such as frequent extreme weather events (e.g., flooding), significant species loss, increased drought, extreme heatwaves, sea-level rise, lower agricultural productivity and lower economic growth globally [26-28].

Since 2015, there has been a concerted effort by the global community to combat global warming. In December 2015, at COP21 in Paris, parties to the United Nations Framework Convention on Climate Change (UNFCCC) reached a landmark agreement (the "Paris Agreement" = PA) to combat the threats posed by climate change by keeping global temperature rise this century to below 2°C [1]. Indeed, the PA aims to limit global temperature rise further to within 1.5°C of pre-industrial levels [1]. Limiting global temperature rise to within 1.5°C above pre-industrial levels is generally predicted to pose less climate-related risks compared with warming of 2°C [27].

According to the IPCC special report, reducing global warming to below 1.5°C and 2°C above pre-industrial levels requires substantial global emission reduction [27]. To reduce global warming to below 1.5°C of pre-industrial levels, global emission needs to decline by 45% from the 2010 level by 2030, and should reach net zero by 2050. Similarly, to reduce global warming to within 2°C of pre-industrial levels, there is the need to cut global emission by 25% by 2030 and attain net zero emission by 2070 [27,29].

To reach the common goals of climate risk reduction set in the PA, all parties are required to set commitments to cut their greenhouse gas emissions over time [1]. These commitments are Nationally Determined Contributions (NDCs) which are climate action plans pledged by nations to cut greenhouse gas emissions and adapt to climate effects [30]. Nations specifically set their targets to cut their emissions in NDCs with clear descriptions of how to reach the target. Every five years, the new or updated NDCs are submitted to the office of the UNFCCC Secretariat. These commitments of climate actions are used to evaluate the progress made by each party, which collectively determines global commitments towards achieving the long-term goal of the PA.

Recent analysis of global climate actions suggests that current actions are falling short of the PA targets [29,31]. The United Nations Environment Programme's Emission Gap Report (2021) showed that the new and updated NDCs, coupled with the announced pledges for 2030, have negligible impact on global emissions [31]. Similarly, the NDCs synthesis report concluded that the global emissions level in 2030 will be more than 16.3% of the 2010 level, and that cumulative CO_2

emission in 2020-2030 will likely use up 89% of the remaining carbon budget consistent with reducing global warming to 1.5˚C by 2050 [29].

The role of land-based CCMA in reducing global warming below 2˚C

Limiting global warming to within either 1.5˚C or 2˚C above pre-industrial levels requires far-reaching transformation across every sector of society. The United Nations Environment Programme estimates that 43 Gt of CO_2 equivalent emission reduction can be achieved across six sectors annually [32]. This includes 12.5 Gt of CO_2 equivalent from the energy sector; 7.3 Gt from industry; 6.7 Gt from agriculture, food and waste; 5.9 Gt from nature-based solutions; 5.9 Gt from buildings and cities; and 4.7 Gt from transport [32].

The importance of land-based activities in reducing global warming to within 1.5˚C or 2˚C have been particularly highlighted in global climate forums and scientific publications [21,25,26,33]. On one hand, land-based emissions account for about 14% of net global anthropogenic CO_2 emissions through deforestation, agriculture, peatland drainage and mangrove clearance, livestock farming and rice paddies, fertiliser use, etc. [26,34]. At the same time, land is a major CO_2 sink and is estimated to have absorbed about one third of the CO_2 released since the first Industrial Revolution. It is estimated that significant CO_2 emission reductions and removals can be achieved by modifying land use, land-use change and forestry (LULUCF) activities [26]. Indeed, there is substantial evidence that agriculture, forestry and other related land use (AFOLU) can provide up to 20-30% of the net emission reduction needed by 2050 to limit global temperature rise to 1.5˚C [16,25,26,32,33].

Climate change trends in Africa

Africa has contributed among the least to historical global GHG emission, accounting for about 9% of total GHG emissions for the time period 1990-2019 [4]. Africa's GHG emission is mostly in the form of carbon dioxide (CO_2) and methane (CH_4) from the AFOLU and energy sectors, but emissions from industry, transport and buildings have picked up in recent years [4,35]. Despite its low GHG contribution, Africa is predicted to experience the most severe impact of global warming and associated climate change [4,35,36]. The recent IPCC report on climate change in Africa indicated, among others, increasing mean and extreme temperature (greater than the global rate of warming), increased heatwaves, frequent drought (particularly in West and Southern Africa) and frequent and intense heavy rains across much of Africa [4,5]. The predicted impact of such warming and climate change includes increased risk of reduced food production due to a decline in agricultural productivity and net primary productivity in rangelands; significant shifts in the range and distribution of plants and animals, with associated loss of biodiversity; increasing conflicts, particularly over land-based resources; and a rise in the proportion of Africans living under extreme poverty [4,5].

Climate change impacts are already being felt in key sectors across Africa [36]. Climate impacts include water scarcity, food insecurities (e.g., in Southern Africa), spread of invasive species, sea-level rise (especially in West Africa) and extreme weather events [5,36,37]. Given that the majority of Africans are employed in climate-exposed sectors (e.g., crop production, pastures and pastoralism), the impact of climate change is predicted to affect the most disadvantaged groups (e.g., children, women, youth and pastoralists) disproportionately [5]. Importantly, urbanisation and population growth are expected to result in rapid development of infrastructure and an increased demand for

“Despite its low GHG contribution, Africa is predicted to experience the most severe impact of global warming and associated climate change.”

food, water and energy, which will increase emission of GHG, further compounding global warming 38.

Key commitments on climate change in Africa

Given the high vulnerability, low adaptive capacity and low resilience of most African countries, global warming and climate change represent the most difficult bottleneck for economic growth and sustainable development 3. Therefore, African countries and the continent's intergovernmental bodies (e.g., the African Union (AU) and its sub-regional organisations) have demonstrated strong interest in climate change adaptation. Currently, 54 African Union Member States (AUMS) have ratified the Paris Agreement, and 53 of these have submitted their first NDCs.

At the continental level, several initiatives are promoted to contribute to climate mitigation, often with landscape restoration and job creation as co-benefits. These include the Great Green Wall initiative (https://www.greatgreenwall.org/about-great-green-wall), the African Resilient Landscape Initiative (ARLI), the African Forest Landscape Restoration Initiative (AFR100; https://afr100.org/) and several other national initiatives (e.g., the Green Legacy Programme in Ethiopia). However, African nations vary in the degree to which they embrace climate mitigation versus adaptation actions, and there is a sense that these initiatives are driven largely from outside the continent, sometimes with insufficient understanding of the ecosystem and the social consequences of various proposed interventions.

Africa's framework for climate change adaptation and mitigation

FIGURE 2.1 summarises Africa's climate change adaptation and mitigation framework, which is also partly set out in Agenda 2063 ("The Africa We Want") 2. Agenda 2063 is Africa's blueprint and master plan for attaining inclusive and sustainable economic growth and development. Agenda 2063 is strongly aligned with the Sustainable Development Goals (SDGs) and envisions *"an integrated, prosperous and peaceful Africa, driven by its own citizens and representing a dynamic force in the international arena"*. Agenda 2063 spells out the seven Aspirations of the "Africa We Want" by 2063, which range from a prosperous Africa based on inclusive growth and sustainable development, to a united, strong, resilient and influential global player and partner. Aspiration 1 of Agenda 2063 outlines the goals of Africa's climate change response, which are:

I. Africa shall address the global challenge of climate change by prioritising adaptation in all our actions for sustainable development and shared prosperity.

II. Africa shall participate in global efforts for climate mitigation that support and broaden the policy space for sustainable development on the continent.

Therefore, Africa's response to global warming and climate change involves, first, prioritising adaptation, and supporting global efforts aimed at climate change mitigation, particularly if they provide opportunities for achieving sustainable development.

Africa's response to climate change is further articulated in the "Draft African Climate Change Strategy 2020-2030" 3. The overall objective of the strategy is to ensure the achievement of the vision of Agenda 2063, by building resilience of the African continent to

"African nations vary in the degree to which they embrace climate mitigation versus adaptation actions, and there is a sense that these initiatives are driven largely from outside the continent, sometimes with insufficient understanding of the ecosystem and the social consequences of various proposed interventions."

the impacts of climate change – a goal that is linked to SDG 13: "Take urgent action to combat climate change and its impacts." The draft climate change strategy integrates relevant climate-oriented (e.g., the Sendai Framework for Disaster Risk Reduction (SFDRR) and the Convention on Biological Diversity (CBD)) and non-climate commitments, while providing flexible options for the sub-regional organisations to determine the exact nature of interventions to be implemented 3.

A central theme of both Agenda 2063 and the African Climate Change Strategy is the fundamental role of land and natural resources in both sustainable development and climate change mitigation and adaptation. Africa is the world's second largest continental land mass – with a total land area of 30.37 million square kilometres – with impressive ecological diversity, including wetlands, lakes, forests, grassy ecosystems as well as extensive arable land (60% of the world's arable land). This vast land and diversity of ecosystems can play an important role in both adaptation (on the continent) and mitigation (globally). Therefore, the strategy places the conservation and management of natural resources at the core of climate change adaptation and mitigation in Africa.

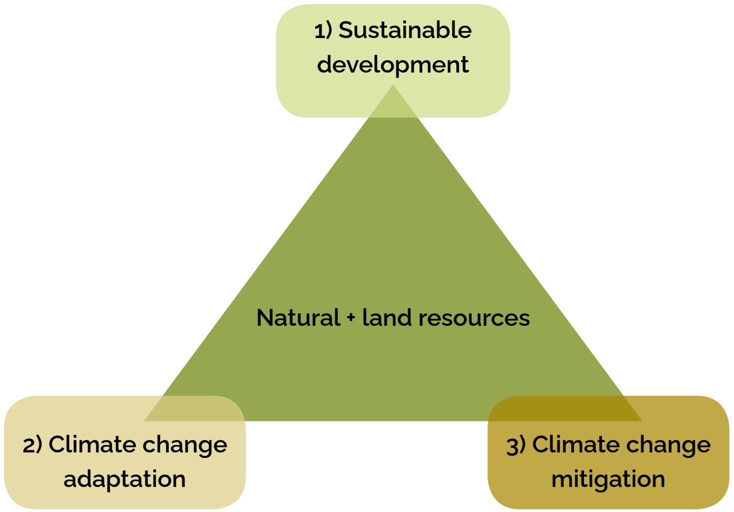

FIGURE 2.1: Interdependence between sustainable development and climate change adaptation and mitigation, and the central role of land and natural resources in Africa

Trends in climate actions in Africa

Consistent with the framework presented under section 2.4, two recent reviews of the NDCs of African countries show a clear prioritisation of adaptation compared with mitigation measures 39,40. These reviews show that adaptation actions are considered across multiple sectors and reflect perceived climate risks associated with these sectors 40. The number of adaptation measures was highest for agriculture, and include actions such as climate-smart agriculture, provision of irrigation, and land and soil management, with the goal of ensuring food security (FIGURE 2.2). The water sector had the second highest adaptation measures, encompassing actions such as water management, water supply and quality, water conservation and reuse, water infrastructure and watershed management. Several adaptation measures were also found to be geared towards disaster risk management (e.g., disaster preparedness, monitoring and evaluation) and health and disease surveillance 40. In urban areas, the use of infrastructure and services which shape behavioural choices and restructure markets is limited in terms of built environment 41,42.

Mitigation measures targeted mostly the energy, conservation, transport, waste management and agriculture sectors 40. Energy-related mitigation measures targeted replacement of fossil fuels with renewable energy sources – mostly hydropower, but also biofuels, solar and efficient cooking stoves – and enhanced energy efficiency. Mitigation actions in conservation focused broadly on reducing GHG emissions as well as carbon sequestration through actions linked to sustainable forestry, reducing emission from deforestation and forest degradation (REDD), afforestation, reforestation and sustainable land management. Transport mitigation measures covered mostly improvement in urban and public transport and transport fuel use, whereas waste management mitigation encompassed waste-to-energy, agricultural and water waste, recycling and reuse. Mitigation measures in agriculture involved climate-smart agriculture, agricultural waste, soil management, livestock and, to a lesser extent, fisheries and aquaculture [39,40].

Synergies and trade-offs in climate actions and sustainable development in Africa

Efforts to address climate change – through mitigation and adaptation – could affect sustainable development in Africa. On one hand, well-designed and well-implemented mitigation measures could have significant positive influence on sustainable development. For instance, Africa has huge mitigation potential – untapped potential for clean and renewable energy – that could be leveraged for technology transfer and funding towards adaptation and sustainable development [3]. Indeed, mitigation measures such as renewable energy could offer strong synergies for sustainable development in Africa by stimulating growth of microenterprises through provision of cheaper off-grid power, and hence contribute to poverty alleviation in rural areas [40].

In contrast, poorly designed and implemented mitigation measures could have adverse effects on sustainable development. For instance, several authors have pointed out the potentially negative ecological impacts of large-scale afforestation projects in Africa's grassy ecosystems, on biodiversity and livelihoods (e.g., through reduction of fodder for pastoralists) [9,43]. Indeed, even well-designed

FIGURE 2.2: Innovative agricultural practices and climate-smart agriculture as an adaptation strategy to build community and farm resilience in the face of climate change (Photo credit: M. Tall: CCAFS West Africa, Creative Commons Licence Attribution-Non-Commercial 2.0)

mitigation measures could have negative biodiversity and social impacts. For instance, Hussein et al. [44] showed that forest carbon sequestration incentives could raise poverty levels in developing countries, as competition for land results in displacement of farmers. Importantly, given the high dependence of African countries on land- and natural resource-based sectors, adaptation and mitigation actions – irrespective of how well intended – will have consequences for equity [40].

Finally, economic development in Africa is driven by natural resources, which are also important for climate change adaptation and mitigation [40,45]. Consequently, Africa's natural resources – land and soil, forests and mangroves, rangelands and their intact large mammal assemblages, fisheries and water resources – are currently under intense pressure and threats [6]. Unsustainable practices – such as habitat conversion, over-harvesting, poaching and illegal wildlife trade, pollution, and invasion by alien species – are resulting in land degradation, loss of habitat, loss of soil fertility and productivity, and, ultimately, loss of economic opportunities for the most vulnerable groups [6]. Efforts to produce a sustainable circular bioeconomy in Africa [46] can be seen to be at odds with the desire to manage Africa's natural resources to maximise carbon sequestration. Identifying when and how these two priorities compete, who benefits from these different land-use decisions, and how to manage benefit-sharing, is essential.

Africa, therefore, faces two main issues in relation to using its immense and diverse ecosystems and natural assets towards development and climate change adaptation and mitigation. First, and as noted by several analyses [6,40,45], there is the urgent need to reduce unregulated land cover changes, i.e., the conversion of forests, rangelands and other natural ecosystems to agriculture and other land-use types. Second, selection of appropriate ecosystem-based CCMA options is critical to ensure delivery of benefits to people through the conservation and sustainable use of Africa's natural assets. In chapter 3, we analyse the different land-based CCMA options to identify promising climate actions for the different ecosystems and land-use types across Africa.

Land governance and climate change actions in Africa

Land is an essential socio-economic resource in Africa. African lands are used for production crops, livestock, nature conservation, human settlements as well as other economic and socio-cultural purposes. Over 52% of Africans are employed in agriculture, which accounts for about 19% of the continent's Gross Domestic Product (GDP) [47]. In Africa, land provides a safety net because it is the ultimate source of income, food, shelter and energy for most of the citizens [48]. Importantly, large areas of land in Africa – currently about 14-17% of the total land area – are already dedicated to conservation [49].

Land governance issues – land ownership, access and tenure rights – are identified by the African Union Commission (AUC) as central to sustainable development and climate change mitigation and adaptation [48]. For instance, significant changes and investment in land use are required to reverse the negative impacts of climate change in Africa [48]. However, in the context of land-based CCMA in Africa, interventions will be implemented on lands that already have multiple ownership, access and tenure claims [7]. Given that most interventions will be effective only when deployed at large scales (e.g., afforestation and tree planting), CCMA will likely compete with existing land uses, which will have direct impact on livelihoods [43,50].

Existing knowledge from Lands System Studies (LSS) [7] suggests that while win-wins can be crafted for CCMA and other co-benefits in some situations, trade-offs (between competing uses, such as food production and biodiversity conservation; and within uses, such as biodiversity and carbon sequestration) are often the norm. This suggests that CCMA interventions in Africa will likely compound land governance issues. This is particularly worrying, given that land tenure systems in Africa are already under stress due to increasing population, and climate-induced disasters are expected to disrupt land tenure systems further [48].

Competition between land uses – both existing and new land uses – is likely to increase under current trends of climate change, and will particularly affect the most vulnerable groups (e.g., women, migrants and pastoralists). For instance, pastoral areas occupy about 40% of Africa's lands and operate on flexible, internationally (e.g., ECOWAS passports) and locally defined land tenure systems [48,51]. Climate change is increasingly bringing pastoralists in Africa into contact with

" Competition between land uses – both existing and new land uses – is likely to increase under current trends of climate change, and will particularly affect the most vulnerable groups (e.g., women, migrants and pastoralists). "

farmers, often triggering conflicts 52. These conflicts are likely to increase, given that changes to tenure rights – which may be required to improve CCMA investment in lands – are likely to affect such pastoral communities disproportionately 48,51 due to loss of flexible, customary grazing tenure.

between farmers and herders 55-57. The dynamics of conflict and cooperation over natural resources connected to land systems could therefore emerge as a major pathway observable at regional scales within and across countries in Africa.

Climate securities in Africa

In Africa, where the economies and communities are heavily dependent on natural resources and rainfed agriculture, localised violence and tensions on a smaller scale can be connected to the question of land-based resource availability and access 53,54, interacting with conditions like growing population, regional disparity, weak governance as well as the increasing impact of climate change (FIGURE 2.3). The recent IPCC Sixth Assessment Report acknowledges that climate change has already contributed to changes in terrestrial and freshwater ecosystem structures 28. By impacting availability of and access to natural resources, climate variability and extremes linked to climate change could disproportionately affect communities depending on those resources for their livelihoods, such as farmers, herders and fishermen, leading to decreased economic output and growth, and increased food insecurity, poverty and inequality rates, which are often at the heart of conflicts and insecurity.

For instance, lack of access to water and pasture for livestock, induced by drought and desertification, can force pastoral communities to deviate from their usual migratory routes and seasons. This often brings them into closer proximity to farming communities, which are simultaneously trying to bring more land under cultivation in response to climatic stressors. In this situation, issues of limited availability and contested access to critical natural resources like land and water can contribute to risks of small-scale violent conflict

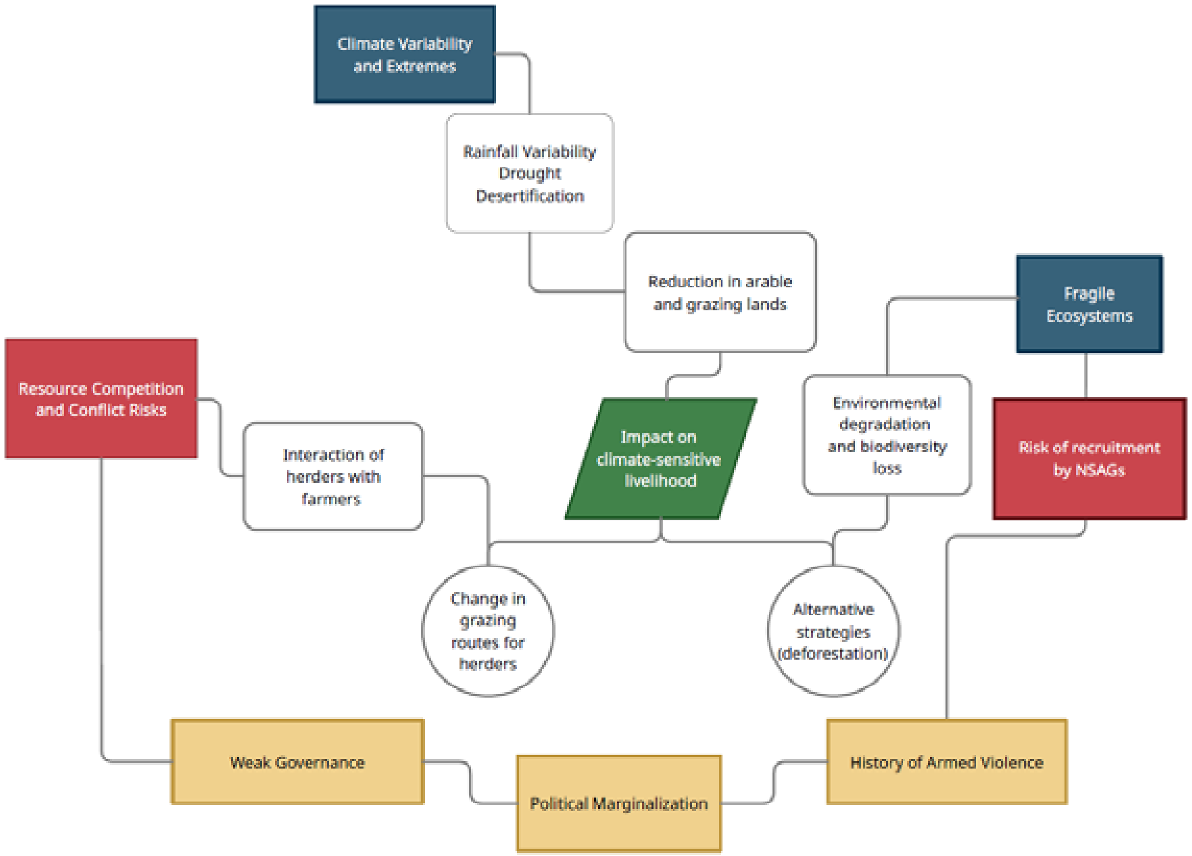

FIGURE 2. 3: Climate-natural resources-security nexus: Climate change can disrupt nature-based livelihoods, which in turn can perpetrate ecosystem degradation and trigger migration and land conflicts in Africa. NSAGs = Non-state armed groups.

Ecosystem degradation in the context of Africa

Land-based CCMA options in Africa often emphasise protection, management and restoration of ecosystems [3,40]. Defining and mapping out degraded ecosystems are prerequisites for identifying restoration opportunities. Substantial scientific effort has been directed towards identifying areas of the world that are degraded and have potential for restoration [58]. However, the definition of ecosystem degradation is often viewed from a forest-based perspective that is unsuitable for the extensive grassy ecosystems of Africa [59,60]. For instance, one recent study classifies substantial areas of Africa's grassy ecosystem as degraded and earmarked for restoration through afforestation [58]. Although several authors have pointed out these false claims [61-65] and proposed improved frameworks for defining ecosystem degradation [7,59,60,66], facts about land systems for sustainability) – that accommodates degradation in both forest and grassy ecosystems –are yet to be taken up into policy consideration.

The misreading and misclassification of Africa's grassy ecosystems [67] is driven by both methodological and historical definitional misconceptions. For instance, global assessment of degradation is often based on remote sensing data and focuses on productivity (aboveground biomass) within a landscape [58,68]. For Africa's open and grassy ecosystems, fire and herbivory remove large amounts of biomass, which would likely register on remotely sensed data as decreased productivity (and hence be classified as degradation). However, these variabilities are perfectly normal for open ecosystems [60]. Importantly, long-standing debates about what constitutes forest, woodland, savanna, and grassland [8,69,70] have led to inconsistencies in the mapping of the different vegetation types of Africa [8,71-74].

An inappropriate definition of ecosystem degradation, particularly in Africa's open ecosystems, will likely lead to maladaptive climate change mitigation and adaptation interventions, with profound consequences for biodiversity and livelihoods [9,43,75]. For instance, fire and herbivory are important management tools for grassy ecosystems, but fire suppression is strongly advocated as an important intervention for climate change mitigation and adaptation. Importantly, grassy ecosystems require open canopies, and the current push for more tree planting, which prioritises carbon sequestration, will have severe negative impacts on biodiversity and provision of ecosystem services.

> "...the definition of ecosystem degradation is often viewed from a forest-based perspective that is unsuitable for the extensive grassy ecosystems of Africa."

Chapter 3

Evidence for land-based climate change adaptation and mitigation in Africa

Credit: Sally Archibald, Bicuar National Park, Angola

We examined a substantial number of case studies on climate change adaptation and mitigation actions in Africa. To ensure adequate representation in the selection and review of case studies, we first identified the major biomes of Africa (FIGURE 3) using the Bob Scholes Africa Ecoregion Map. This map was derived by regrouping and smoothing the vegetation classification of the UNESCO/AETFAT/UNSO Vegetation Map of Africa [8] to follow the delineation of mean annual precipitation (MAP)-determined (i.e., "stable savannas", which occur at MAP of <650 mm) and disturbance-determined (i.e., "unstable savannas", which occur at MAP of >650 mm) savannas in Africa by Sankaran et al. [76]. The Bob Scholes map identifies five main ecoregions, namely forests, sub-humid savannas, semi-arid savannas, North Africa desert and Southern Africa desert and semi-desert. Here, we combined both the North Africa and Southern Africa deserts under "arid zones, deserts and desertification". Similarly, we combined the sub-humid and semi-arid savannas into the "open and grassy ecosystems" category for ease of analysis and discussion. However, under the "grassy ecosystems" category, we further reviewed, reported and discussed case studies under "rangelands", "woodlands" and "savannas and grasslands" to highlight issues that are specific to these vegetation subtypes. It is important to note that the Bob Scholes map does not cover mangroves, but we included mangroves in the analysis, given their significance to climate mitigation and adaptation. We also reviewed case studies for the three major land uses in Africa (i.e., conservation, agriculture and urban). We considered three sub-categories for agriculture, namely cropland, livestock (pasture) and agroforestry. Note, therefore, that free-ranging livestock are considered under "rangelands", as the CCMA activities in rangelands overlap and are aligned with those in other untransformed land covers, whereas livestock systems on planted pastures are considered under agriculture.

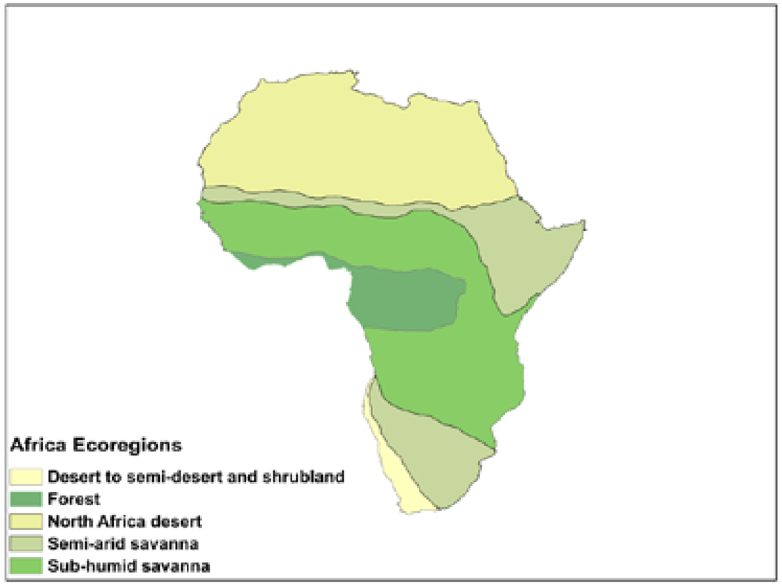

FIGURE 3: The Bob Scholes Africa Ecoregion Map

Mangroves

Mangroves are complex coastal forest ecosystems that occur where the ocean, freshwater and land meet. Mangrove trees have evolved special adaptations that allow them to live in waterlogged, salty and often unstable conditions [77]. Globally, mangroves are found mostly in tropical regions, covering an estimated area of about 150,000 km^2 [77]. Southeast Asia (32% of the global mangrove area) hosts the highest coverage of mangroves, followed by North and Central America and the Caribbean (15%) and West and Central Africa (14.5%) [77].

In Africa, mangroves are estimated to cover a land area of about 35,000 km^2, representing 19-23% of the global mangrove area [78,79]. Mangroves in Africa are concentrated mainly in West (10 of the 17 countries), Central and East Africa [78,79]. Mangroves in Africa provide important ecological, social and economic services. For instance, mangroves play a critical role in coastal fisheries in Africa by providing habitats for over 80% of commercial fisheries and many aquatic species [79]. African mangroves also provide wood and non-wood forest products, a resource base for the salt industry, coastal protection and biodiversity conservation [78].

Despite their importance, African mangroves are currently facing enormous degradation pressures, with an estimated loss of 20-30% of the mangroves in West and Central Africa over the past 25 years [79]. Main threats to mangroves in Africa include deforestation (linked to fish smoking), urbanisation and urban infrastructure development, salt extraction and sand winning, quarrying, pollution, invasive species and climate change [78-80].

The conservation, management and restoration of mangroves is identified as one of the most promising land-based CCMA options. Generally, mangroves have remarkable carbon stocks and sequestration potential, compared with tropical forests [77,81]. Therefore, the conservation, management and restoration of mangroves has consequence for carbon sequestration and emission reduction [81,82]. The conservation, management and restoration of mangroves can also play a vital role in climate change adaptation, improving coastal protection (and disaster risk reduction), biodiversity conservation and coastal livelihoods (e.g., fisheries habitat conservation, and sustainable energy sources) [79,83].

Avoided mangrove deforestation

Avoided deforestation of mangrove ecosystems is generally of high priority, given the high carbon stocks and livelihood implications. Carbon stocks in undisturbed mangroves are higher than in degraded mangrove ecosystems in Central Africa [82]. Although mangroves have a limited extent in Africa [78,83], they seem to have particularly higher carbon storage potential than even intact African rainforests [82]. Several examples of case studies on avoided deforestation initiatives – often linked to REDD+ and blue carbon financing – exist in Africa. These include the establishment of marine protected areas covering large areas in West Africa [80], the protection of mangroves in the Mikoko Pamoja carbon credit initiative in Kenya [84] as well as other initiatives combining mangrove conservation and restoration in Tanzania [85] and Guinea-Bissau [86], among others.

There is consensus from the case studies examined that successful "avoided deforestation" mangrove projects across Africa involve, among other things, those with: 1) local people's involvement (e.g., co-management, participatory forest management, and community-led sustainable forest management), 2) strengthening of institutional and individual capacity, 3) financial incentives for avoided deforestation (one study estimates between \$6.69 and \$7.20/t of CO_2 as the minimum amount required to be successful [87], 4) provision of sustainable alternative energy sources (e.g., woodlots), 5) action embedded in the larger framework of mangrove management (conservation, management and restoration), and 6) mainstreaming with national forest programmes.

Sustainable mangrove management

Improved management of mangroves has been identified as one of the nature-based solutions to protect the structure, function and ecosystem services of mangroves globally. Improved management of mangrove forests can provide a wide range of ecological, social and economic benefits in Africa [83]. For instance, the structure and regeneration of mangrove forests in Kenya were found to be greatly improved, with important implications for carbon stock in both the soil and the biomass [88]. Improved management of mangroves

"The conservation, management and restoration of mangroves is identified as one of the most promising land-based CCMA options."

does not only enhance carbon storage, but also improves the livelihood of residents through community enterprises such as tomato farming, community micro-lending and fishing schemes, and oyster cultivation [80]. Improved mangrove forest management could be sustained with provision of wood lots as an alternative source of fuelwood for residents and the establishment of buffer zones to minimise sediment load and human pressure [89]. Such approaches help to reduce heavy human contact with primary mangroves and reduce carbon emission through degradation and deforestation [82].

Mangrove restoration

Several examples of mangrove restoration initiatives exist in Africa, and case studies were selected from Ivory Coast [90], Tanzania [85,91], Guinea-Bissau [86,87], Senegal [92] and Kenya [84], among others. Most of the case studies suggested successful re-establishment of mangroves, indicating carbon gains as well as other environmental and social co-benefits (e.g., alternative income sources from carbon credits, additional livelihood activities and sustainable energy sources). However, not all mangrove restoration projects yielded favourable results. Indeed, mangrove restoration efforts globally have low success rates of 15-20% [93,94]. For instance, restoration projects focusing on tree planting obtained mixed results, compared with those deploying community-based ecological mangrove restoration (CBEMR) approaches [85,86]. The CBEMR approach focuses on creating the enabling environmental conditions for natural recovery in disturbed sites [86]. This approach combines elements of hydrology, sediment dynamics and soil management to facilitate natural regeneration, with active tree planting applied only when necessary [85]. The CBERM approach also addresses the socio-economic factors that are likely to compromise long-term sustainability of restored mangroves [86]. Indeed, one case study demonstrated that if the socio-economic factors of degradation are not addressed, efforts to restore mangroves will be viewed by local stakeholders as "land-grabbing" or "green-washing" attempts [92].

Forests

According to the FAO, Africa contributed 15.7% (636 million hectares) of the global forest cover in 2020 [95]. Africa's forest is diverse in composition, structure and function, ranging from wet to dry types [74]. At the continental level, three prominent forest blocks exist, namely the Upper Guinean (West Africa), the Lower Guinean (coastal Central Africa) and the Congolian (Congo basin) forests, which together form the Guinea-Congolian forest [74]. The Guinean forest of West Africa is highly diverse – i.e., high species richness and endemism – and is one of the 36 global biodiversity hotspots [96,97].

Forests are of fundamental importance to African societies. They provide essential livelihood products (meat, food, medicine, etc.), serve as the resource base for many businesses (timber and non-timber forest products) and provide safety nets to rural communities, including provision of a conducive microclimate for production of cash crops (e.g., cocoa in West Africa and tea in East Africa) [98]. African forests are also home to diverse species of plants and animals. They also ensure water supply and store substantial amounts of carbon [98].

Despite their importance, the rate of forest loss (deforestation) in Africa is higher than anywhere in the world and continues to increase [95]. However, both deforestation rates and forest cover in Africa, based on the FAO definitions, are contested, with some experts asserting that both forest cover and deforestation rates in Africa are overestimated [99]. Human population growth, economic development (particularly in Asia) and changing demographic trends indirectly influence the rate of deforestation in Africa. In Africa,

“...both deforestation rates and forest cover in Africa, based on the FAO definitions, are contested...”

agriculture (both subsistence and commercial) is the main direct driver of deforestation [100]. Tropical forest loss is particularly troubling, given that it accounts for 8-15% of global greenhouse gas emissions [101]. Reversing forest loss in Africa has immense potential for reducing GHG emissions, increasing the adaptive capacity of local communities and enhancing biodiversity conservation.

Avoided deforestation

Given the importance of forests in Africa, deforestation represents a significant threat to sustainable development. Intact African forests have higher carbon stocks [102-105] and are more diverse than degraded forests or any other land-use type [95,106-108]. Several examples of effective avoided deforestation projects in various parts of Africa exist and demonstrate the workability of this option. Examples include: 1) participatory forest management in Zambia that is estimated to have saved 228,000 tons of CO_2 emission; 2) an externally verified 62% reduction in deforestation – compared with the national average – in the Bale eco-region of East Africa [109]; and 3) a community-led sustainable forest management initiative in Senegal [110]. These and many other success stories reported elsewhere show that avoided deforestation works when the right approach is adopted [111].

The case studies examined indicated that avoided deforestation – through REDD+ initiatives – often provide both carbon benefits [91,112] and other co-benefits for biodiversity and livelihoods [113-115]. As with mangroves, successful "avoided deforestation" projects across Africa involve those with 1) local people's involvement (e.g., co-management, participatory forest management and community-led sustainable forest management); 2) alternative livelihood opportunities, particularly those that supplement on-farm income; 3) strong local political will and interest [111]; 4) adequate funding and credits (in the form of carbon credits, payment for ecosystem services, or grants); and 5) adoption of technology (e.g., near real-time deforestation alerts) [116].

Sustainable forest management

Sustainable forest management (SFM) is a valuable tool for keeping and increasing forest carbon stocks in Africa [117]. Many African communities heavily depend on forests for their livelihoods, and both improved community-based and improved concession-based forest management are key for achieving sustainable forest management in Africa [118-120]). Case studies examined were selected from the Democratic Republic of Congo [112,120], Ethiopia [121], Malawi [122]), Morocco [123] and Madagascar [118], and spanned both community-based and concession-based [112]) SFM in Africa.

The case studies analysed showed that there is high potential for carbon storage, improved livelihoods and biodiversity conservation through SFM in Africa [112,113,124]. Analysis of the available case studies shows that SFM through community-based forest management (CBFM) creates positive incentives for appropriate behaviour for sustainable forest management, and works better if local communities play enforcement roles [91,119,121]. However, studies on SFM involving local community involvement indicate that 1) environmental, livelihood and shared management responsibilities are not always reinforcing, and may trade off under some circumstances; 2) democratic decentralisation is rarely established; and 3) environmental benefits (including carbon sequestration) often accrue for distant stakeholders while local communities carry the cost [114]. These observations suggest that carbon and biodiversity benefits of SFM may trade off with local community livelihood if specific alternative livelihood interventions are not crafted as part of the SFM [125,126].

Sustainable forest management in timber concessions – a common feature of forestry in Africa – can limit negative impacts of logging

" Reversing forest loss in Africa has immense potential for reducing GHG emissions, increasing the adaptive capacity of local communities and enhancing biodiversity conservation. "

on biodiversity and improve carbon sequestration, particularly for concessions under certification initiatives [124,127-129]. Concession-based SFM can be achieved through reduced impact logging (RIL) or reduced logging intensity (RLI). However, the limited case studies available suggest that reduced logging intensity in Africa is attractive only where there is complete cessation of logging, in forests with low stocking and in low-profit forests [112,127]. Indeed, current carbon market prices are too low to be a strong incentive for reduced impact logging or reduced logging intensity [112].

Reforestation

Technically speaking, reforestation is the restoration of forest cover on degraded or deforested lands. Reforestation is identified as an important land-based CCMA option for capturing carbon, improving biodiversity conservation and providing green jobs in Africa [58,113]. Numerous past and ongoing reforestation projects are dotted across Africa. However, the feasibility and benefits of large-scale reforestation are often the subject of intense political and scientific debates [9,50,130,131].

Analysis of case studies on reforestation in Africa highlighted three main approaches, namely natural regeneration, mixed-species plantation and single-species plantation. Case studies across Africa showed that reforestation does not only provide climate benefits, but also has significant environmental and social co-benefits. However, trade-offs were clear and depended on the reforestation approach adopted.

A limited number of the examined case studies indicated that reforestation through natural regeneration – including assisted natural regeneration – achieved greater biodiversity success [132], fast recovering of forest structure [133] and agricultural productivity [134]. Combining natural regeneration with direct seeding – for large-seeded, late-successional trees – has been shown to accelerate forest restoration further [135]. Although natural regeneration is a cost-effective restoration pathway, it has limitations in addressing social needs such as providing jobs and wood products. Also, the actual reforestation process provides fewer direct jobs to local communities. In contrast, mixed-species plantations have higher aboveground biomass (high carbon storage), but lower abundance of understorey native saplings and liana (low biodiversity), compared with naturally established secondary forest and eucalyptus plantation [136-138]. Despite this, quantitative evidence of biodiversity and livelihood benefits is sparse for the different regeneration methods, and is often affected by positive site selection bias [139]. Importantly, there is a need to assess critically whether planting trees to restore degraded forests is the best restoration pathway in terms of ecological efficiency and livelihood improvement. Despite this, some of the most successful forest restoration projects in Africa are those undertaken by large-scale commercial forestry.

The case studies examined also highlighted major constraints on reforestation in Africa [140]. The major forest zones of Africa (e.g., Upper Guinean forest in West Africa and Lower Guinean forest in Central Africa) are also the centres of cash crop (e.g., cocoa, oil palm, coffee and tea)-driven deforestation. Large-scale deployment of reforestation in this region faces strong resistance from other land uses [7,50,130], and in some cases is perceived as "green grabbing" that disempowers the local communities [50,92,141]. Reforestation, even if successful, can also indirectly drive deforestation leakage elsewhere in the region [142-145]. Importantly, existing customary land tenure represents a significant bottleneck to large-scale deployment of reforestation [7,130]. Several case studies show that reforestation efforts can be efficient if they are designed to accommodate traditional African customary tenure systems [50,130]. In this context, novel forest landscape level restoration approaches [146-149] may offer the best

“…there is a need to assess critically whether planting trees to restore degraded forests is the best restoration pathway in terms of ecological efficiency and livelihood improvement.”

chance for integrating carbon, social and biodiversity benefits, but their deployment in Africa is at its initial stages, and case studies on its effectiveness are lacking.

Fire management

Intact forest ecosystems in Africa are remarkably resistant to fire – there are field and remote sensing studies indicating that forest-grassland mosaics can co-exist, even though grasslands burn frequently [150,151], because the fires do not penetrate the forests [152,153]. However, this resistance is weakened once any form of forest degradation or wood harvesting occurs, as the microclimate and ground-layer fuels create conditions where fire can spread [154]. Therefore, attempts to manage fires in forest ecosystems need to focus on recreating the stabilising feedbacks, as forest fires can quickly destroy large amounts of forest biomass, and accelerate climate change and biodiversity loss [155,156]. Increasing occurrence of fires in forest ecosystems in Africa would have significant negative consequences – on carbon storage, biodiversity conservation and rural livelihoods [157-159] – highlighting the importance of fire management as a climate change adaptation and mitigation intervention [160]. We reviewed several case studies proving effective fire management practices undertaken by the communities and other stakeholders that reduce the negative effect of fire on forest resources [161-164]. Generally, participatory fire management schemes that engaged residents, NGOs, government agencies, women's groups and farmers' organisations – in South Africa, Congo Republic, the Democratic Republic of Congo, Kenya and Ghana – showed great promise [165,166]. However, regional differences were observed, particularly in North Africa and Southern Africa, suggesting that the effectiveness of fire protection measures is context-dependent (e.g., vegetation type, drought conditions, etc.) [167]. In some regions of Africa (e.g., South Africa), fire control uses helicopters and organised teams to protect urban areas and flammable crops, and requires large, organised bodies. Further, fire protection in commercial forestry, including large-scale commercial plantations, involves well-organised and equipped fire teams, which involves millions of dollars in operation costs. Importantly, the case studies examined revealed that, in addition to climate change, forest degradation significantly made forests in Africa particularly prone to fire [168,169]. These findings suggest that effective fire management interventions, deployed with other measures addressing degradation, are likely to yield the highest carbon, biodiversity and livelihood benefits. As Africa rapidly urbanises, such fire problems and large-scale fire control will likely grow.

> "…effective fire management interventions, deployed with other measures addressing degradation, are likely to yield the highest carbon, biodiversity and livelihood benefits."

Open and grassy ecosystems

Africa is predominantly a grassy continent, with about 55% of the land area composed of grassy vegetation such as grasslands/savannas, woodlands and rangelands [8,170]. Africa's grassy ecosystems are distinct from forests in terms of vegetation composition, structure, functioning and management. Africa's grassy ecosystems have continuous cover of shade-intolerant herbaceous understorey with variable tree cover [171,172]. Fire and herbivory – by both intact wildlife fauna assemblage and livestock – exert significant control over the composition, structure and function of Africa's grassy ecosystems [170,173,174].

Africa's grassy ecosystems are fundamental to the livelihoods of a large population of people. The grassy ecosystems of Africa provide diverse ecosystem goods and services, including biodiversity; regulatory services such as water flow and quality, climate and protection of soils; non-wood forest products (NWFPs) such as medicinal plants; wood fuels; timber and wood products; and wildlife and livestock. Indeed, in most countries in Africa, the major zone of crop production falls within the grassy ecosystems [98], highlighting the importance of this zone to food security. Importantly, Africa's grassy ecosystems also store a substantial amount of carbon [175,176], playing a vital role in global land-atmosphere feedback systems and hence climate change [177].

Despite their importance, the grassy ecosystems of Africa are threatened by unsustainable use (over-exploitation), rapid conversion to other seemingly profitable land uses, drastic changes to fire regimes, and replacement of wildlife with livestock [60,178]. Climate change and increasing population growth in Africa are projected to accelerate the degradation of Africa's grassy ecosystems further, with severe consequences for biodiversity and livelihoods [60,177]. Coupled with this, the grassy ecosystems of Africa have historically been understudied and underfunded, leading to widespread misconceptions about their structure, function and management [179]. Indeed, several well-intended but ill-informed landscape restoration initiatives – e.g., large-scale afforestation projects – are currently being promoted for Africa's grassy ecosystems under the guise of climate change mitigation and adaptation. Such initiatives are likely to affect the structure and function of these grassy ecosystems adversely, leading to biodiversity loss and loss of economic opportunities [9,10,43,180].

Rangelands

Rangelands are lands on which the vegetation is composed predominantly of grasses, grass-like plants, forbs or shrubs – whether with or without trees – that are grazed or have the potential to be grazed by livestock and wildlife [68]. Most of the grassy ecosystems of Africa – i.e., grasslands, savannas, woodlands and open forests – are grazed by livestock or wildlife and are therefore rangelands.

Importantly, Africa is home to over 40 million pastoralists who depend on rangelands for their livelihood [3,51,57]. Rangelands provide substantial ecosystem services [181,182] and carbon storage and CO_2 sequestration benefits [183,184]. Despite their importance, a century of misplaced rangeland management approaches has compromised substantial areas of rangeland in Africa. Importantly, large-scale adoption and implementation of CCMA measures are likely to occur on rangelands without adequate consideration of the needs of pastoralists, who are affected in many ways. For instance, large-scale afforestation projects in Africa's open and grassy ecosystems will result in reduced fodder availability for pastoralists [9,43]. In addition, with increasing urbanisation and unhealthy conflicts between farmers and pastoralists, the latter are forced to limit their movements, which can be detrimental to animal productivity [185]. Therefore, CCMA measures should be formulated in a holistic way that accounts for the needs of pastoralists. In this section, we focus mostly on climate actions targeting grazing management on rangelands in Africa. We distinguish rangelands from pastures – which are treated under sustainable agriculture – and focus here on naturally occurring grazing lands.

Grazing management

Most climate actions on rangelands focus on conserving and increasing soil carbon stocks through changes in land-use practices. Given that rangelands are rarely tilled, increased SOC generally relies on C inputs from plant roots and residues [186]. There are several ways by which C inputs can be enhanced for increased SOC. These include regulating plant biomass removal by grazing, increasing forage production using improved species, irrigation, and fertilisation [186]. A recent meta-analysis showed that improved land management – including grazing management – does lead to increased SOC [183,187]. Indeed, several studies demonstrated that the impact of grazing management on SOC exists [188]. However, these case studies indicate

> "...several well-intended but ill-informed landscape restoration initiatives – e.g., large-scale afforestation projects – are currently being promoted for Africa's grassy ecosystems under the guise of climate change mitigation and adaptation."

that the effect of grazing management on SOC is dependent on rainfall variability (total quantity and variability) [189-191]. Under 600 mm of annual rainfall and inter-annual variability in rainfall have larger impacts on SOC than grazing [188,189]. At above 600 mm of annual rainfall, grazing leads to a reduction of SOC [191,192]. Given that pastoralism – which is the dominant livestock production system – in Africa involves high mobility and opportunism and follows seasonal trends in resource-available areas [75,193,194]), the total impact on SOC is likely minimal. Further, pastoralism in Africa takes place in areas of lower and more variable rainfall. Thus, pastoralism and extensive livestock keeping persists in areas where cultivation is very risky. Given this, livestock keeping in essence will have minimal impact on SOC.

Conservation and restoration of plant and soil resources are key to enhancing SOC in rangelands [183], which can be achieved by grazing management that allows for longer resting periods. Therefore, there has been significant interest in promoting short-intense rotational grazing as a more viable grazing strategy for productivity and improved soil conditions [186]. Short-intense rotational grazing is thought to facilitate conservation and restoration of plant and soil resources, as well as reduce rangeland degradation. Some experimental evidence suggests that short-intense rotational grazing does indeed increase SOC rapidly in abandoned farmlands [195] and under commercial pasture [196]. However, some case studies questioned the ecological efficiency of rotational grazing over continuous grazing [197,198]. For instance, a synthesis of several studies observed that plant production and animal production per head per area were either equal or higher for continuous grazing, relative to rotational grazing [199]. These contrasting results suggest that differences among the two grazing systems are largely context-dependent, and that additional research is required for better understanding of the grazing systems and SOC [186]. In the African context, rotational grazing is the norm among both settled herders and pastoralists [51,194]. A key consideration for both pastoralists and ranchers is mobility that allows livestock keepers to escape unfavourable conditions (e.g., drought) and, if possible, make use of variable forage resources when they emerge.

Holistic management (HM)

Holistic management (HM) has been proposed as an integrated sustainability concept with great promise and potential for grassland restoration, reversal of desertification, climate change mitigation and adaptation, as well as increased food and fibre production [200-202]. The HM approach is similar to all major global sustainability frameworks in that it advocates integration of the ecological, economic and social aspects of grazing management. It recognises that the social and economic well-being of herders and pastoralists is linked to the health of the land [203]. It further identifies continuous movement and the grazing actions – such as grazing, defecation, stomping, salivation, etc. – of native wildlife populations as major determinants of grassland health [203,204]. Thus, the loss of native wildlife and their replacement with smaller, sedentary livestock leads to biological decay of soils and grassland vegetation. In this respect, HM proposes mimicking native wildlife behaviours by strategically planning grazing and using short-intense grazing rotations – referred to as Holistic Planned Grazing (HPG) [201,203].

Although HM has been increasingly adopted in recent years, its central tenet is still strongly contested in the scientific literature [204]. For instance, the claim that short-intense rotational grazing is ecologically more efficient than continuous grazing is still widely debated [197-199]. Further, a recent review concluded that HM's intensive rotational grazing approach had either no effect or reduced production across farms in the United States, Argentina and South Africa [205]. Again, the claim that HM, when practised on 50% of the world's grasslands, could reduce atmospheric CO_2 to pre-industrial levels, is currently unsubstantiated [205-207]. However, some

> "...the loss of native wildlife and their replacement with smaller, sedentary livestock leads to biological decay of soils and grassland vegetation."

published studies have also found that, if practised appropriately, HPG results in positive ecological outcomes 195,204,208. Importantly, controversies over the HM approach stem from miscommunication and inconsistent use of terminologies by both proponents and opposing camps 204. Therefore, clarifying the key concepts of the HM approach and its associated practices is key to reconciling the differences and controversies 204.

The wilder rangeland concept (WRC)

The wilder rangeland concept is currently promoted as an innovative rangeland management approach with substantial climate change adaptation and mitigation benefits 209. The WRC approach has two distinct forms. The first approach involves replacing managed livestock with harvestable communities of native wild herbivores 209. The second approach involves the "rewilding" of livestock grazing practices through learning from wild grazing systems. Two types of rewilding are recognised. One form of rewilding involves adding herbivores and predators to places where they have been extirpated. In contrast, the second rewilding approach entails mixing livestock with wildlife 209,210.

The WRC approach is thought to have several climate change mitigation and adaptation benefits. For instance, species-rich wild grazing systems often have high numbers of non-ruminant species, which directly reduces methane emission at the landscape level 209,210. Further, large herbivores emit more methane per unit biomass than smaller ones 211, and therefore changing the size-class distribution of herbivores in a rangeland can reduce whole-landscape emission factors. However, there is little by way of empirical data and examples in Africa 212.

There is also evidence that adding elephants to rangelands can improve SOC 213,214, despite significant reduction of aboveground woody biomass 215,216. Importantly, adding wild grazers, such as elephants and rhinos, to rangelands reduces fire impacts through the consumption of grass phytomass 217-220, and thus contributes to methane and carbon dioxide emission reduction.

The WRC approach, particularly rewilding by adding wildlife to livestock systems, is touted as an approach that improves farmers' and herders' welfare. Some evidence exists that suggests rewilding may increase and diversify revenue streams and make livestock production more resilient to climate and economic shocks like droughts, and changes in commodity prices 218,221. In spite of its potential benefits, large-scale adoption of WRC in Africa is likely to be constrained, given the existing land tenure system and human-wildlife conflicts 212.

> "...evidence exists that suggests rewilding may increase and diversify revenue streams and make livestock production more resilient to climate and economic shocks like droughts, and changes in commodity prices."

Woodlands

African woodlands are composed of an overstorey of small- to medium-sized trees with loosely touching crowns (canopy cover ranging from 70 to 90%), a sparse woody undergrowth and a continuous ground layer of sun-loving grasses 222-224. The herbaceous ground layer of woodlands is generally compositionally distinct from that of the adjacent savanna and reflects differences in tree cover 98,222,224. Although tree densities are high in woodlands, grasses occur in sufficient density in the understorey to allow for annual fire occurrence 171,223. The woodlands of Africa include the *Isoberlinia* woodlands of the Sudanian region, the *Acacia* woodlands of the Sahel and East Africa, and the extensive Miombo woodlands of the Zambezian region 98,171,223,225. African woodlands have high diversity and endemism of plant species 98. The woodlands are also crucial for water resource management, given that most major water basins in sub-Saharan Africa are either located in or have their headwaters in woodlands 98. Woodlands are also a source of diverse wild foods and medicinal plants, providing a safety net in times of crop failure 224. African woodlands are currently threatened by policy failures, extensive conversion to cropland, over-exploitation, charcoal and wood-based fuel use, changing fire regimes, climate change and overgrazing 98,224.

Conservation of woodlands

Given their socio-economic and carbon storage potentials, conservation of African woodlands is essential for climate change adaptation and mitigation 98. Although only few woodland-specific climate actions exist 226, the available literature suggests that there is great potential for both mitigation and adaptation actions 227. For instance, woodlands store substantial amounts of carbon, with 40-70% of carbon stored in soils 98,175,223. Conversion of woodlands to agriculture significantly reduces aboveground carbon stocks, coupled with a narrowing of the range of soil C stock relative to intact woodlands 175,223. Therefore, conserving existing woodlands is not only essential for continuous provision of ecosystem services, but also critical for reducing CO_2 emissions 98,224.

Improved woodland management

Improved management of woodlands is essential to securing the integrity and ecosystem services provided by woodlands, particularly under the current regime of climate change. Climate change is predicted to affect woodland plant reproductive success, overall plant productivity and fire regimes, which could lead to significant changes in the composition, structure and functions of woodlands 228, and adaptive management approaches are required to ensure long-term sustainability 98. Improved woodland management is particularly important, given that even mature stands have potential to accumulate additional carbon 98,176.

Existing knowledge suggests that improved management of woodlands could promote biodiversity and carbon storage 98,171,224. One proposed approach to increase carbon storage in woodlands is to reduce either fire frequency or fire season 229-231. Early dry season fires tend to be less destructive, compared with late dry season fires 223,232. However, across natural woodland areas, a given site rarely burns every year and at the same time 223,233, suggesting that appropriate management should rather adopt variability in fire season and frequency. Importantly, experimental evidence of the impact of combined fire season and frequency on composition, structure and dynamics of woodlands is lacking 223. Notwithstanding this, biome appropriate levels of grazing and fire tend to increase the diversity of forbs, with fire promoting species richness and abundance of annual and perennial grasses, whereas grazing favours the diversity of perennial grasses 234,235.

Given their ecology and carbon sequestration potential, woodlands are particularly suitable for international government mechanisms such as payment for ecosystem services, REDD+ and other carbon trading instruments 98,231. However, given their variable C stocks and low carbon price, large areas of woodlands (and other open and grassy ecosystems) are needed to make such investment feasible and attractive. Finding continuous and undisturbed areas or regions willing to adopt CCMA actions is particularly challenging. Importantly, the effectiveness of these mechanisms in supporting improved woodland management and generating local socio-ecological benefits is still uncertain 236.

Woodland restoration

Restoration of Africa's woodlands also has great promise for biodiversity, carbon sequestration and rural livelihoods. A significant area of the original woodland biome in Africa has been lost to other land uses or degraded 98,171. Restoration of degraded or converted woodlands using natural regeneration and indigenous trees is considered the most promising adaptation strategy 237. Indeed, allowing abandoned agricultural lands to regrow naturally has shown

" Existing knowledge suggests that improved management of woodlands could promote biodiversity and carbon storage. "

substantial aboveground carbon gains, with carbon accumulation continuing even after 20-50 years 176, suggesting high mitigation potential. However, soil carbon stocks in regrowing woodlands remain low even after 60 years, compared with intact woodlands 98,176,238. Importantly, woodlands can regenerate easily following abandonment of farming, but variations exist in the rate of recovery and are influenced by factors such as land-use history and regeneration methods 98,239. For instance, regrowing woodland had similar species diversity compared with intact woodland, but woodland indicator species were missing from the regrowing site, suggesting slow recovery of matured woodland composition 176 and the need for some active planting interventions. Woodland restoration success is likely eased by reforms in natural resource governance that allow for decentralisation of decision-making and equitable benefit-sharing 236,240.

Savannas and grasslands

Savannas and grasslands are the most dominant ecosystem type in Africa 8,71. Africa's savannas and grasslands are species-rich, store substantial amounts of carbon and are home to and a source of livelihood for many people. Africa's savannas and grasslands are distinct from forests in terms of tree cover 241,242, composition and physiognomy 243-246, carbon stocks and energy budgets 247,248, and functioning and management 60,249. Regular disturbances, in the form of fire and herbivory, are important determinants of the structure and functioning of Africa's savannas and grasslands 60,172,173,250. Although collectively treated as a single homogeneous biome, Africa's grasslands and savannas are diverse in their composition, structure and functioning, and reflect sub-regional differences 70,73,222. These differences have important implications for appropriate management of Africa's savannas and grasslands.

Conservation of savannas and grasslands

From grasslands/savannas to farms or croplands

A substantial area of Africa's savannas and grasslands have been converted to farmlands and other land-use types 71. All case studies examined – from Burkina Faso, Kenya, Uganda, Benin, Niger and Zimbabwe – suggest that conversion of natural grasslands and savannas to croplands is associated with drastic biodiversity loss 251-254 and entails high carbon cost 253,255,256. The impact of conversion of natural grasslands and savannas to farmlands has far-reaching consequences for whole ecosystem functioning. For instance, recent regional trends suggest significant declines in burned areas – i.e., changes in savanna fire regime – in Africa 156,257,258, driven by cropland expansion and human influence 211,259,260. Similarly, decline in wildlife biomass and replacement by livestock in many parts of Africa is shifting historical herbivory regimes 174,178. These changes in disturbance regimes are expected to affect, and are already affecting, species composition and structure of savannas and grasslands 60.

Afforestation

Afforestation involves planting trees or creating forests on lands that historically had no forest cover 261. Afforestation and tree planting in savannas and grasslands have been proposed as an effective CCMA option with huge potential for carbon capture 58,262. In response, several large-scale afforestation and tree-planting initiatives – such as AFR100 and the Great Green Wall – have been instituted across grasslands and savannas in Africa. The benefits of such large-scale afforestation projects in grasslands and savannas are strongly contested 9,10,61,62,65.

The case studies examined provided inconclusive SOC benefits of afforestation in grasslands and savannas. Net SOC benefit of

“The benefits of such large-scale afforestation projects in grasslands and savannas are strongly contested.”

afforestation ranged from positive 263 and negative 263-266 to neutral 263,265. However, the case studies examined were extremely critical of afforestation of grasslands and savannas, citing numerous negative impacts of such initiatives. For instance, several studies have proven the negative impact of afforestation in grasslands and savannas on hydrology and water availability in semi-arid and arid environments 267-269. Large-scale afforestation projects in savannas and grasslands are also predicted and seen to impact biodiversity and local livelihoods negatively, particularly through their impacts on rangeland resources 9,75,188,270,271. Indeed, it has been shown that once afforested, grasslands and savannas are particularly difficult to restore 272, highlighting the need for careful consideration of the impacts of large-scale afforestation projects in Africa. Importantly, fire risk in savannas and grasslands implies that robust fire protection measures are required to safeguard carbon sequestration potentials of such tree-planting programmes. This requirement massively increases the cost of tree-planting programmes in savannas and grasslands.

Despite this, some case studies showed examples of successful local and community-based tree-planting initiatives targeting land restoration and livelihood improvement with carbon and biodiversity co-benefits 188,273-277. These examples demonstrate apparent local successes that need to be noted and further examined. However, existing global finance mechanisms that focus primarily on tree cover and carbon stocks will be inappropriate for protecting Africa's savannas and grasslands. Rather, financing mechanisms – i.e., REDD+ equivalents for grassy and open ecosystems – that favour the management and conservation needs of Africa's grasslands and savannas will have significant positive impact on biodiversity conservation, carbon emission and livelihoods (278).

Sustainable management of savannas and grasslands

Sustainable management of savannas and grasslands must ensure the maintenance of vegetation structure and functioning, and the continuous provision of ecosystem services. Several climate change mitigation and adaptation options are proposed for savannas and grasslands, often focusing on fire and grazing management, with the goal of enhancing carbon stocks in these systems. However, sustainable management of Africa's savannas and grasslands not only ought to target carbon gains, but also ought to focus on conserving the unique biota of Africa, as well as meeting the socio-economic and cultural needs of the local communities. Here, we review the major CCMA proposals made for Africa's savannas and grasslands.

Fire management

Fire is both a disturbance factor 249,279,280 and a management tool 164,281,282 for savannas and grasslands. A major proposal made for fire management in savannas and grasslands for climate change mitigation is to reduce or avoid savanna burning (i.e., fire frequency) and/or change fire season (i.e., promote early dry season burning over late dry season burning) 229,283,284. Indeed, savanna burning emits substantial quantities of GHGs, such as carbon dioxide, methane and nitrous oxide 285,286, and, under the Kyoto Protocol, avoided "savanna burning" is identified as a major GHG abatement activity 283. However, most of the CO_2 emitted during burning is rapidly taken up by regrowing vegetation, such that the net impact of savanna burning in terms of GHGs is minimal 287. In spite of this, successful deployment of fire abatement projects in Australian savannas has led to calls for large-scale implementation of a similar approach in Africa 283,284.

The case studies examined suggested the following about large-scale fire abatement or change in fire regime in Africa: 1) it is likely impractical to achieve 288; 2) it does not consider current trends and changes in fire and burned areas 258,260 or the impact on

> "...once afforested, grasslands and savannas are particularly difficult to restore 272, highlighting the need for careful consideration of the impacts of large-scale afforestation projects in Africa."

savanna and grassland vegetation [289]; 3) the scientific basis for such a large-scale proposal is currently weak [286]; and 4) proposed fire regimes are decoupled from human livelihood activities in Africa [211]. Indeed, within the African context, there is an observed decline in savanna fires [258,260] due to human population growth and cropland expansion [289]. Given the importance of fire in reducing tree numbers in savannas [215,249,290], such decline in fire activity is currently driving widespread bush or woody encroachment of Africa's savannas and grasslands [289,291-294].

Fire frequency

Although savanna and grassland fires in Africa are influenced by humans, not all aspects of fire can be easily controlled by humans or management practices, emphasising the difficulty of deploying large-scale shifts in fire regimes. For instance, fire-return interval and radiative power in Southern Africa is less influenced by human activity [259]. Similar evidence is found in the Kruger National Park. Here, although management activities affected spatial heterogeneity and seasonal distribution of fire, fire frequency and the area that burns in any given year were less influenced by management approach [281]. These and several other sources of evidence point to the difficulty of enforcing drastic changes in fire use and management in Africa. Indeed, local communities and resource managers in Africa have adopted variable fire and burning practices suited to their local needs and management goals [164,286].

Fire season

There is substantial evidence that fire season affects emission characteristics in Africa, but the case studies examined lend little support to the emission reduction benefits of early dry season burning. Indeed, combustion efficiency and the type and quality of carbon emissions follow seasonal trends in Africa, correlating with metrics of vegetation moisture [288,295-298]. However, emission ratios between early and late dry season burning differ significantly across savanna and grassland types. For instance, early burning in grasslands may lead to a higher number of products of incomplete combustion, compared with late dry season burning [297]. In contrast, early dry season burning in woodlands results in lower emissions in products of both complete and incomplete combustion [297]. Laris et al. [288] concluded, based on extensive analysis of methane gas emission from savanna fires of West Africa, that policies aimed at shifting savanna and grassland burning to early dry season fires will likely yield negligible impact on emissions. Essentially, people in Africa already set large numbers of early dry season fires, such that the proposal for shifting fire regime will not drastically change the current burning practices [164,282,286].

Soil carbon stocks

Soils of savannas and grasslands hold substantial amounts of carbon and contribute significantly to global soil organic carbon (SOC) and total ecosystem carbon (TEC) [299]. In grasslands and savannas, about 50% of the total ecosystem carbon stocks are stored belowground [248,300]. Soil organic carbon is in a relatively stable form and once sequestered is less vulnerable to anthropogenic removals. Therefore, conserving existing soil carbon in savannas and grasslands and enhancing soil carbon accumulation are essential for climate change mitigation [299,301].

For both savannas and grasslands, the case studies examined show that moderate or biome-appropriate fire and grazing regimes do not adversely impact SOC and in some cases can improve SOC, compared with extremes (e.g., high frequency fires, overgrazing or total fire/grazing exclusions). In the grasslands and savannas of Africa, disturbance (fire and herbivory) has variable effects on tree cover and grass biomass [241,302,303] and ultimately SOC and TEC. Broadly put, fire decrease [304] and increase [305] have little effect on

“…such decline in fire activity is currently driving widespread bush or woody encroachment of Africa's savannas and grasslands.”

SOC [306,307], depending on the vegetation type, climate and soil type. A recent study evaluating a 60-year fire exclusion experiment in South Africa demonstrated that fire exclusion only marginally increased TEC, suggesting that frequently burned savannas in Africa store substantial belowground carbon, especially in biomass and deep soil layers [308]. Similarly, herbivory tends to have variable impact on SOC, depending on vegetation, climate and soil. However, overgrazing generally leads to a reduction of SOC across distinct grasslands and savannas in Africa [301,309,310].

Balancing carbon, ecosystem functioning and biodiversity objectives in savannas and grasslands

Climate actions targeting carbon storage (either SOC or TEC) by introducing large-scale changes in fire and herbivory regimes are likely to trade off with ecosystem functioning and biodiversity conservation. There is substantial scientific evidence that fire and grazing are required to reduce tree cover and maintain open-canopy savannas in Africa [173,215,249,280,290,301,303,311,312]. Such open canopies are essential for maintaining grass biomass and the diversity of the herbaceous ground layer [244,248,313], upon which a variety of life forms depend [312,314,315]. Indeed, the positive relationship between biome-appropriate fire and grazing regimes and biodiversity in grassy ecosystems has been sufficiently demonstrated [302,314,316,317]. Therefore, global climate actions designed to increase carbon storage in savannas and grasslands are unlikely to meet the management goals of grasslands and savannas, which are mainly to balance carbon management priorities with ecosystem function, biodiversity and socio-economic priorities [188].

Bush and woody encroachment

Bush encroachment – i.e., increasing woody cover and biomass in savannas and grasslands – is currently widespread across Africa [289,293,318] and represents a major challenge to sustainable management of savannas and grasslands [292]. Although still debated, bush encroachment in savannas and grasslands is attributable to increased atmospheric CO_2, warmer and wetter climates, and declines in fire and herbivory [289,291,318-320]. There are ongoing debates on whether bush encroachment will have net positive or negative effects on grasslands and savannas, particularly considering the potential carbon gain from increased woody biomass [294].

The case studies examined indicate that TEC and SOC response to bush encroachment is variable and contingent on climate and topo-edaphic conditions. For instance, SOC increased under bush-encroached sites in drier environments, but decreased under wetter conditions [321] in a South African grassland. A meta-analysis involving 142 studies showed that woody encroachment resulted in significant changes in topsoil SOC, but this was contingent on soil type and rainfall [322]. The study found that SOC, under bush encroachment, increased only in semi-arid and humid regions, and that soil properties were the primary factors responsible for changes in SOC [322]. However, this study was a global analysis and included temperate and other savanna and grassland types that are functionally distinct from African grassy biomes. Despite this, these observations suggest that soil carbon gain because of bush encroachment may be highly variable and dependent on climate and rainfall conditions [323].

The case studies examined clearly pointed out that bush encroachment in grasslands and savannas is often associated with loss of biodiversity and ecosystem services. For instance, an evaluation of the impact of bush encroachment on the grassy ecosystems of South Africa concluded that bush encroachment leads to significant biodiversity loss and ecosystem services, but yields overall carbon gain [292]. There is now increasing evidence that bush encroachment leads to declines in vertebrate, mammalian and herpetofaunal diversity, especially at low net productivity [324]; termite activity [325];

> "...global climate actions designed to increase carbon storage in savannas and grasslands are unlikely to meet the management goals of grasslands and savannas,"

and mesocarnivore scavenging activity 326 in African grasslands and savannas. Importantly, a meta-analysis involving 43 studies of the impacts of bush encroachment globally concluded that shrub encroachment had negative effects on vertebrate richness and diversity, particularly in Africa 324.

Several examples of successful management of bush encroachment in African savannas and grasslands exist 327-329. Methods for controlling and managing bush encroachment include use of fire 330,331, mechanical and chemical shrub and tree removal 332, thinning 333 and variable livestock grazing 327,334. These case studies suggest that often, single methods applied individually are less effective compared with integrated approaches such as combination of fire, grazing and thinning 335. Further, there is a recent increase in projects where woody encroaching species, such as *Vachellia karroo*, are being used as alternative fodder for livestock 336-342, suggesting a potential livelihood co-benefit of efforts to combat bush encroachment.

Restoration of grasslands and savannas

Restoration of grasslands and savannas could contribute substantially to climate change adaptation and mitigation. Because they store substantial carbon 343, there is a huge climate benefit from restoring degraded grasslands and savannas, through either the conservation of existing carbon stocks 344 or new sequestration by regrowing grasses 345. Grassland and savanna restoration faces several challenges, including past land-use practices (e.g., afforestation) 272,346 and climate change and variability 278,347. In spite of these challenges, several examples of successful grassland and savanna restoration exist 348. Examples of restoration approaches involve simply removing pressures and allowing natural recovery 349, fire management 283,350 and grazing management 193,351. Other successful restoration approaches include use of traditional and indigenous knowledge 194 and direct seeding 352,353. In dry and arid climates, integrating irrigation with other restoration measures facilitates establishment and restoration 354.

Arid zone, deserts and desertification

About a third of the land area of Africa is arid and comprises deserts 8. Africa hosts two main desert formations, namely the Sahara (in North Africa) and Namib (in Southern Africa) Deserts. Deserts are land areas with extensive bare ground and sparse plant cover. Most species in deserts occur at the physiological limit of their range. In spite of this, variable plant growth forms – such as shrubs, forbs, succulents, etc. – and diverse desert vegetation types exist in Africa 355-357. In addition to the existence of the two major desert systems in Africa, several African countries are also experiencing significant rates of desertification, which is expected to have negative impacts on economy, ecology and society 358-361. Land-use change and climate change are also expected to accelerate desertification further 6,26.

Although the core desert area in Africa has expanded over the twentieth century 362, projections indicate that it is likely to contract in the twenty-first century 363 due to potential increase in precipitation 364. Both the direction of change and the wilder repercussions for the earth system are being explored, but are currently far from certain. Thus, though desertification in a hotter world is widely threatened, the actual trends from remote sensing are that arid areas are getting greener. Should this extend to the Sahara, for example, and in arid areas where it is occurring, it could affect the world by changing transfer of dust to oceans, influencing phytoplankton productivity and even influencing distant forests, e.g. the Amazon in South America, which has been shown to depend, in part, on nutrients transported by Sahara dust 364-367. The high albedo of

> “Restoration of grasslands and savannas could contribute substantially to climate change adaptation and mitigation,”

deserts also plays a key role in the global land-atmosphere feedback system [368,369]. Importantly, across the world, arid areas and deserts are getting greener due to CO^2 fertilisation effects [367], and therefore contributing to climate change mitigation. Such greening and more productive deserts and arid lands should offer benefits to livestock grazing, particularly if managed conservatively.

Generally, climate change adaptation and mitigation actions in respect of deserts and desertification focus on 1) increasing contribution of deserts to mitigation through increase in plant cover, 2) reducing and reversing desertification, and 3) harnessing the renewable energy potentials of deserts. Although some case studies suggest that afforestation in deserts can increase plant cover and improve climate [370], there is a dearth of evidence in support of this claim in Africa. Instead, the limited evidence suggests that large-scale afforestation in arid and desert environments is likely ineffective due to high mortality [277], and may even worsen climatic conditions in some cases [371].

Several case studies focusing on reducing or reversing desertification were reviewed. There is consensus across the case studies that land degradation is a major challenge for most African countries [26,106,358,359,361]. Indeed, Africa's flagship programme, the Great Green Wall, is in direct response to the notion of increasing desertification [275,276]. However, several case studies were critical of the use of the term "desertification" and suggested that what is being experienced is land degradation arising from over-exploitation of natural resources, rather than a southward expansion of the Sahara Desert [359,372,373]. These authors indicated that wrongly framing the issue as desertification leads to promotion of large-scale afforestation projects that are decoupled from the root cause [374]. Indeed, several examples exist that demonstrate that local level actions to restore degraded land tend to be more effective than large-scale afforestation efforts [375-377].

Africa's population is rapidly growing, and energy needs will continue to outpace supply. In this regard, most African countries have turned their attention to renewable energy sources, such as photovoltaic solar and wind farms [40]. Several proposals have been made to deploy large-scale photovoltaic solar and wind farms in Africa's deserts to generate sustainable energy for both Africa and Europe [378]. The potential benefits, negative impacts and appropriate technologies are still being discussed [379]. However, proponents of the project envision substantial climate benefits through reduction in the use of fossil fuels in electricity generation and local climate benefits. For instance, one study concluded that large-scale solar farms in the Sahara Desert are likely to cause more local rainfall, particularly in the neighbouring Sahel region [380], which should lead to increased vegetation cover and carbon sequestration. In contrast, simulation [381] suggests that large-scale solar and wind farms may have repercussions for local and regional climate systems, and that such deployments require careful monitoring and future exploration.

> “...wrongly framing the issue as desertification leads to promotion of large-scale afforestation projects that are decoupled from the root cause.”

Agriculture

Agriculture is a major contributor to the economy, livelihoods and lifestyle of Africa. Africa accounts for 15% of global cropland, 20% of global pasture and 7% of global value of agriculture and fish production (2018-2020) [382]. The agriculture sector of Africa is composed of four main subsectors, namely crops, livestock, fisheries and forestry. The crop subsector is made up of the industrial crops or cash crops (tree crops such as cocoa, oil palm, rubber, etc.), staples (starches, tubers, roots, cereals and legumes, such as rice, maize, yam, cassava, etc.) and horticultural crops (fruits and vegetables). The livestock subsector includes poultry, sheep and goats, dairy, pork, beef and other lesser reared species. The fisheries subsector encompasses marine fishery, inland fishery and aquaculture. The forestry subsector includes logging and wood processing, ecotourism and wildlife.

Agriculture, fisheries and forestry account for 14% of Africa's Gross Domestic Product (GDP), but this is expected to decline by 2030 382. The crop subsector is dominant and accounted for almost 85% of total agricultural production value between 1990 and 2013, with West and Southern Africa contributing 60% and 22% of agricultural output in sub-Saharan Africa over the same period, respectively 382. Importantly, the agriculture sector employs more than half (53%) of the total labour force in Africa 383. Given the high population growth rate in Africa, closing this huge yield gap is essential for ensuring food security and economic welfare. Closing the yield gap will require an increase in agricultural inputs (e.g., organic and inorganic fertiliser), improved germplasm, and efficient agronomic and water management practices 384-386.

Agricultural growth in Africa is likely to interact with climate change, which may amplify the challenges in the agriculture sector. On one hand, there is high potential for agricultural expansion in Africa, in terms of both value addition and transition from traditional exports to high-value and processed commodity exports 387, as well as suitable land area for expansion 388. However, such expansion is likely to increase direct emissions of GHGs from agriculture in Africa. Indeed, GHG emissions from agriculture in Africa are expected to increase to 16% by 2030 and account for 62% of the global increase in direct emissions from agriculture 382. Importantly, Africa is the only region in the world where the rural population is expected to increase (53% of population in rural areas) by 2030 382. This implies that rural labour will increase, which may likely trigger shortages in agricultural lands. Under such conditions, climate change impact on productivity and rural livelihoods may be severely threatened, leading to a cycle of poverty and land degradation. Therefore, addressing issues related to agricultural productivity, climate change and rural livelihoods is critical to achieving Agenda 2063 2.

Croplands

Several case studies were examined to identify indigenous crop-based climate change adaptation and mitigation practices, the targeted impacts and the actual results achieved. Case studies were mainly from East and West Africa and were from forest 389-391, grassy 392-395 and multiple biomes 396-401. Most of the case studies examined indigenous adaptation practices, with a few focusing on both adaptation and mitigation 392,393,398. Examined practices covered by the case studies range from climate-smart agriculture (CAS) to conservation agriculture (CA) and land intensification. Analysed practices include combinations of multiple cropping, intercropping, agroforestry/restoration, mulching, water harvesting, planting drought-resistant species, local tillage practices, manure application, adaptive planting season, etc. Adaptation and mitigation practices generally targeted soil fertility, yield, GHG emissions and CO_2 sequestration, drought, flood, windstorm, bushfires and crop income risks.

Generally, studies reported that adoption of South African practices had positive impacts on productivity (yield), carbon storage and livelihood gains. Most carbon and some livelihood benefits – in terms of aboveground biomass, SOC and tree-based products – were linked to incorporation of trees in croplands 390. However, some combinations of practices, although delivering positive mitigation benefits (e.g., use of biochar) 393, may incur negative social (health impact) and overall environmental impacts 392. Surprisingly, biodiversity conservation and gains were generally not evaluated and reported. Lack of finance was reported as the main bottleneck to adopting SA practices, as the initial cost (e.g., buying drought-resistant species or less harmful pesticides) can be extremely high 400. Importantly, in spite of the benefit and

“Generally, studies reported that adoption of South African practices had positive impacts on productivity (yield), carbon storage and livelihood gains.”

importance of indigenous knowledge and practices in supporting adaptation in Africa, there is a dearth of data and information on the cost-effectiveness of these practices, and they are currently not fully considered when designing modern adaptation and mitigation strategies [377,394,399].

Livestock – Pastures

Livestock production in Africa contributes to climate change through emission of GHGs such as carbon dioxide (from burning of pastures and rangelands), methane (as a by-product of ruminant digestive processes) and nitrous oxide (from mineral nitrogen fertiliser, manure and decomposition of wildlife excreta). Removing or reducing these sources of emission could contribute substantially to global mitigation efforts [402]. Proposals for reducing livestock-based emissions include improved pasture, intensification of ruminant diet, changes in pasture and rangeland management practices, and changing livestock composition and breeds [402].

The case studies examined covered both mitigation and adaptation practices in the livestock sector, including approaches such as emergency fodder for drought adaptation, multi-species composition of herds, culling of weak livestock for food, changes in livestock type (e.g., from cattle to sheep or goat) and traditional grazing practices [238,397,403-408]. Adaptation measures from these case studies included cattle watering, fodder and pasture management [403], rangeland productivity [404][395] and livestock management [408]. Mitigation measures were limited mainly to improved feeding practices and manure management [405,407,409] and increased SOC [238].

Generally, all adaptation measures were found to have positive impacts on livestock productivity. Similarly, mitigation measures were found to reduce GHG emission and improve livestock productivity. However, production of improved/high-quality forage may cause greater emission from land use unless driven by greater fertiliser input [405,407-409]. For livestock farmers who are unable to afford such high-fertiliser input, land scarcity will make it impracticable for adoption of high-quality forage production. Although there is a dearth of data, one case study saw that measures to increase SOC – i.e., grazing and fire management – on pastures, may yield limited improvement. In this study, it was observed that 19 years of prescribed burning and grazing exclusion in West African savannas did not change SOC stocks [238]. One more case study demonstrated that mixed livestock farms are less vulnerable to climate risk relative to specialised livestock farms, but the latter earn greater income per hectare [408].

Agroforestry

Agroforestry, the incorporation of trees on farmlands, is considered a major climate change adaptation and mitigation pathway [410-412]. The potential benefits of agroforestry are enormous and include provision of fruits and leaves for human consumption, fuel for cooking and fodder for animals; soil water conservation and fertility improvement; disease and pest management; and revenue diversification [274,413,414]. Adoption of agroforestry in Africa is an old practice [415], and variations in on-farm tree cover reflect local communities' experiences [274,406].

Several case studies from Ethiopia [397], Democratic Republic of Congo [416], South Sudan [417], Nigeria [418], Benin [403] and Ghana [102,419] and across diverse biomes [406,413,414] were reviewed. These case studies examined the impacts of agroforestry on nature conservation, carbon stocks, crop yield, crop survival, pasture and tree fodder, with most assessing multiple environmental and social benefits. The case studies generally confirmed the utility of agroforestry in delivering carbon, biodiversity and livelihood – linked to the sale

> “The potential benefits of agroforestry are enormous.”

of tree products – gains across several biomes. Several examples showed that agroforestry practices can be an effective approach to land and ecosystem rehabilitation in both forest and non-forest ecosystems 102,273,277,399,418 and is often in harmony with local land tenure and use practices 130,415.

In spite of this, a few case studies raised some important potential negative impacts and data gaps of agroforestry. For instance, one study showed that incorporation of some tree species on cocoa farms resulted in increased water stress and mortality of cocoa trees 419. Similarly, Buxton et al. 413 reported that in spite of the positive impacts of agroforestry on rural income and climate adaptation, there were trade-offs between carbon goals and crop yield in agroforestry in Kenya. Importantly, Rother et al. 414 observed that in spite of the general perception of the benefit of regenerating trees on farms, there is little mechanistic understanding relating to how context conditions affect the diversity and abundance of regenerating trees, or how this is related to ecosystem function and livelihood benefits. These observations suggest that in spite of its promise, more studies from different contexts are required to improve understanding of when agroforestry may be maladaptive.

Urban

Climate change is expected to have substantial impacts on Africa's cities and urban centres. Africa's cities and urban centres have low capacities to respond adequately to the threat of climate change due to a combination of high exposure (most key African cities are coastal), increasing urbanisation, poor urban infrastructure, limited institutional and technical capacities, and limited adaptation opportunities. Given the high exposure and low adaptive capacities of African cities and urban centres, strengthening their climate resilience is fundamental to mitigating the negative impacts of climate change. Surprisingly, there is a dearth of case studies providing empirical evidence of successful adaptation and mitigation strategies for cities and urban centres in Africa.

The few case studies reviewed covered adaptation issues, but were mostly exploratory, providing analysis of potential approaches to sustainable climate change adaptation and mitigation. These included issues such as drainage and flood management 420-424, urban green infrastructure and natural resource use 425-428, water and watershed use and management 429-433, spatial planning 434-436 and institutional and governance approaches 421,437.

Although from disparate viewpoints, these case studies generally suggested that successful climate change adaptation and mitigation in African cities requires multi-sectoral approaches. Such multi-sectoral approaches need to be built on strong coordination across all governmental levels and must involve all relevant stakeholder groups (local, national and international). The role of local actors – such as local governments, community-based organisations, non-profit organisations, etc. – participatory learning and knowledge sharing, biodiversity actions and integrated and sustainable resource management are particularly highlighted.

> “...successful climate change adaptation and mitigation in African cities requires multi-sectoral approaches.”

Cross-cutting themes

Wood harvest

Natural forests, woodlands and savannas provide wood products that are important to people's livelihoods. Reducing wood harvesting from these sources through different techniques could maximise carbon sequestration while meeting people's demand for wood fuels. There is always an inherent trade-off between socio-economic benefits and conservation across all land-use types, particularly in the context of wood harvesting in Africa 438. The production and use of wood fuel is a significant socio-economic activity in Africa, with over 60% of the population relying on wood fuel as the primary source of household energy. Examination of case studies across Africa shows that wood harvesting from natural sources is substantially minimised when communities are provided with efficient cooking stoves. For instance, one case study showed that the use of an efficient cooking stove maximised the forest carbon store by avoiding emissions of 2.2 tons of CO_2 per household per year in Mali, and 150,000 tons of CO_2 per year in Ghana 439. Similarly, the use of cooking stoves and biogas in East Africa has huge potential to prevent 0.562-5.673 million tons of CO_2e emissions per country per year from wood harvesting 440. Importantly, the provision of an efficient stove also has the co-benefit of improved health conditions of rural households 441 and saving of time for children and women 442. Overall, the case studies examined across the continent showed that maximum carbon storage in natural ecosystems could be attained with avoided wood harvest practices, by providing alternatives to improve the socio-economic status of the local communities.

“...maximum carbon storage in natural ecosystems could be attained with avoided wood harvest practices, ”

Credit: ILRI/Stevie Mann, Tanzania

Chapter 4

Data and knowledge gaps in climate actions

Sally Archibald, Lubango Angola

Overview

Several climate actions have been proposed for Africa. In chapter 3, we undertook extensive review of case studies to identify evidence supporting the appropriateness or otherwise of these climate actions. Through these reviews, we also identified significant knowledge and data gaps that need to be addressed to enhance climate actions on land in Africa. As pointed out in chapters 2 and 3, Africa's ecosystems are unique – for instance, it is the only continent with complete wildlife assemblage – and diverse. Importantly, most Africans are employed in climate-sensitive sectors, where climate change or climate actions could have direct and significant impacts on their livelihoods. Therefore, context-specific climate actions that improve ecosystem functioning, biodiversity and livelihoods are particularly desirable for Africa. Developing such context-specific actions requires climate data and information that has been verified and validated across Africa. Here, we highlight the main knowledge and information gaps that are critical for enhancing climate change adaptation and mitigation on land in Africa.

Cross-cutting themes

1. **The mitigation potential of Africa** – As shown in chapters 2 and 3, several climate actions proposed for Africa often emphasise the huge mitigation potential of the continent. For instance, climate actions targeting reforestation, afforestation, fire in grasslands, or grazing management commonly tout the mitigation potential of these actions. However, data on exact figures or estimates of mitigation potential across climate actions, ecosystems and land-use types, and sub-regions is lacking. Importantly, it is uncertain whether global estimates – e.g., GHG emission reduction from reforestation, afforestation and changing fire practices – are realistic for Africa, given that such estimates and proposals are often met with fierce criticisms from African scientists and researchers. For instance, conservative estimates indicate that the benefit from AFR100 is less than 3% of annual increase in atmospheric CO_2 (9). Similarly, analysis of actual CO_2 sequestration potential of agroforestry practices in Africa – e.g., in the Sahel region, it is estimated that if Sahelian parklands covered their maximum range, they could sequester two billion tons more carbon dioxide – showed that current projections are unrealistic due to global carbon prices and total area of land needed to achieve appreciable sequestration gain (443).

2. **The limit of adaptation in Africa** – Africa's ecosystems, economy and livelihoods are all predicted to be significantly affected by ongoing climate change. The extent to which climate change will impact socio-ecological systems in Africa is still being investigated. A major concern for climate change adaptation and mitigation in Africa is the limit to adaptation with increasing global warming. With current data and knowledge, the climatic sensitivity and the tipping points of the various socio-ecological systems in Africa under different climate change scenarios remain unknown.

3. **Cost-benefit of large- versus local-scale climate actions** – Most climate actions proposed for Africa, particularly those driven by external agents, target large-scale deployment. However, the evidence gathered from the case studies suggests that local-scale initiatives often work better, are cost-effective, are suited to the context, and deliver multiple benefits across all ecosystems and regions. However, studies assessing the effect of scale on cost-effectiveness of climate actions in Africa are lacking. Such knowledge is crucial to inform policy, planning and practice of

“Developing such context-specific actions requires climate data and information that has been verified and validated across Africa.”

climate actions in Africa. Understanding the cost-benefit of the climate change mitigation and adaptation measures is crucial, as it is a key variable for technology adoption. We are still to test the hypothesis that local communities will only adopt CCMA measures if they are more profitable and reliable over time (from the local point of view) than the current land-use practices. Perverse incentives in the agriculture sector still abound, and these need to be dealt with.

4. **Lack of evidence for the effectiveness of nature-based solutions (NbS)** – Currently, NbS projects are highly recommended and widely practised for climate change adaptation and mitigation. However, in Africa, there is limited evidence of the effectiveness of NbS. For instance, the evidence platform (https://www.naturebasedsolutionsevidence.info/evidence-tool/) for NbS currently lists only a few case studies from Africa. Given that NbS involves working with nature and people, understanding its effectiveness or trade-offs in different contexts is crucial for upscaling.

5. **Gender and social inclusion in climate actions** – In reviewing the various case studies, we observed that there is little to no consideration of gender and social issues in relation to most proposed climate actions in Africa. Some studies consider gender- and age-based variations in climate change sensitivity and adaptation practices in Africa. However, there is complete silence on gender and social inclusion in relation to climate actions, particularly those linked to improved management and ecosystem restoration. Understanding the gender and social gap in climate change adaptation and how climate actions are likely to impact this gap is crucial for effective policy development in Africa.

6. **Conserving the genetic resources of Africa** – As pointed out in section 2.5, climate change adaptation and mitigation in Africa will rely heavily on nature; the genetic resources of Africa are fundamental to climate change adaptation. However, there is inadequate information on the conservation status of plant genetic resources and utilisation across Africa. Importantly, there is a critical knowledge gap on how current biodiversity conservation policies and plans relate to climate change adaptation and mitigation strategies. Evaluating existing policy frameworks for genetic resource conservation – e.g., storage of high biodiversity in DNA and seed banks, ex situ and in situ conservation, etc. – in Africa and its linkages with climate actions is crucial for effective climate change adaptation and mitigation policy development.

7. **Climate change projections at local scale** – It is evident that projections of climate change impacts are more available at global and regional scale than at local scale, missing out the local impacts and adaptation potentials. However, studies that looked at the local impacts of climate change generally found a very diverse spatial variation of these impacts on ecosystems and crops. Although such specific insights might be important to inform local decision-makers better, they are always associated with uncertainties, which also vary from one AR to the other. Consequently, local decisions made from downscaled projections could be unreliable in the long term.

8. **Land tenure systems and CCMA actions in Africa** – Understanding how land tenure systems are going to affect large-scale CCMA measures in Africa is crucial for anticipating the effectiveness of these measures across land-use types (forestry, rangelands, grassy ecosystems, etc.). However, there is a lack of strong analytical frameworks projecting changes in land tenure

> “...climate change adaptation and mitigation in Africa will rely heavily on nature.”

systems, such as increasing land privatisation, and how these changes will influence the implementation of CCMA actions.

9. **Role of water/hydrological processes in ecosystems and CCMA measures in Africa** – Water is an important element of climate variability and also plays a crucial role in all ecosystems. This report briefly explained how different ecosystems are affected by water-related events. For instance, in section 2.9, "Climate securities in Africa", a short analysis was presented on how water availability and accessibility can affect pastoralism and even lead to conflicts with farming communities. Under section 3.6, it was shown that the CCMA measures in urban landscapes are mostly related to drainage and flood management, and that their successful implementation would require adoption of multi-sectoral approaches. There are examples where CCMA measures could negatively impact water availability, even when they are clearly intended to serve as mitigation purposes. Therefore, it is essential to understand how multi-sectoral approaches can be used to optimise positive impacts of CCMA measures on water resources.

Data and research gaps for forest and mangrove climate actions

10. **Forest and mangrove response to climate change in Africa** – As outlined in sections 3.2 and 3.3, climate actions for forests and mangroves are crucial for climate change adaptation and mitigation in Africa. However, there is insufficient data and understanding of forest response to climate change in Africa. Generally, African countries have limited research infrastructure and funding, which significantly hampers climate research. For instance, Africa is often poorly represented in most global databases of inventoried and surveyed plots (see, for instance, https://bien.nceas.ucsb.edu/bien/ and https://forestplots.net/). There is therefore limited understanding of the current and future impact of climate change on forest and tree resources under varying land-use contexts.

11. **Improved forest and mangrove management** – The case studies examined highlighted potential trade-offs associated with prescriptions for improved forest and mangrove management. For instance, actions to enhance carbon sequestration or storage were found to trade off with biodiversity conservation and livelihoods of local communities. Despite this, there is a dearth of knowledge of how the strength of this trade-off varies across forest and land-use types. Closing this knowledge gap is essential for improving synergies between climate, biodiversity and livelihood goals through sustainable natural resource management.

12. **Forest and mangrove restoration pathways** – Natural regeneration, mixed-species plantation and single-species monoculture were identified as the main forest and mangrove restoration options. However, the review identified only a few studies on each of these restoration options. Currently, there is limited qualitative evidence of the benefits and trade-offs associated with each of these restoration options. More studies across forest and mangrove land-use types are required to appropriately examine the carbon, biodiversity and livelihood benefits of each of these restoration pathways.

13. **Landscape sustainability initiatives** – Novel landscape sustainability initiatives were highlighted in the review as being

"There is therefore limited understanding of the current and future impact of climate change on forest and tree resources under varying land-use contexts."

particularly promising for reducing conflict and trade-offs between carbon, biodiversity and livelihood goals. However, only a few such initiatives exist in Africa, and so far, rigorous scientific analysis of their workability is lacking. Further studies are required to assess whether such initiatives can enhance climate actions on land in Africa.

Data and research gaps for climate actions in grassy ecosystems

14. **Extent of grassy ecosystems in Africa** – At the core of most scientific disagreements on climate actions in Africa is whether proposed actions are appropriate for the ecosystem targeted. There has been a long-standing disagreement on the definitions and classifications of Africa's ecosystems, particularly grassy ecosystems. Although biome maps – such as the UNESCO/AETFA/UNSO Vegetation Map of Africa – exist, there is often disagreement on which vegetation types can be classified as "grassy" and "forest". For instance, there is strong disagreement on whether Miombo woodlands are grassy ecosystems or forest. Ecosystem definition has implications for management and climate actions (see section 2.10). Therefore, it is essential to map and quantify the extent of various grassy ecosystems in Africa to serve as a baseline for climate action appraisal, monitoring and evaluation.

15. **Total ecosystem value (TEV) of Africa's grassy ecosystems** – In spite of their enormous economic, social and ecological contributions, the total ecosystem value of grassy ecosystems has hardly been estimated. As a result, most climate actions proposed for grassy ecosystems assume no value or low value of the existing ecosystem. For instance, Bastin et al. (58) identified several of Africa's pristine grassy ecosystems – for instance, the Kruger National Park – with remarkable levels of biodiversity as degraded, and mapped them for restoration through tree planting. Quantifying the TEV of grassy ecosystems in Africa is critical to proper evaluation of the opportunity and trade-off costs associated with climate actions.

16. **Effectiveness of international government mechanisms** – International government mechanisms such as REDD+, PES (payment for ecosystem services) and other carbon trading mechanisms provide financial support and motivation for climate actions in Africa. These instruments have played significant roles, particularly for climate actions in forests. However, it remains questionable whether these instruments are effective for Africa's grassy ecosystems. For instance, there is currently no REDD+-type arrangement for avoided conversion and degradation of grassy ecosystems. Importantly, there is a dearth of information on whether such instruments or mechanisms can lead to improved management of grassy ecosystems and generate local socio-ecological benefits.

17. **Soil organic carbon (SOC) in grassy ecosystems** – Most climate actions for Africa's grassy ecosystems target enhancing above- and belowground carbon (see section 3.4). Increasing SOC is seen as a more sustainable carbon sequestration approach, given the relative stability of SOC under arid and frequently disturbed conditions. SOC levels under different types of grassy ecosystems across Africa remain largely unmapped, and GHG emissions from grassy ecosystems under varying management regimes remain unknown. However, this information is essential to serve as a

“At the core of most scientific disagreements on climate actions in Africa is whether proposed actions are appropriate for the ecosystem targeted.”

baseline to guide monitoring for carbon offset trade for grassy ecosystems.

18. **Carbon accounting for grassy ecosystems** – There is increasing understanding of fluxes in carbon capture and emission in grassy ecosystems. Although tools and methodologies for total ecosystem carbon (TEC) and soil organic carbon (SOC) accounting are being developed and improved, large uncertainties still exist. With these uncertainties, it remains unclear how most proposed climate actions – especially NbS intervention types – will work. Reducing these uncertainties is central to improving carbon accounting and carbon offset trade in grassy ecosystems.

19. **Improved understanding of impact of disturbance on SOC stocks** – As pointed out under section 3.4, fire and grazing are both disturbance factors and management tools. Unsurprisingly, climate actions seek to manipulate these factors either to enhance carbon capture or to reduce emissions. However, data on impact of fire and grazing management on SOC in grassy ecosystems is relatively sparse and has been slowly accumulating over the past few years. Additional experimental evidence is required to achieve better understanding of the impact of grazing and fire management on SOC. Importantly, more experimental evidence is required to better understand the effect of new innovative climate actions – such as rewilding and holistic management – on SOC and other environmental and social co-benefits.

20. **Role of indigenous knowledge for managing grassy ecosystems** – Several case studies demonstrated that indigenous and traditional knowledge can be effective in conserving, managing and restoring grassy ecosystems. However, rigorous scientific documentation and assessment of the effectiveness of indigenous and traditional practices across grassy ecosystem types and management regimes are currently lacking, but are important for improving climate actions. This is particularly important, given that climate change is likely to limit the effectiveness of indigenous practices (e.g., fire use in bush-encroached landscapes), and new, innovative approaches may be required.

Data and research gaps for agriculture

21. **Agroforestry in arid and dry lands** – As pointed out in section 3.6, agroforestry practices have unique value for nature conservation, carbon stocks and rural livelihoods. However, there is low adoption of agroforestry under arid conditions due to the impact of climate change, browsing animals and fires on tree regeneration. Improving seedling establishment and growth under arid conditions is central to promoting adoption of agroforestry. Although information is generally available, effort to promote low-cost and best practices for tree regeneration under arid conditions is currently limited. Improved education and demonstration are required to motivate farmers' interest in agroforestry in arid zones.

22. **Benchmarking sustainable agricultural practices** – Sustainable agriculture (SA) is promoted as an important climate change adaptation and mitigation pathway. Under the umbrella of SA are several practices, including fertiliser management, agroforestry, improved germplasm, etc. The case studies reviewed in this report generally indicated that SA practices had positive impacts across multiple targets. However, adoption can be low if the specificity of the agricultural ecosystem is not taken into consideration. The concept of "benchmarking" has been proposed as an approach that can match SA technologies with the right site and farming

"…rigorous scientific documentation and assessment of the effectiveness of indigenous and traditional practices across grassy ecosystem types and management regimes are currently lacking, but are important for improving climate actions."

context. However, benchmarks for many SA practices, including traditional and indigenous practices, are currently lacking.

23. **Impact of farm-based climate actions on biodiversity** – Conversion of natural ecosystems to agricultural lands generally leads to loss of biodiversity. Although some agriculture-based climate change adaptation and mitigation actions have potential to reduce or ameliorate biodiversity loss, the review indicated a lack of case studies reporting loss or gain of biodiversity in relation to climate actions on farms. This is a significant knowledge gap that constrains effective evaluation of climate actions on farms in Africa.

24. **Cost-effectiveness of local and indigenous adaptation practices** – We reviewed a substantial number of case studies involving local and indigenous climate change adaptation practices. While some case studies indicated benefits of these practices, a substantial majority of case studies either failed to report benefits or reported benefits for only a single or a few results areas (e.g., yield, drought impact, fertility, etc.). For most of the case studies, the cost-effectiveness of local and indigenous adaptation practices was generally non-existent. This is a significant knowledge gap that will hinder upscaling and promotion of innovative local and indigenous adaptation practices.

Data and research gaps for urban areas

25. **Cost-effectiveness of urban adaptation and mitigation strategies** – The urban case studies examined in this report were mainly exploratory in nature. There is a dearth of empirical evidence of the benefits and trade-offs of urban-based adaptation and mitigation actions in Africa.

26. **Regional disparity in urban-based climate actions in Africa** – A significant majority of case studies on urban-based adaptation and mitigation were from South Africa, indicating lack of data and research on urban actions in other countries and regions.

27. **Limited scope of urban-based climate actions** – The case studies examined in this report indicated that only a limited number of urban-based climate actions have been explored in Africa. So far, important climate change adaptation and mitigation strategies that are potentially useful to the African context – e.g., utilising urban wastewater management for agriculture, and power generation using urban waste – have rarely been examined.

28. **Impact of rapid urbanisation in Africa** – Rapid population growth and urbanisation present a complex scenario for climate change adaptation and mitigation in urban areas in Africa. First, urbanisation is potentially the biggest source of GHG emissions in Africa. Second, as Africa urbanises, more effort should be placed in energy-efficient technologies that reduce use of fossil fuels, to limit GHG emissions. Hence, international support should be geared toward this. However, there is limited understanding of the efficiency and cost-effectiveness of urban-based CCMA measures in Africa, particularly in relation to changing urbanisation trends.

> “…the cost-effectiveness of local and indigenous adaptation practices was generally non-existent. This is a significant knowledge gap.”

Chapter 5

Conclusions

Credit: Jean van der Meulen, Cape Town, South Africa

Climate change and related impacts represent the most significant threat to sustainable development in Africa. Land-based mitigation and adaptation options will play a crucial role in reducing global warming to within 1.5˚C to 2˚C of pre-industrial levels. In this respect, Africa is uniquely positioned to become a major player in global climate actions. Although Africa's historical contribution to global GHG emissions is significantly low (< 9% of total GHG emission for the period 1990-2019), it is expected to bear the brunt of climate change impact in terms of both adaptation and mitigation – for instance, through massive land-use changes. Substantial financial support from the international community is required for African countries to support global climate change mitigation measures. However, to realise this potential, Africa must advance a common position and interest on climate change in global forums.

This report seeks to deepen understanding of the relationship between land and climate change mitigation and adaptation in Africa. The report examined all major climate actions across the diverse biomes, land uses and sub-regions of Africa, and developed a working paper on how to enhance climate actions on land to help inform a common African position. The report first reviewed climate actions in Africa and concluded that climate actions in Africa must not only address climate change risks and threats, but must also meet the following minimum criteria :

1) Address Sustainable Development Goals, particularly rural livelihoods.
2) Improve natural resource governance.
3) Reduce land inequalities and tenure constraints.
4) Improve climate securities.
5) Be based on sound understanding of the ecology, structure and function of the targeted ecosystem.

Extensive review of climate actions in forests, mangroves, grassy ecosystems, arid areas and deserts, and urban centres can be enhanced as follows:

1. Avoided deforestation of mangroves can be achieved through improved financing, local participation and stewardship, provision of alternative wood fuel sources, and improved regulatory frameworks. The community-based ecological restoration approach (CBEMR) was highlighted as a promising restoration approach.
2. Although REDD+ initiatives can contribute to avoided deforestation, there is an urgent need to close the funding gap. Community-based forest management initiatives can support forest conservation if there is sustained political will, adequate funding, provision of alternative livelihood activities, and adoption of technology.
3. Significant trade-off between carbon, biodiversity and livelihood goals exists for improved forest management and can be reduced through provision of alternative livelihood interventions.
4. Natural regeneration and mixed-species plantations are superior forest restoration options relative to monocultures. Irrespective of restoration options, novel landscape level sustainability initiatives may be better at integrating livelihood, biodiversity and carbon goals and hence reducing trade-offs.
5. Decline in burned area, changes in historical herbivory regime, and bush encroachment threaten the savannas and grasslands of Africa. Despite this, there are no global financing mechanisms (e.g., REDD+-type initiatives) for conservation of grasslands and savannas.
6. There is no conclusive evidence that afforestation in savannas and grasslands leads to increased soil organic carbon (SOC) or total

“…to realise this potential, Africa must advance a common position and interest on climate change in global forums.”

ecosystem carbon (TEC). In contrast, there is substantial evidence that afforestation in savannas and grasslands has a negative impact on hydrology, groundwater and biodiversity. Importantly, afforestation in savannas and grasslands makes them prone to fire outbreak and will require significant financing for fire protection measures, which steeply increases the cost of such tree-planting programmes.

7. Current evidence suggests that proposals – which are derived from Australian savannas – to alter fire frequency and season in grasslands and savannas of Africa are unlikely to deliver the projected emission reductions.
8. The case studies indicated that biome-appropriate levels of fire and grazing have little impact on SOC, whereas extremes reduce SOC. However, the impact of grazing on SOC is dependent on rainfall. Despite this, there is clear evidence that fire and grazing (disturbance) are critical for maintaining open canopies, which in turn is essential for conserving the diversity of the herbaceous layer.
9. The impact of bush encroachment in savannas and grasslands on SOC is variable and contingent on climate and topo-edaphic factors. However, there is substantial evidence that bush encroachment leads to biodiversity loss.
10. Short-intense rotational grazing is not superior to continuous grazing in rangelands.
11. Although the central tenets of holistic management (HM) are challenged, some case studies suggest that when properly practised, HM does lead to some positive ecological, social and economic outcomes. However, there is little support for the proposal that HM, if widely applied, can reduce atmospheric CO_2 to pre-industrial levels through OSC accumulation in rangelands.
12. The wilder rangeland concept (WRC) has huge potential for climate change adaptation and mitigation in rangelands. However, existing land tenure systems and potential for increased wildlife-human conflict may constrain its adoption.
13. Desert greening may have a negative effect on provision of ecosystem services (e.g., reduced fertilisation in the Amazon) and worsen local climatic conditions. However, such greening and more productive deserts and arid lands should offer benefits to livestock grazing, particularly if managed conservatively.
14. There is inconclusive evidence of the climatic benefits of desert-based solar and wind farms.
15. There is substantial evidence that land degradation is widespread in Africa and is caused by over-exploitation of land and natural resources. However, conflating land degradation and desertification leads to promotion of climate actions that are decoupled from the root cause of the problem. For instance, degradation may include reduction in plant cover or increase in woody cover (e.g., bush encroachment), whereas desertification is usually interpreted as a decrease in plant cover and productivity.
16. Most crop-based climate actions result in improvement in yield, productivity, carbon storage and livelihoods. However, there is limited understanding of the cost-effectiveness of indigenous and traditional adaptation practices.
17. Climate actions in livestock production systems have positive impacts on productivity and GHG emissions. However, production of improved forage in Africa may increase land-based GHG emissions, unless driven by high fertiliser inputs.
18. Agroforestry is highly promising for biodiversity, livelihoods and, to a lesser extent, carbon sequestration across all biomes and land uses.

> “…there is substantial evidence that afforestation in savannas and grasslands has a negative impact on hydrology, groundwater and biodiversity.”

19. The biggest potential contribution to reducing GHG emission from Africa is to manage urban areas better. However, there is limited empirical evidence of the effectiveness of urban-based climate actions, with most existing studies coming from South Africa. Improving urban-based climate actions in Africa will require importing relevant technologies in addition to local development.

20. Provision of efficient cooking stoves is particularly promising for reducing natural wood harvesting, reducing CO_2 emissions and improving health conditions, particularly in urban centres across Africa.

21. There are significant knowledge, information and data gaps that need to be addressed to enhance climate actions on land in Africa.

“The biggest potential contribution to reducing GHG emission from Africa is to manage urban areas better.”

Credit: Jozua Douglas, Ghana

Glossary

1. **Afforestation:** Planting of new forests on lands that historically have not contained forests; or the direct human-induced conversion of land that has not been forested for a period of at least 50 years, to forested land through planting, seeding and/or the human-induced promotion of natural seed sources
2. **Agriculture:** A form of land use and economy that includes both animal (animal husbandry) and plant (agronomy, horticulture and forestry in part) farming. In this report, the term "agriculture" is used to encompass cropland, agroforestry and specialised crop-livestock systems (e.g., agropastoral, mixed crop-livestock farming, etc.) but excludes pastoralism (see definition for "Pastoralism").
3. **Agroecology:** The application of ecological principles to the production of food, fuel, fibre and pharmaceuticals. The term encompasses a broad range of approaches and is considered a science, a movement and a practice.
4. **Agroforestry:** An ecologically based natural resource management system in which trees are integrated in farmland and rangeland
5. **Bush encroachment:** The increase of woody plants (cover and biomass) in open and grassy ecosystems, such that natural equilibrium of the woody plant layer (i.e., trees and shrubs) and herbaceous (grasses and forbs) layer is shifted unfavourably
6. **Conservation agriculture:** A farming system that promotes minimum soil disturbance, maintenance of permanent soil cover and diversification of plant species. Conservation agriculture encompasses practices such as zero-tillage, rotational cropping and intercropping.
7. **Continuous grazing:** Grazing system which allows free access of livestock to any given area of a pasture or rangeland at any given time. In continuous grazing, pastures are not divided into sub-pastures or paddocks.
8. **Climate change:** A statistically significant variation in either the mean state of the climate or its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.
9. **Climate-smart agriculture:** An integrated approach to managing agricultural landscapes – croplands, livestock, forests and fisheries – that addresses the interlinked challenges of food security and climate change
10. **Deforestation:** Conversion of forest or forest lands to non-forest ecosystem or non-forest land-use
11. **Desertification:** Land degradation in arid, semi-arid and dry sub-humid areas resulting from several factors, including climatic variations and human activities. In its true form, desertification refers to the progressive destruction or degradation of vegetative cover, especially in arid or semi-arid regions bordering existing deserts.
12. **Ecosystem conversion:** Change of a natural ecosystem to another land use, or profound change in a natural ecosystem's species composition, structure or function
13. **Forest:** This report adopts an ecological definition of "forest". A forest ecosystem in the African context is an ecosystem that is a closed-canopy system dominated by trees and shrubs and lacking a shade-intolerant herbaceous layer (grasses and forbs).
14. **Global warming:** The observed or projected gradual increase in global surface temperatures, one of the consequences of radioactive forcing caused by anthropogenic emissions

Glossary

15. **Grasslands:** Open ecosystems dominated by shade-intolerant grasses and often lacking appreciable tree cover
16. **Grazing systems:** A defined, integrated approach of managing the interactions between plants, soil and grazing animals to achieve specific results or management goals
17. **Holistic management:** A rangeland management framework for decision-making, rooted in the fundamentals of ecosystem processes and with a suite of planning procedures that include planned grazing, land planning, financial planning and ecological monitoring
18. **Land degradation:** Reduction or loss of the biological or economic value of rainfed cropland, irrigated cropland, or range, pasture, forest or woodland resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: i) soil erosion caused by wind and/or water; ii) deterioration of the physical, chemical, biological or economic properties of soil; and iii) long-term loss of natural vegetation
19. **Pastoralism:** A form of agriculture involving raising domestic animals in rangelands. In this report, pastoralism refers exclusively to free-ranging livestock in mostly untransformed lands (i.e., non-croplands)
20. **Pasture:** Lands used primarily for production of adapted, domesticated forage plants for livestock
21. **Rangelands**: Lands on which vegetation is composed predominantly of grasses, grass-like plants, forbs or shrubs, and often with trees that are grazed or have the potential to be grazed by livestock and wildlife
22. **Reforestation:** Planting of forests on lands that have previously contained forests but have been converted to some other use
23. **Rewilding:** Conservation activities and efforts aimed at restoring and protecting natural processes and wilderness areas. In this report, the term "rewilding" is used to denote approaches of integrating wildlife and livestock systems in rangelands.
24. **Rotational grazing:** A grazing system or practice of containing animals and moving them through pastures to improve soil, plant and animal health. In rotational grazing, one or two pastures are rested from grazing for an entire year, while the remaining pastures are grazed seasonally.
25. **Savanna:** An open ecosystem dominated by a shade-intolerant herbaceous layer (grasses and forbs) with variable woody cover (trees and shrubs)
26. **Urbanisation:** Movement of populations from rural to urban settings, and the consequent physical changes to urban settings
27. **Woodland:** An open ecosystem composed of small- to medium-sized trees with loosely touching crowns (canopy cover up to 90%), with sparse woody undergrowth and a continuous ground layer of sun-loving grasses

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